Received: 17 April 2018 | Accepted: 10 June 2018
DOI: 10.1111/jen.12552

ORIGINAL CONTRIBUTION

WILEY JOURNAL OF APPLIED ENTOMOLOGY

Abundance of natural enemies of *Nezara viridula* (Hemiptera: Pentatomidae) on three cultivars of sweet alyssum

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Funding information
USDA, NIFA; 1890 Capacity Building Grants Program, Grant/Award Number: 2012-38821-20151; Extension IPM Coordination and Support Program, Grant/Award Number: 2013-41534-21505

Abstract

The southern green stink bug, *Nezara viridula* is one of the most serious pests of tomatoes in Florida. During 2014 and 2015 tomato cropping seasons, three cultivars of sweet alyssum, *Lobularia maritima* (Brassicales: Brassicaceae) were evaluated in north Florida to determine their effectiveness in conserving the natural enemies of the southern green stink bug in open field conditions. The experimental refuge crops were cultivated on two outer rows and one center row of the tomato crop. Each section of the rows of trap crops and refuge crops was 20 × 3 ft. (6 × 0.91 m) in size. Pest insects and their natural enemies were collected weekly and identified. On refuge crops, big-eyed bug, *Geocoris punctipes* (Hemiptera: Geocoridae); minute pirate bug, *Orius insidiosus* (Hemiptera: Anthocoridae), ladybird beetles (Coleoptera: Coccinelidae), assassin bugs (Hemiptera: Reduviidae), damsel bugs (Hemiptera: Nabidae), hover flies (Diptera: Syrphidae) and spiders (Arachnida) were collected. All cultivars of *L. maritima* attracted the natural enemies of the southern green stink bug; however 'carpet of snow' was the most effective cultivar followed by 'tall white' in attracting *G. punctipes* in the tomato crop. *N. viridula* population first peaked in July and declined in week 11 and then had a sharp increase in weeks 12 and 13 when *G. punctipes* population was comparatively high. Data on the availability of suitable refuge crops which provide nectar and shelter to natural enemies are useful for integrated pest management of the southern green stinkbug, because these plants provide necessary resources to conserve beneficial species.

KEYWORDS
conservation, natural enemies, refuge crops, southern green stink bug

1 | INTRODUCTION

Florida ranks first in production of fresh market tomatoes. In 2016, tomatoes were planted in 30,000 acres with a sale value of more than $3.82 billion in the Sunshine State (USDA, National Agricultural Statistics Service, 2017). Florida serves as the major tomato supplier throughout the United States during the late fall, winter and early spring months (Freeman, Dittmar, & Vallad, 2015). Production cost for tomato in Florida often exceeds $16,000 per acre in large part due to the high cost of pest management. Exotic insect pests are considered serious threat to sustainable tomato production and food security in Florida. The known common insect pests on tomatoes in Florida include: Southern Green Stink Bug, *Nezara viridula* (L.) (Hemiptera: Pentatomidae); Brown Stink Bug, *Euschistus servus* (Say) (Hemiptera: Pentatomidae); Silverleaf Whitefly, *Bemisia argentifolii* (Bellows & Perring) (Hemiptera: Aleyrodidae); Green Peach Aphid, *Myzus persicae* (Sulzer) (Hemiptera: Aphididae), Tomato Fruitworm, *Helicoverpa zea* (Boddie) (Lepidoptera: Noctuidae), Tomato Hornworm, *Manduca quinquemaculata* (Haworth) (Lepidoptera: Sphingidae) and Western Flower Thrips *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae). The greatest challenge to tomato producers in Florida is the management of serious insect pests especially *Nezara viridula*

(Linnaeus) (Hemiptera: Pentatomidae), a highly polyphagous feeder which attacks many important food crops (Squitier, 2013). In tomato crops, *N. viridula* populations reach their peak in late summer (Kamminga, Koppel, Herbert, & Kuhar, 2012) and the economic injury potential of *N. viridula* feeding varies to other host crops.

Nezara viridula has piercing-sucking mouthparts with which they puncture plant tissues and suck the sap. As a result, plant shoots may wither or, in severe cases, may eventually die (Squitier, 2013). Feeding damage on young tomatoes induces early maturity and reduces fruit size and weight (Lye, Story, & Wright, 1988). Direct feeding is the main cause of yield loss. Adult injects saliva into plant parts via stylet penetration damaging plant tissue, causing blemishes, discoloration and malformation; while sucking removes plant nutrient resources resulting in retarded growth (Plantwise, 2015). The pest reduces the quality and quantity of tomatoes, making them unmarketable; thus affecting grower's profitability and productivity.

Nezara viridula is tolerant to many insecticides and thus it is very difficult to control. The possible buildup of toxic residues from some pesticides in the environment and the development of pesticide resistance leads to loss of pesticides effectiveness (Lewis, Van Lenteren, Phatak, & Tumlinson, 1997). The establishment of habitats that are favourable to beneficial fauna within the agroecosystem can boost the survival, reproduction, dispersal and ultimately the regulation of pest populations by natural enemies (Flint & Gouveia, 2001; Landis, Menalled, Lee, Carmona, & Perez-Valdez, 2000). Developing improved methods to establish beneficial habitat and conserve natural enemies can improve ecosystem sustainability and help growers produce quality marketable produce.

Currently, limited options are available to vegetable growers in Florida to combat *N. viridula*. In addition, lack of awareness of beneficial species and reliance on conventional pesticides are some of the major contributing factors to pest problems, including pesticide resistance, pest resurgence, residue and secondary pest outbreaks. (NRDC, 2013). A substantial amount of research has been done on the use refuge crops to conserve natural enemies of certain serious pests in vegetable and other crops production, as well as research that has examined the relationship between refuge crops and main crops (Eyre & Leifert, 2011; Lundgren, Wyckhuys, & Desneux, 2009; Reeves, Greene, Reay-Jones, Toews, & Gerard, 2010). The refuge crops are planted within and adjacent to high cash crops; refuge crops serve to attract, maintain or increase predator and parasitoid populations by providing them with food source and more suitable habitat for the population to grow and feed on the pests attacking the main crop (Rechcigl & Rechcigl, 2000).

Conservation of natural enemies in agricultural systems is important for biological control of pests. Beneficial species such as tachinid fly, *Trichopoda pennipes* Fabricius (Diptera: Tachinidae), Big-eyed Bug, *Geocoris punctipes* Fallen (Hemiptera: Geocoridae); and Minute Pirate Bug, *Orius insidiosus* Say (Hemiptera: Anthocoridae) are usually present in agroecosystems and feeds on eggs of *N. viridula*, therefore, improvement in habitat for these beneficial species will enhance pest management in tomatoes. In addition, numerous natural enemies including parasitoids, predators and entomopathogens (Todd, 1989) feeds on *N. viridula*. Among these natural enemies are the hymenopteran scelionid parasitoid *Trissolcus basalis* (Wollaston) which oviposits in the eggs of *N. viridula* and a tachinid parasitoid *Trichopoda pennipes* (F.) feeds on the late-instar nymphs and adults (Panizzi, McPherson, James, Javahery, & McPherson, 2000; Todd, 1989). Several African and Asian egg parasitoids in the genera *Trissolcus*, *Telenomus* and *Cryon* were recorded feeding on *N. viridula* (Jones, 1988). For example, the scelionid parasitized 45% of *N. viridula* egg masses in earlier studies in Florida during 1974-1975 (Buschman & Whitcomb, 1980). Many generalist predators, including spiders, ants, frogs, crickets, beetles and predatory bugs prey on *N. viridula* (Stam, Newsom, & Lambremont, 1987; Van Den Berg, Bagus, Hassan, Muhammed, & Zega, 1995). In this study, we determined the abundance of natural enemies of *N. viridula* on three cultivars of sweet alyssum (refuge crops) with a view to protect tomatoes in north Florida.

2 | MATERIALS AND METHODS

2.1 | Study site and crops

The study was conducted at the Vegetable IPM Demonstration Site, located at the Center for Viticulture and Small Fruit Research (CVSFR), Florida Agricultural and Mechanical University, in Leon County, Florida (at approximately 30°28′39″ N, 84°10′16″ W). The size of the plot was 0.137 acre (0.055 ha). West of the study site were cultivated muscadine grapes cultivar: majesty, carlos), and several small fruit trees (peach (cultivar: gulfcrest); pear (cultivar: baldwin); apple; fig (cultivar: brown turkey); Citrus (cultivar: satsuma). On the East, persimmon (cultivar: fuyu), and oriental chestnuts (Chinese) were grown, while on the north side citrus (cultivar: satsuma) was grown. The land to the south side was not cultivated. The soil was primarily sandy loam, fairly well drained with a good infiltration rate and a pH of 6.5. The study was carried out from May to July in 2014 and 2015.

2.2 | Experiment layout

Refuge crops and main crops were sown in seedling trays and transplanted to the experimental plots in 60 ft. (18.2 m) rows (Table 1). Proper fertilization and irrigation were provided to promote suitable plant establishment. Drip irrigation was provided, one hour in the morning and one hour at the night.

The experimental refuge crops were cultivated on two outer rows and one center row of the major crop (tomato) plot (Figure 1). Each treatment area consisted of three cultivars of sweet alyssum (*Lobularia maritima*): royal carpet, carpet of snow and tall white. The control was a similar plot of six rows of tomatoes grown under the same agronomic practices in a plot about 70 ft. (21 m) north of the experimental plot. Each section of the rows of trap crops and refuge crops was 20 × 3 ft. (6 × 0.91 m) in size (Figure 1). The row to row and plant to plant distance was kept at 36 and 18 ft, respectively.

TABLE 1 Tomato and refuge crops monitored from May to July 2014 and 2015

Common name	Family	Scientific name	Collection method/tool
Tomato var			
Marglobe	Solanaceae	*Solanum lycopersicum*	Handpicked/Insect net
Sweet alyssum var			
Carpet of snow	Brassicaceae	*Lobularia maritima*	Vacuum aspirator[a]
Royal carpet			
Tall white			

[a]Hand-held insect vacuum aspirator (Craftsman): 19.2 volt.

Treatments	Replicates		
	←20 ft→	←20 ft→	←20 ft→
Refuge crop	TC_1	TC_2	TC_3
Main crop		Tomato	
Main crop		Tomato	
Main crop		Tomato	
Refuge crop	TC_3	TC_1	TC_2
Main crop		Tomato	
Main crop		Tomato	
Main crop		Tomato	
Refuge crop	TC_2	TC_3	TC_1

↕ 63.75 ft

FIGURE 1 Field layout (TC_1: Carpet of snow; TC_2: Royal carpet and TC_3: Tall white)

2.3 | Insect collection

In summer 2014 and 2015, tomato and refuge crop (sweet alyssum) were cultivated to determine the presence or absence of insect pests and natural enemies. Every week insects (pest and their natural enemies) were collected. Adult and late instar nymphs of *N. viridula* were hand-picked and also collected with an insect collection net. The natural enemies were collected using a battery operated vacuum aspirator. Unidentified insects and parasitized (eggs, nymphs and adults) were and brought back to the laboratory and partially reared in the incubator set at 75 ± 3°F; 65% ± 5% RH and 14:10 hr photophase. Partial rearing was done to determine any eggs, nymphs or adults were parasitized. Upon emergence, parasitoids were identified using diagnostic characters under the microscope and/or hand lens (20×).

2.4 | Abundance of beneficial species

Sampling was performed weekly from May to July in 2014 and 2015 to know the number of natural enemies on the three refuge crops (carpet of snow, royal carpet and tall white). Each treatment block was vacuum-sampled for 20-s on the sampling date. The entire procedure was repeated in the summer of 2015. Sampling continued through until all tomatoes were harvested. Insects were sampled in the morning time (9:00–11:00 a.m.) Since most insects were less mobile under cooler temperatures. Stink bugs were sampled with sweep nets (three sweeps per treatment). We used the sampling procedure of Todd and Herzog (1980) with some modifications. Natural enemies were sampled using a vacuum sampler (30-s per treatment) in an area of about 30 ft^2. Some qualitative data from general inspections were also recorded. The insects collected via sweep net were recorded on a data sheet and were placed in plastic vials and ziplock bags (quart, BioQuip) and their respective sample numbers were recorded. Insects were identified using microscopes, hand lens and taxonomic keys. Insects collected from trap crops, refuge crops and tomatoes were identified, tabulated and grouped into families, genera and species. *N. viridula* adults collected in the field were brought in the laboratory and partially reared to determine parasitism rates of *T. pennipes* in the field conditions. In case of egg parasitoid, *T. basalis*, number of egg batches of *N. viridula* were collected and partially reared to determine the parasitism rates.

2.5 | Statistical analyses and evaluation

All data were checked for normality and homoscedasticity and were $\log_{10}(x + 1)$ transformed when necessary. Data on number of insect pests for each trap crop were analysed to determine if treatment effects were statistically significant. Data were subjected to Two-Way Analysis of Variance (ANOVA) and treatment means were separated using Tukey's HSD (honestly significant difference) Test. Alpha level of 0.05 was used to determine statistical significance for all major variables (SAS Institute, 2013).

3 | RESULTS

3.1 | Major insect pests and their natural enemies in tomatoes and refuge crops

Insect pests found in this study were identified to genus and species levels. Four major species of natural enemies (two parasitoids and two predators) were identified. In addition, predators belonging to order: Diptera, Araneae, Coleoptera and Hemiptera were recorded (Table 2). Three major insect pests, *Nezara viridula*;

TABLE 2 List of hemipteran pests and natural enemies collected from cultivated crop (tomato) and refuge crops during summer of 2014 and 2015

Orders/status	Species/status	Tomato (*Solanum lycopersicum*)	Sweet alyssum (*Lobularia maritima)*		
			Carpet of snow	Royal carpet	Tall white
Insect pests					
Hemiptera	*Nezara viridula*	+	–	–	–
Hemiptera	*Euschistus servus*	+	–	–	–
Hemiptera	*Leptoglossuss phyllopus*	+	–	–	–
Natural enemies					
Diptera	*Trichopoda pennipes*	+	–	–	–
Hymenoptera	*Trissolcus basalis*	+	–	–	–
Hemiptera	*Geocoris punctipes*	+	+	+	+
Hemiptera	*Orius insidiosus*	+	+	+	+

Note. Species present (+) & Species absent (–).

Euschistus servus and *Leptoglossuss phyllopus* were collected and a parasitoid, *Trichopoda pennipes* was associated with all these pests. The parasitism rate on these three species ranged from 18%–35% in north Florida conditions. The parasitoid preferred adults and later instar nymphs for oviposition. *T. basalis* was the only egg parasitoid recorded on *N. viridula* in this study. The highest egg parasitism rates were recorded in May (27%) and June (33%). For the refuge crops, two predators *Geocoris punctipes* and *Orius insidiosus* were collected. Other predators including ladybird beetles (Coccinellidae), assassin bugs (Reduviidae), damsel bugs (Nabidae), hover flies (Syrphidae) and spiders were found in small numbers. These insects were not identified at species level. However, the pest most frequently recovered throughout the season were the *N. viridula*; *E. servus* and *L. phyllopus* and among the natural enemies *G. punctipes* was the dominant predator species found throughout the season.

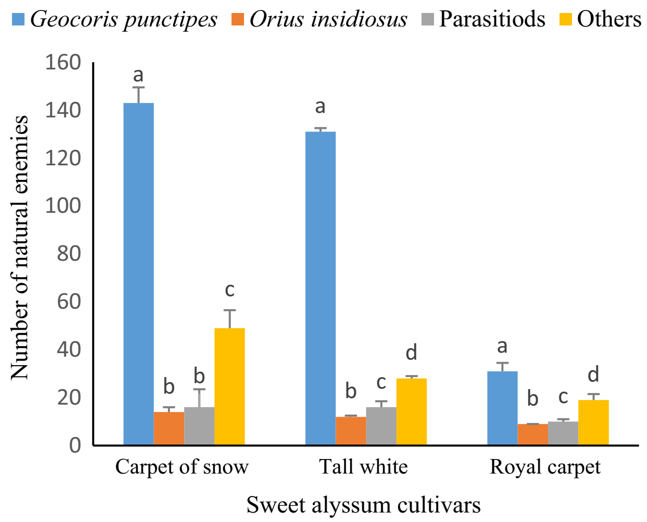

FIGURE 2 Cumulative number of natural enemies captured (Mean ± *SE*) on three refuge crops for two cropping season (2014 and 2015)

3.2 | Abundance of beneficial species

The big eyed bug, *Geocoris punctipes* was the most dominant natural enemy species found on all three cultivars of sweet alyssum (*Lobularia maritima*). Other natural enemies included the minute pirate bug (*Orius insidiosus*), and predators, such as hover flies, spiders, ladybird beetles, assassin bugs and damsel bugs (Table 2). The higher number (143 adults) *G. punctipes* were recorded on the carpet of snow variety (F = 1.38; df =1, 24; p = 0.2520) followed by tall white (131) (F = 0.01; df = 1, 24; p = 0.9125) and royal carpet (31) (F = 0.77; df = 1, 24; p = 0.3886) (Figure 2). *Goecoris punctipes* was recorded on all three cultivars of *L. maritima*, starting on the first week of sampling (Figure 3) during the cropping seasons of 2014 and 2015. All three cultivars attracted the predators. However, the carpet of snow attracted the most adults of *G. punctipes* in May, June and July. The predator numbers were significantly higher in May and June and then declined at the end of season in the July. The royal carpet attracted the least number of predator during the 2 years of study (Figures 3 and 4). In the control treatment, very few number (0–5 adults/month) of predators were recorded in both years.

3.3 | Effect of *Geocoris punctipes* on *Nezara viridula* population

In 2014, when the *Geocoris punctipes* population was high the number of *N. viridula* was low in the week 4–9 (Figure 5). *Nezara viridula* population first peaked in week 10 (July) declined in week 11 and then had a sharp increase in week 12 and 13 when *Geocoris punctipes* population was comparatively high. There was a sharp decline in week 14. *Geocoris punctipes* highest peak was in week 7. Increased *N. viridula* numbers from week 9–13 were found when precipitation rates and *G. punctipes* numbers declined. Unknown factors may have caused decline in *N. viridula* numbers (Figure 5). Similarly in 2015, in weeks 1–7, *G. punctipes* population was the highest and *N. viridula* was low except for week 4.

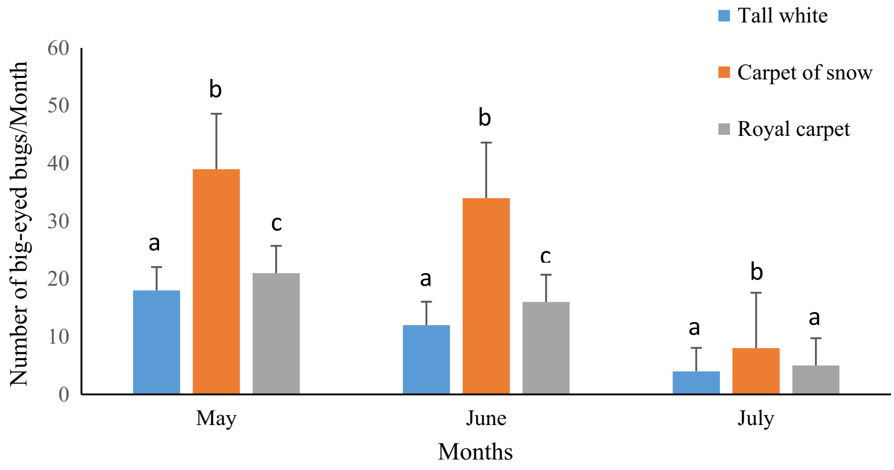

FIGURE 3 Natural enemies captured (Mean ± SE) on three refuge crops during the 2014 (May-July) cropping season

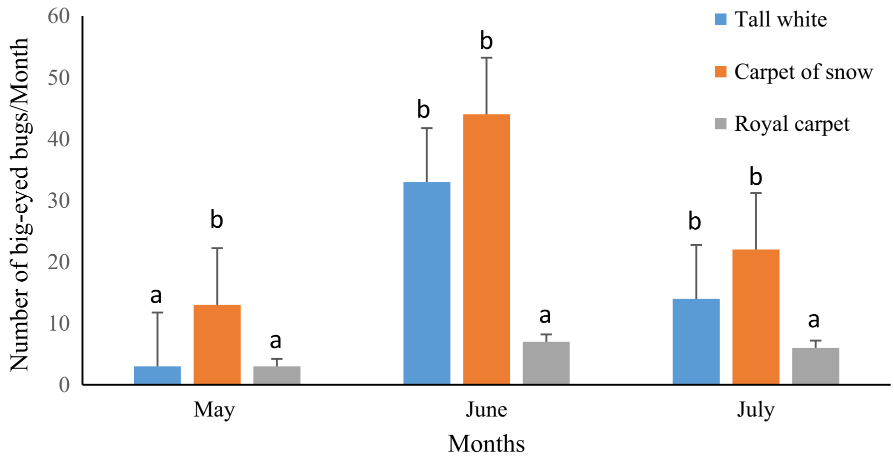

FIGURE 4 Natural enemies captured (Mean ± *SE*) on three refuge crops during the 2015 (May-July) cropping season

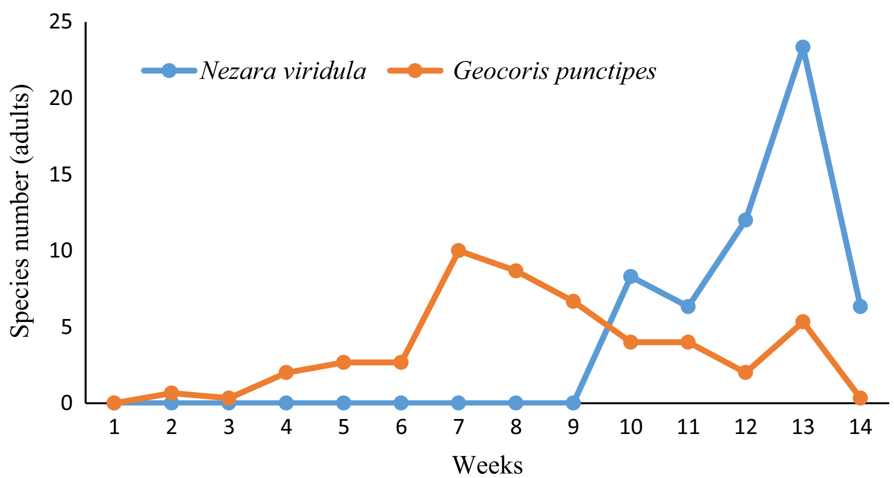

FIGURE 5 Relationship between *Geocoris punctipes* and *N. viridula* in summer 2014 (May-August) treatments

4 | DISCUSSION

The carpet of snow, tall white and royal carpet all started blooming at the same time. All cultivars of *L. maritima* attracted the natural enemies of the southern green stink bug; however, carpet of snow was the most effective followed by tall white in attracting *G. punctipes* to the tomato crop during both years. Natural enemies showed preference for the flowers that had white blooms; carpet of snow and tall white. Flower colour may influence beneficial species choice (Colley & Luna, 2000; Smith & Capinera, 2011). Cowgill (1989) surveyed wild plants on farmlands and noted that white and yellow flowers were particularly attractive to natural enemies. Our results are consistent with previous reports on attractiveness of insects to flower colors.

In an earlier study, *N. viridula* population were managed by *T. basalis* in Hawaii (Jones, 1995) and Australia (Clarke & Walter, 1993). It is probably the best known *Trissolcus* species, due to its widespread introduction against *N. viridula* and other pentatomid crop pests (Plantwise, 2015). In a study conducted by Corrêa-Ferreira and Moscardi (1995), inundative releases of *T. basalis* (15,000/ha) were made in soybean trap crops, and the population density of *N. viridula* consequently decreased by 58% in the main crop. The effectiveness of both introduced and native natural enemies can be enhanced by modifying the environment to favor predators and parasitoids. The big-eyed bugs, ladybird beetles, syrphid flies and lacewings are examples of predators that can be conserved around the tomato field. Similarly, the association of egg and nymphal parasitoids of the southern stinkbugs can be enhanced using conservation biological control in tomatoes. Conservation often involves establishing plants that provide alternate food sources, such as nectar and pollen for beneficial insects, or selective use of insecticides so as not to injure the beneficial species. Many beneficial insects feed on the pollen of plants, such as sweet alyssum, cilantro, fennel and buckwheat. It may be possible to increase the numbers of beneficial insects by including such plants in a farm.

Indeed, tomato IPM is a highly complex practice in Florida and it depends on numerous factors, especially the conservation of natural enemies to control *N. viridula*. In general, the refuge crops prevent pesticide resistance development and sustain the cropping systems in the long run. In addition, information on the availability of refuge crops which provide nectar and shelter to natural enemies are very useful. Further studies are necessary to determine the comparative effects of sweet alyssum to potential natural enemies of other pests of tomato like western flower thirps, whiteflies and leafminers. We recommend tomato growers to use either carpet of snow or tall white because both cultivars attracted similar natural enemies. An IPM strategy which consist of three components that include physical control (trap and refuge crops), biological control (predators and parasitoids) and possibility of using biobased selective chemicals could provide better pest management option against *N. viridula*. This will certainly increase the tomato grower's crop productivity and profitability.

ACKNOWLEDGEMENTS

We greatly appreciate Mr. Neil Miller (USDA-ARS) for the technical support and Mr. Gilbert Queeley for statistical analyses for this study. Mr. José Jimenez assisted in sowing seeds and maintaining vegetable and refuge crop plots. Ms. Janice Peters provided helpful review on the earlier version of this manuscript. This research was funded by the United States Department of Agriculture, National Institute for Food and Agriculture (NIFA), 1890 Capacity Building Grants Program (grant/award number: 2012-38821-20151) and Extension IPM Coordination and Support Program (grant/award number: 2013-41534-21505).

AUTHOR CONTRIBUTION

All authors contributed to the design of the research. The experiments and analyses were carried out by TLG, MH and JCL, supervised by LHBK. The writing up of the manuscript was led by MH with contributions from all authors.

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How to cite this article: Haseeb M, Gordon TL, Kanga LHB, Legaspi JC. Abundance of natural enemies of *Nezara viridula* (Hemiptera: Pentatomidae) on three cultivars of sweet alyssum. *J Appl Entomol*. 2018;00:1–7. https://doi.org/10.1111/jen.12552

Journal of Economic Entomology, 110(6), 2017, 2478–2482
doi: 10.1093/jee/tox267
Advance Access Publication Date: 11 October 2017
Research Article

OXFORD

Horticultural Entomology

Potential of Three Trap Crops in Managing *Nezara viridula* (Hemiptera: Pentatomidae) on Tomatoes in Florida

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Subject Editor: Michael Furlong

Received 20 January 2017; Editorial decision 1 September 2017

Abstract

The southern green stink bug, *Nezara viridula* (L.) (Hemiptera: Pentatomidae), is a serious insect pest of tomatoes in Florida. In this study, we examined the use of three species of trap crops to manage *N. viridula* in North Florida tomato crops in 2014 and 2015. We used striped sunflower (*Helianthus annuus*) (Asterales: Asteraceae) and wild game feed sorghum (*Sorghum bicolor*) (Poales: Poaceae) in both years, but different species of millet each year: browntop millet (*Panicum ramosum*) (Poales: Poaceae) in 2014 and pearl millet (*Pennisetum glaucum*) (Poales: Poaceae) in 2015. The number of stink bug adults collected from wild game feed sorghum exceeded the number from sunflower, and none were collected from either species of millet. Sorghum attracted a significantly higher number of adults than did striped sunflower; however, both sunflower and sorghum attracted the adults of *N. viridula.* Adults of the pest feed on the sorghum panicle and sunflower head (inflorescence). Although fewer stink bugs were found feeding on sunflower, the sunflower was found to be a good source of other natural enemies and pollinators and also attracted significantly greater numbers of the brown stink bug *Euschistus servus* (Say) (Hemiptera: Pentatomidae) (another pest of tomatoes). While this study demonstrated the effectiveness of sorghum, we recommend that sorghum be planted with another trap crop, preferably sunflower, for better preventive control of the southern green stink bug.

Key words: southern green stink bug, trap crop, tomato, pest management

The Southern Green Stink Bug, *Nezara viridula* (L.) (Hemiptera: Pentatomidae), is a highly polyphagous feeder that attacks many important commercial crops (Squitier 2013). Virtually, all vegetable crops are affected, including fresh market tomatoes in Florida (USDA: FASB, 2014). *N. viridula* reduces the quality and quantity of tomatoes, making them unmarketable and thus affecting grower's profitability and productivity. Currently, limited options are available to vegetable growers in Florida to combat the southern green stink bug. In addition, reliance on conventional pesticides contributes to pest problems including pesticide resistance, pest resurgence, secondary pest outbreaks, and pesticide residues (NRDC 2013). There is a substantial amount of research on the use of trap crops in vegetable production. As defined by Shelton and Badenes-Perez (2006), trap crops are plants that are cultivated to attract, divert, intercept, and/or retain targeted insect pests (often vectoring pathogens) in order to reduce damage to the main crop.

In addition, successful crop production and protection of organically grown vegetables requires a higher level of preventive pest management for crop profitability and productivity because growing organic vegetables is extremely expensive and labor intensive.

Push-pull strategies use a combination of behavior-modifying stimuli to manipulate the distribution and abundance of pest or beneficial insects in pest management with the goal of pest reduction on the protected host or resource (Radcliff et al. 2009). Pests are repelled or deterred away (push) from the resource by using stimuli that mask host appearance or are deterrent or repellant in nature. Pests are simultaneously attracted (pull), using highly apparent and attractive stimuli, such as trap crops, where they are concentrated, facilitating their elimination (Radcliff et al. 2009). The use of trap crops to pull pests from the main crop is also referred to as a 'push-pull' strategy (Kahn and Pickett 2008).

Trap crops benefit vegetable growers and increase crop quality by attracting beneficial insects, enhancing biodiversity and reducing use of synthetic insecticides (Pollock 2013). Farmer interest in trap cropping, a traditional tool of pest management, has increased considerably in recent years. The concept of trap cropping fits into the ecological framework of habitat manipulation of an agro-ecosystem for the purpose of pest management (Shelton and Badenes-Perez 2006). Overall, the benefits of trap cropping include reduced dependence on synthetic insecticides, low cost of trap crop seed, conservation of natural enemies, and better crop and environmental quality (Majumdar 2014).

Insect pests are often one of the key constraints to crop production in organic and conventional cropping systems. Generally, pesticides are widely used to manage vegetable pests on commercial crops in Florida, but reliance on synthetic pesticides as the primary method of pest control is not a sustainable approach to pest management (Fisher et al. 1999). Repeated pesticide use leads to pesticide resistance, resurgence, secondary pest outbreaks, and pesticide residues (Fisher et al. 1999). *N. viridula* is a major pest of tomato and a secondary pest of cotton. In the United States, *N. viridula* and other stink bugs invaded transgenic (Bt) cotton (*Gossypium hirsutum*) due to reduced insecticide applications in South Carolina; subsequently, pentatomid damage to Bt cotton bolls ranged from 15 to 71% in 1995 (Greene and Turnipseed 1996). *N. viridula* is tolerant to many insecticides, and thus, it is very difficult to suppress its population. The possible buildup of toxic residues in the environment by some pesticides and the development of pesticide resistance leads to an imbalance in agroecosystems (Lewis et al. 1997). The elimination of pesticide applications and the establishment of habitats that are favorable to beneficial fauna within the agroecosystem can boost the survival, reproduction, dispersal, and ultimately the regulation of pest populations by natural enemies (Landis et al. 2000, Flint and Gouveia 2001).

The main goal of this study is to provide critical knowledge-based solutions to stakeholders, organic farmers, and conventional farmers that will enable them to effectively protect and conserve plant and human resources. The continued use of conventional pesticides causes major hazards to human health and the environment. The purpose of this study was to evaluate the effectiveness of plant-mediated pest management strategies (use of trap crops) to manage *N. viridula* on tomato crop in Florida. In particular, this study focuses on the most effective plant species to be used as trap crops for the management of *N. viridula*.

Materials and Methods

The study was conducted at the Vegetable IPM Demonstration Site, located at the Center for Viticulture and Small Fruit Research (CVSFR), Florida Agricultural and Mechanical University, in Leon County, Florida (at approximately 30° 28′39″ N, 84° 10′16″ W). The size of the plot was 0.137 acre (0.055 ha). On the West of the study site were cultivated muscadine grapes cultivar: majesty, carlos, and several small fruit trees (peach [cultivar: gulfcrest], pear [cultivar: baldwin], apple, fig [cultivar: brown turkey], citrus [cultivar: satsuma], and others); on the East, persimmon (cultivar: fuyu) and oriental chestnuts (Chinese); on the North, citrus (cultivar: satsuma); and on the South, no fruit crop. The soil was primarily sandy loam, fairly well drained with a good infiltration rate, and a pH of 6.5. The study was carried out during the summers of May to July 2014 and 2015.

Trap crop plant species were selected based on previous studies (Tillman 2006, Frank et al. 2008, Mizell 2008, Majumdar 2014). All seeds were purchased from Gramlings (Tallahassee, FL), Johnny's Seed (Ft. Myers, FL), and Harris Seeds (Rochester, NY). Trap crops (three rows, each 60 ft in length), and tomatoes (six rows, each 60 ft in length) (Table 1) were planted. Trap crop seeds were sown directly in the field approximately 2 wk before the main crop in order to allow early start and good synchronization between plant species and arrival of insect pests. Proper fertilization and irrigation were provided to promote growth and development of plants. Drip irrigation was provided twice per day or as needed.

Experimental Design

The experimental trap crops were cultivated on the two outer rows and in the center row of the major crop (tomato) plot. In total, trap crops were cultivated in three threw rows (each 60ft) with 20 ft of each traps crop (sorghum, millet, and sunflower). The control was a similar plot of six rows of tomatoes grown under the same agronomic practices in a plot about 70 ft (21 m) north of the experimental plot. The design of the experiment was a randomized complete block design with three treatments and three replicates. Each section of the rows of trap crops was 20 × 3 ft. (6 × 0.91 m) in size. Field layout of plots is provided in Fig. 1.

The three trap crops were compared to each other regarding their attractiveness to *N. viridula*. The 2014 experiment was conducted using the following three trap crops: Striped sunflower (*Helianthus annuus*), wild grain feed sorghum (*Sorghum bicolor*), and browntop millet (*Panicum ramosum*). Because browntop millet was ineffective in 2014, another variety of millet (pearl millet) was used for the 2015 season.

Sampling and Monitoring Procedure

Within the total research plot of 300 tomato plants, 30 plants were randomly chosen for each sampling date, representing 10% of the total plants. For each of the three treatment blocks of trap crops (sunflower, millet, and sorghum), five plants per block were randomly sampled on each sampling date. Samples were taken weekly in 2014 and 2015 during the cropping season. Sampling continued until all tomatoes were harvested. Adults of *N. viridula* on the main crop, trap crops, and control were collected and recorded. Temperature, rainfall, and relative humidity data were downloaded from a local weather channel on each sample date. Insects were sampled in the morning (09:00–11:00 a.m.) because most adult insects are less mobile under cooler temperatures. Stink bugs were sampled with sweep nets (three sweeps per treatment) using the sampling procedure of Todd and Herzog (1980) with some modifications. Insects collected via sweep net were recorded by sample number and then placed in plastic vials and resealable plastic bags (quart). Species which could not be immediately identified in the field were taken to

Table 1. Tomato crop and trap crops monitored from May to July 2014 and 2015

Common name	Family	Scientific name	Collection method/tool*
Tomato var: Marglobe	Solanaceae	*Solanum lycopersicum*	Handpicked
Striped sunflower	Asteraceae	*Helianthus annuus*	Sweep Net/Aspirator
Browntop millet (2014)	Poaceae	*Panicum ramosum*	Sweep Net
Pearl millet (2015)	Poaceae	*Pennisetum glaucum*	Sweep Net
Wild game feed sorghum	Poaceae	*Sorghum bicolor*	Sweep Net

Sweep net with handle from Bioquip: 15″ diameter collapsible net, 12″ net handle extension; BioQuip Aspirator with 9-dram clear styrene tubes and snap-on caps.

the laboratory for identification. All insects collected from trap crops and tomatoes were identified and tabulated.

Statistical Analysis and Evaluation

All data were checked for normality and homoscedasticity and were $\log_{10}(x + 1)$ transformed when necessary. Data on number of insect pests for each trap crop were analyzed to determine if treatment effects were statistically significant. Data were subjected to two-way analysis of variance (ANOVA) and treatment means were separated using Tukey's HSD (honestly significant difference) test. Alpha level of 0.05 was used to determine statistical significance for all major variables. All analyses were done using SAS v 9.4 statistical software (SAS 2013).

Results

Major Insect Pests Present on Cultivated Crops

Six insect pests found in this study were identified to species and two were identified to genus (Table 2). Most common in samples were the southern green stink bug *N. viridula*, the brown stink bug *Euschistus servus* (Say) (Hemiptera: Pentatomidae), and a leaffooted bug *Leptoglossus phyllopus* (L.) (Hemiptera: Coreidae).

Preventative Control Strategies for *N. viridula*

Over the two seasons of study, the highest number of *N. viridula* was recorded on sorghum (362 adults) as compared to sunflower (26 adults) and millet (0 adults) (Fig. 2). In this study, significantly more adults of *N. viridula* were recorded in sorghum (93%) than in sunflower (7%).

For the other hemipterans, sorghum attracted a total of 45 and sunflower a total of 206 *E. servus* adults, indicating a significant preference of this species for sunflower ($F = 5.38$; df = 1, 31; $P = 0.02$). Sorghum and sunflower attracted 86 ($F = 0.85$; df = 1, 21; $P = 0.3664$) and 76 *L. phyllopus* adults, respectively, indicating no significant difference in trap crop preferences for this coreid bug.

The adults of *N. viridula* were first recorded feeding on sunflower in June and on sorghum in May. The insect like to feed and mate on sunflower inflorescence and sorghum panicle. Sorghum heads reached maturity during weeks 8 and 9 and cumulative insect pests caught at maximum level on this trap crop were 87 in week 9 (Fig. 3), the highest peak. Two population peaks of *N. viridula* occurred in sorghum. Attraction of *N. viridula* to sorghum increased to 84 stinkbugs by week 9 and dropped to 8 by week 11.

Highest population of *N. viridula* in control plots were in July (130 adults) followed by June (75 adults) and May (11 adults). These results indicate that the trap crop(s) were successful in trapping *N. viridula* in tomato crop in north Florida.

Discussion

All three hemipteran species, *N. viridula*, *E. servus*, and *L. phyllopus* feed on both sunflower inflorescence and sorghum head. The time of inflorescence/head formation started attracting *N. viridula*. Their increase in numbers seemed to be a result of availability of mature sorghum panicles. At week 11, the number of *N. viridula* adults dropped which may be due to heavy rain; however, the number increased to 70 by week 13. Sunflower inflorescence attracted the first *N. viridula* in week 6, when five *N. viridula* adults were captured. Thereafter, the number of *N. viridula* increased slightly for week 8 with a total of nine adults of *N. viridula* captured (Fig. 4). *N. viridula* numbers continued to rise and then decreased on week 11 to 1 and then zero by week 12. Our data suggest that the crop and time were important factors in determining *N. viridula* abundance. The slight differences in colonization timing we observed between sunflower and sorghum suggested that they could be used synergistically to provide at least a 7-wk period of attractiveness to *N. viridula*. Together, the attractive period of sunflower and sorghum coincides with peak activity of *N. viridula*, from mid-June to July. Ehler (2000) reported that endemic stink bugs track plant phenology and this was further validated by Mizell et al. (2008) for potential trap crop species in Florida. In addition to these plants, several other

Treatments	Replicates		
	20ft	20ft	20ft
Trap Crops	TC_1	TC_2	TC_3
Main crop	Tomato		
Main crop	Tomato		
Main crop	Tomato		
Trap Crops	TC_3	TC_1	TC_2
Main crop	Tomato		
Main crop	Tomato		
Main crop	Tomato		
Trap Crops	TC_2	TC_3	TC_1

63.75ft

Fig. 1. Field layout. TC_1: browntop millet; TC_2: sunflower; and TC_3: sorghum.

Table 2. List of insect pests collected from cultivated crop (tomato) and trap crops during summer of 2014 and 2015

Orders/status	Species/status	Tomato, *Solanum lycopersicum*	Sunflower, *Helianthus annuus*	Millet, *Panicum ramosum*	Sorghum, *Sorghum bicolor*
Hemiptera	*N. viridula*	+	+	–	+
Hemiptera	*E. servus*	+	+	–	+
Hemiptera	*L. phyllopus*	+	+	–	+

+ Species present; – species absent.

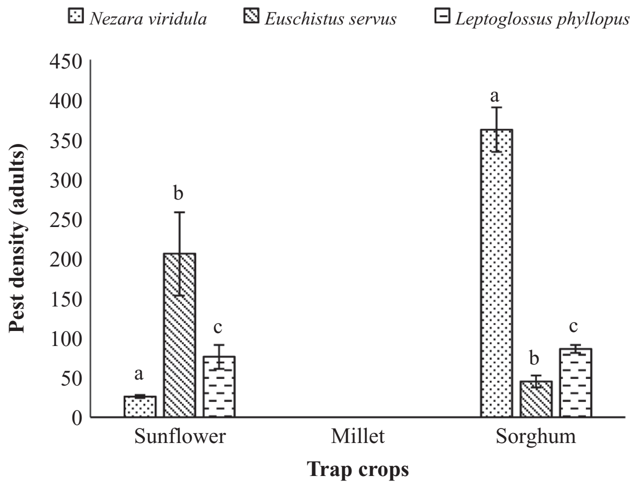

Fig. 2. Comparison of three insect species (mean ± SE) per trap crop (May–July 2014 and 2015). Histograms bearing the same letters are not significantly different within the three traps crops evaluated (two-way ANOVA followed by Tukey's HSD, $P < 0.05$).

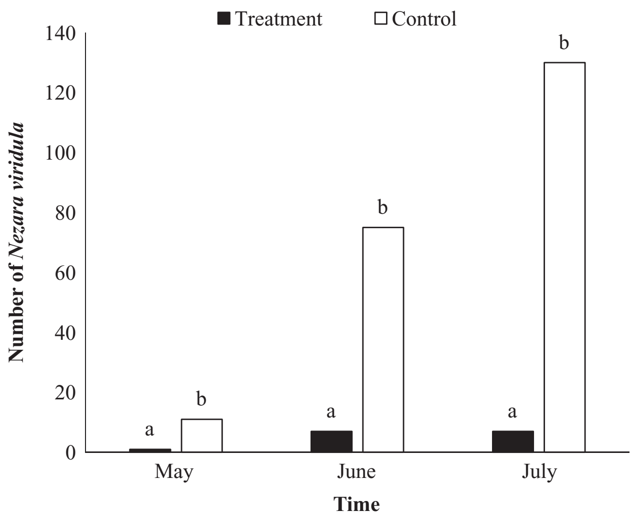

Fig. 3. Total number of *N. viridula* adults collected on treatment (tomato with trap crops) and control (tomato without trap crops; 2014 and 2015). Histograms bearing the same letters are not significantly different within the three months for the traps crops evaluated (two-way ANOVA followed by Tukey's HSD, $P < 0.05$).

insect pests and natural enemies were found during this study. The plant that produced bloom (sunflower) served as host to other herbivores [tarnished plant bugs, *Lygus lineolaris* (Palisot de Beauvois) (Hemiptera: Miridae) and glassy winged sharpshooter, *Homalodisca vitripennis* (Germar) (Hemiptera: Cicadellidae)] and their natural enemies including generalist predators, big-eye bugs, *Geocoris* spp. (Hemiptera: Geocoridae); minute pirate bug, *Orius insidiosus* Say (Hemiptera: Anthocoridae); spined soldier bug, *Podisus maculiventris* (Say) (Hemiptera: Pentatomidae); and multicolored Asian ladybird beetle, *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae).

None of the three major insect pests were found on the both varieties of millet tested. More *E. servus* were found on sunflower, *N. viridula* was more abundant on sorghum, and *L. phyllopus* was equally present on both, but none of these were found on either variety of millet. Tillman (2014) reported that taller trap crops appeared to be a barrier to *E. servus, C. hilaris,* and *N. viridula* in cotton. The

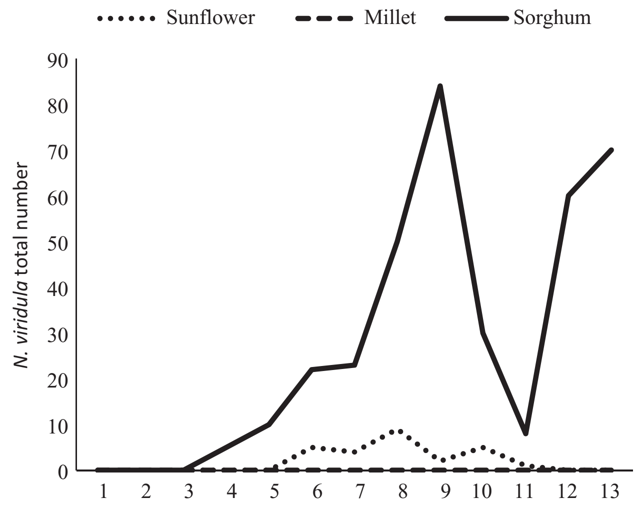

Fig. 4. Cumulative number of *N. viridula* adults captured on three trap crops (2014 and 2015).

striped sunflower variety can grow as tall as 2.4–3.6 m, while sorghum only grows to 1 m, and millet is shorter (0.6 m).

The use of trap crops for managing any insect pests depends on strong host preference by the pest for the trap crop over the cash crop (Hokkanen 1991). In 2014 and 2015, the study confirmed that *N. viridula* adults strongly preferred sorghum to tomato because populations of *N. viridula* were higher in sorghum compared with sunflower and millet. Millet did not attract any major stink bug species; therefore, it is not recommended for the management of *N. viridula*. According to Hokkanen (1991), an ideal trap crop should be able to arrest the pests reducing the likelihood of them dispersing into the main crop. Sunflower attracted *N. viridula*, pollinators, and other beneficial species. The extrafloral nectaries provide ready-made food to most of adult insects. Polyphagy is an apparent manifestation of the stringent requirements the stink bugs have for their food quality (Patel et al. 2006). Food quality is important in trap crops, because it is necessary to provide a continuous source of high-quality food embedded in the trap crops to prevent the buildup of *N. viridula* in the cash crop, which at some point will be very favorable for stink bugs feeding. Thus, the reason why trap crops require multiple plant species to maintain competitive food source to outcompete and lessen the incidence of stink bugs on cash crop (Mizell et al. 2008). When the trap crops were planted as perimeter and interplanted with tomato, the total number of stink bugs and leaffooted bugs remained much higher in the trap crops than in the tomato crop. These results showed the potential of using selected trap crops for tomatoes preventive pest management strategy against *N. viridula*. Sorghum was very effective in capturing *N. viridula* adults reducing their numbers in tomato crop. Therefore, this crop has a great potential to be used for the IPM for *N. viridula* on tomatoes.

In both the 2014 and 2015 study periods, *N. viridula* adults strongly preferred sorghum to tomatoes because density of *N. viridula* adults was higher in sorghum when compared to tomatoes (control) for almost every sampling date. Compared with the control tomato fields, the density of *N. viridula* adults was much lower in tomato fields with sorghum trap crops demonstrating that the sorghum was serving as a suitable trap crop for *N. viridula*. Sorghum was a suitable trap crop for *N. viridula* confirming results from other studies with cotton where sorghum reduced the need for insecticide applications against *N. viridula* (Rea et al. 2002, Tillman and Mullinix 2003). This suggested the possibility of using sorghum as a trap crop for tomatoes. 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. In an earlier study in north Florida, Mizell et al. (2008) identified sorghum and sunflower as potential trap crops for use against *E. servus*, *N. viridula*, and *C. hilaris*. In this present research, no *Chinavia* was found; otherwise, results agreed with Mizell et al. (2008), who showed sunflower as the better trap crop for *E. servus*.

Our results are in agreement with those of Mizell et al. (2008).

Trap cropping may be an effective management tool for several stink bug species in an organic agroecosystem. Both sunflower and sorghum serve as host plants for *N. viridula*. Therefore, this crop has a great potential to be used in integrated pest management for *N. viridula* on tomato crops in conventional and organic cropping systems in Florida.

Although this study demonstrated the attractiveness of sorghum to *N. viridula*, we recommend that sorghum could be planted with another trap crop, preferably sunflower, for the management of *N. viridula*. Trap cropping along with other methods, such as habitat management for natural enemies and possibility of using biobased selective chemicals, could provide better pest management option against *N. viridula* in tomato cropping system. This will certainly increase the tomato grower's productivity and profitability in Florida. Trap cropping is a useful integrated pest management tool that has a great potential to control insect pests in tomato cropping system. This strategy is even more useful for organic tomato pest management. The current study demonstrated that sorghum and sunflower as potential trap crop to manage *N. viridula*. Trapping may eliminate the need for pesticides in tomatoes, thereby reducing the cost of pest management, selective pressure for pest resistance development, and impact on beneficial species. Additional studies are needed to further evaluate trap crops in combination with other pest tactics to manage high population densities of *N. viridula* in tomato production systems.

Acknowledgments

Thanks to Neil Miller (USDA-ARS) and Gohar Umar for technical support and Gilbert Queeley for assistance with statistical analyses. José Jimenez assisted in sowing seeds and maintaining vegetable plots. Janice Peters provided a helpful review. This research was funded by the United States Department of Agriculture, National Institute for Food and Agriculture (NIFA), Extension IPM Coordination and Support Program and the USDA, NIFA 1890 Capacity Building Grants Program.

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