The *Journal of Cotton Science 24:27–33 (2020)*
http://journal.cotton.org, © The Cotton Foundation 2020

ARTHROPOD MANAGEMENT AND APPLIED ECOLOGY

Comparisons of Cotton Boll Injury Caused by Four Species of Boll-Feeding Insects (Hemiptera: Pentatomidae and Miridae)

James P. Glover* and Michael J. Brewer

ABSTRACT

Field experiments with individually caged cotton bolls were conducted in 2013 and 2014 to characterize boll injury from a species complex of boll-feeding insects represented by the verde plant bug, *Creontiades signatus* (Distant) (Hemiptera: Miridae); redbanded stink bug, *Piezodorus guildinii* (Westwood); brown stink bug, *Euschistus servus* (Say); and green stink bug, *Chinavia hilaris* (Say) (Hemiptera: Pentatomidae). Field-collected adult bugs were used individually to infest single cotton bolls of several ages (0-7 days post-anthesis) previously maintained free of insect injury. Individual cotton bolls were infested at mid-bloom for seven days with one bug per boll for each species, and an uninfested control was included. Species and boll age varied across years, allowing selective within-year comparisons. Response to feeding resulted in reduced boll retention, increased boll injury in the form of reduced lint, and increased frequency of boll rot. Results showed that verde plant bugs readily fed on comparatively less mature bolls and feeding decreased boll retention. In contrast, stink bugs fed on larger bolls and caused significant injury. Variation in boll retention, boll injury, cotton boll rot, and yield were associated primarily with species differences and secondarily with boll age from 0 to 7 days old. Boll injury was apparent across species and subsequent yield reduction attributed to insect feeding was detected for all species, except the redbanded stink bug.

The advent and widespread adoption of transgenic Bt (*Bacillus thuringiensis*) cotton, *Gossypium hirsutum* L. (Malvaceae: Malvales), and area-wide eradication of the boll weevil, *Anthonomus grandis* Boheman (Coleoptera: Curculionidae), have substantially decreased the use of broad-spectrum nonselective pesticides (Allen et al., 2009). As a result, stink bugs (Hemiptera: Pentatomidae) and plant bugs (Hemiptera: Miridae) have been released from indirect control and their pest status has increased (Glover et al., 2019; Lu ., al 2010). Stink bugs and plant bugs have become recognized as major pests in cotton during the last two decades (Greene et al., 2001) in the southern U.S. (Luttrell et al., 2015) and elsewhere (Lu et al., 2010; Soria et al., 2017).

The sucking-insect complex that feeds on cotton bolls in South Texas is composed of three stink bugs [green stink bug, *Chinavia hilaris* (Say); brown stink bug, *Euschistus servus* (Say); and redbanded stink bug, *Piezodorus guildinii* (Westwood) (Hemiptera: Pentatomidae)] and one mirid species [verde plant bug, *Creontiades signatus* (Distant) (Hemiptera: Miridae)]. These boll-feeding stink bugs also occur at other locations in the southern U.S. (Greene et al., 2001; Suh et al., 2013). Injury from the green stink bug and brown stink bug cause decreased boll retention, lint loss, and seed loss (Greene et al., 2001). Yield loss can be further magnified when bacteria or fungi that cause boll rot are introduced during probing and feeding activity from stink bugs and the verde plant bug (Glover et al., 2019; Medrano et al., 2015). The ability to breach the carpel wall is associated with mouthpart morphology (Esquivel, 2019; Esquivel and Hinze, 2019; Esquivel et al., 2019) and possibly other factors, such as boll wall thickness (Esquivel and Hinze, 2019). Variablity associated with boll rot disease transmission is less studied, limited primarily to the southern green stink bug, *Nezara viridula* (L.) (Hemiptera: Pentatomidae), and the brown stink bug (Medrano et al., 2009, 2016). Soybeans, *Glycine max* (L.) Merr. (Fabales: Fabaceae), grown along the Texas Gulf Coast harbor the redbanded stink bug (Vyavhare et al., 2014), which can move into developing cotton as soybean pods begin to senesce (Bundy and McPherson, 2000). Historically, the southern green stink bug, green stink bug, and brown stink bug are known to be economic pests of cotton (McPherson and McPherson, 2000).

J.P. Glover* and M.J. Brewer, Department of Entomology, Texas A&M AgriLife Research & Extension Center, 10345 State Hwy 44, Corpus Christi, TX 78406.
*Corresponding author: jamesp.jamesp.glover@outlook.com

The verde plant bug is a significant cotton pest in South Texas. Armstrong et al. (2013) demonstrated that the verde plant bug readily injured bolls < 12 d old from the first day of bloom (white flower), whereas older bolls incurred little or no injury in a no-choice test. When given a choice of varied-age squares and bolls on a branch, Brewer et al. (2012a) found that older squares and young bolls were preferred, which decreased boll retention and increased subsequent yield decline. Verde plant bug was also associated with cotton boll rot (Brewer et al., 2012b; Glover et al., 2020). A related species, *Creontiades distant* (Stal) (Hemiptera: Miridae), also has been shown to injure pre-bloom and early-bloom cotton in Australia (Khan et al., 2006).

Glover et al. (2019) compared several species of stink bugs and the verde plant bug to generate economic injury levels using whole-plant caging experiments. They found severity of boll injury and yield decline was greater when cotton was infested at mid-bloom compared with late-bloom. Differences in injury and yield decline were observed among insect species, but these differences were less apparent. The objectives of this study were to compare boll retention, boll injury, boll rot, and yield decline as a result of feeding activity by the green stink bug, brown stink bug, redbanded stink bug, and verde plant bug on individual bolls varying in age.

MATERIALS AND METHODS

Insect Collection and Cotton Management. Adult insects used for infesting caged, single cotton bolls were collected from wild and cultivated host plants, including cotton, sorghum, *Sorghum bicolor* (L.) Moench (Cyperales: Poaceae), soybean, and several seepweeds, *Suaeda* spp. (Caryophyllales:Chenopodiaceae). Insects were collected using a KISS (keep it simple) sampler (Beerwinkle et al., 1997); the sampler is a modified leaf blower that aspirates insects from vegetation and transfers them into an inflatable sock that fits on the opposite end of the blower's fanned nozzle. Verde plant bugs were collected from a mixture of cotton, seepweeds, and grain sorghum from milk through hard dough stages. All stink bug species were collected from cotton and various pod-filling stages of soybean. Following collection, all insects were held individually in plastic portion cups (model S-20778, Uline, Pleasant Prairie, WI) for a 24-h fasting period. Individuals that survived the fasting period were inspected and only adults with all appendages were used for infesting the caged cotton bolls.

The experiment was conducted in 2013 and 2014 at the Texas A&M AgriLife Research and Extension Center farm at Corpus Christi, TX. PHY 367 WRF (PhytoGen Cottonseed, Dow AgroSciences, Indianapolis, IN) cottonseed was planted in early May on 91-m length rows and 96-cm row centers at a field site of ≈0.4 ha, resulting in a plant stand of ≈77,800 plants per ha (31,500 plants per acre). Cotton plots were grown without irrigation in 2013 when 235 mm of rainfall occurred from 15 April to 1 August (National Weather Service, 2019). Supplemental irrigation was provided by a drip system in 2014 (drought year) to attain a total of 241 mm of water inputs from 15 April to 1 August (Glover et al., 2019). Thiamethoxam insecticide (Centric 40WG, Syngenta Crop Protection, Greensboro, NC) was applied at labelled rates every 10 d to maintain plots free of pests before and after infestation. Thiamethoxam application was discontinued 14 d prior to infesting with experimental insects, and applications resumed at the conclusion of the infestation period. Cages were thoroughly examined for any remaining live experimental insects and removed when found. Other agronomic practices were normal for the region (Morgan, 2018).

Insect Infestation and Experimental Design. Individual insects were released into individually caged cotton bolls for a 1-wk period to characterize the effects of insect species and boll age on boll retention, cotton boll injury, cotton boll rot, and yield. Treatments were comprised of a species (including a no-insect control) by boll age factorial. In 2013, available species included verde plant bug, redbanded stink bug, brown stink bug, and green stink bug; boll ages were 0- and 3-d post-anthesis. In 2014, species available included verde plant bug, brown stink bug, and green stink bug; boll ages were 3-, 5-, and 7-d-old post-anthesis. In 2014, the boll age range was modified to eliminate the 0-d interval and increase the age ranges based on first year data that showed a large amount of boll abscission for 0-d-old bolls. Treatment combinations of species and boll ages were replicated 12 times in 2013 and 14 times in 2014; replications were set out in randomized blocks in uniform cotton planting.

Prior to experimental infestation, the bolls were enclosed as white blooms within small organza fabric cages (12 by 13 cm, ~240 µ mesh, JoAnn's Fabrics, Hudson, OH) that protected them from feeding by any naturally occurring insects (Armstrong et al., 2005). At this time, the cotton was in the second week of bloom and was characterized as 10 to 12 nodes above white flower (Kerby et al., 2010). Four days before each infestation, plants were hand sprayed to run-off with a short-residual UV-sensitive pyrethrin insecticide (0.02% by volume, Bonide Products, Oriskany, NY) to remove aphids and other small insects that can contaminate the caged cotton.

Cotton bolls of specific ages including 0- and 3-d post-anthesis in 2013, and 3-, 5-, and 7-d post-anthesis in 2014 were infested with a single adult of each species, along with uninfested controls. To identify boll age, first-position cotton bolls were identified at white bloom by tagging the boll peduncle with a plastic tag indicating the date; a colored ribbon was then tied to the corresponding node of the main stem to identify plants with tagged bolls. First-position cotton bolls were used for uniformity and because they contribute a significant portion of the total yield (Jenkins et al., 1990). Bolls were tagged at least biweekly to ensure availability of developing bolls when insects were available for the experiment.

Each cage ($n > 370$) containing an individual boll was infested with a single insect for 7 d, along with maintaining an uninfested control treatment. The 7-d infestation period was chosen to reflect a commercial field where insects might go undetected during a weekly scouting schedule. At the conclusion of the infestation period, a sampling of cages distributed across all species and both years ($n > 50$) contained active insects. All caged treatments were then treated with thiamethoxam insecticide on day seven post-infestation and again on day 14 to eliminate non-target pest damage and remnant treatment insects including nymphs emerging from eggs laid by the adults.

Boll Injury and Yield Measurements. Cages remained in place until bolls fully matured and opened to expose lint; this also allowed for temporal development of boll rot by any introduced pathogens, if present. Bolls were hand harvested during early August in 2013 and late August in 2014. At harvest, all bolls retained on the plant were brought to the laboratory and rated for boll retention, boll injury, cotton boll rot, and yield. For each treatment combination of species and boll age, mean percentage boll retention was calculated. Mean boll injury was evaluated by first rating each boll using a boll injury scale that ranged from 0 (representing no locule injury) to 4 (representing severe degradation of seed and lint in all locules); ratings of 1 to 3 indicated a progression of seed and lint degradation occurring by damaged locule count (Brewer et al., 2013; Glover et al., 2019). Next, the boll interior was thoroughly inspected for symptoms of cotton boll rot (Medrano et al., 2009). Bolls were scored on visual presence or absence of cotton boll rot. Yield data were estimated by cotton lint weights obtained by ginning seed cotton by hand using a 10-saw laboratory cotton gin (Continental Eagle Crop., Prattville, AL). Weights were recorded as weight (g) of lint per boll.

Data Analysis. Experimental design was a two-way factorial arrangement of treatments in a randomized, complete block design. Percentage boll retention and percentage bolls with symptoms of cotton boll rot were first subjected to arcsine square-root transformation (Neter et al., 1985) and then analyzed using ANOVA (PROC GLM, SAS Institute Inc., Cary, NC). Separate analyses were conducted by year because of the different species and boll ages used. Insect species and boll age were modeled as fixed effects and the residual was set as the error term for the main effects and the boll age-species interaction (Neter et al., 1985). If the interaction was significant, means separation analyses to detect differences across species were conducted for each boll age (Quinn and Keough, 2002). If the interaction was not significant, the same means separations were used to compare means for the species and boll age main effects. The means statement with the LINES option was used to separate means using Tukey-Kramer's test ($\alpha = 0.05$). Back-transformed means are presented in the text and on figures. Retention data was available for analyses from all bolls, but boll injury and lint weight were available only for the subset of bolls that were retained on the plant. We did not know when bolls were abscised from the plant during the 7-d infestation period; therefore, data from abscised bolls were not taken nor were other measurements adjusted for boll retention.

RESULTS AND DISCUSSION

Infestation of verde plant bug, brown stink bug, and green stink bug resulted in increased cotton boll injury and cotton boll rot and decreased boll retention and lint weights (Table 1; Figs. 1, 2). Bolls caged with the redbanded stink bug experienced minimal boll injury and boll retention rates similar to other infested bolls, but no change in cotton boll rot or yield estimates. There was good evidence that the individual boll cages were successful in restricting any non-targeted insect feeding and did not disrupt feeding by the insects introduced into the cages.

Table 1. ANOVA *F* test results of species, boll age, and their interaction when selected species of stink bugs and the verde plant bug were infested individually on caged cotton bolls of several ages for a 1-wk period during mid-bloom (2013, 2014)

Factor	Boll retention		Boll injury		Boll rot		Yield	
	2013	2014	2013	2014	2013	2014	2013	2014
Species[z]	F = 10.98 df = 3, 123 *P* < 0.01*[y]	*F* = 7.91 df = 2, 187 *P* < 0.01*	*F* = 16.93 df = 3, 123 *P* < 0.01	*F* = 20.86 df = 2, 187 *P* < 0.01*	*F* = 3.80 df = 3, 123 *P* = 0.01*	*F* = 16.10 df = 2, 187 *P* < 0.01*	F = 5.82 df = 3, 123 *P* < 0.01*	*F* = 13.21 df = 2, 187 *P* < 0.01*
Boll age	*F* = 4.32 df = 1, 123 *P* = 0.04*	*F* = 2.87 df = 2, 187 *P* = 0.09	*F* = 13.63 df = 1, 123 *P* < 0.01	*F* = 2.76 df = 2, 187 *P* = 0.07	*F* = 4.42 df = 1, 123 *P* = 0.04*	*F* = 2.18 df = 2, 187 *P* = 0.11	*F* = 1.51 df = 1, 123 *P* = 0.22	*F* = 4.98 df = 2, 187 *P* < 0.01*
Boll age by species	F = 0.48 df = 4, 123 *P* = 0.74	*F* = 1.85 df = 6, 187 *P* = 0.09	*F* = 2.98 df = 4, 123 *P* = 0.04*	*F* = 0.91 df = 6, 187 *P* = 0.48	*F* = 2.08 df = 4, 123 *P* = 0.12	*F* = 0.96 df = 6, 187 *P* = 0.45	F = 1.97 df = 4, 123 *P* = 0.13	*F* = 0.88 df = 6, 187 *P* = 0.51

[z] Species were verde plant bug, redbanded stink bug, brown stink bug, and green stink bug in 2013; verde plant bug, brown stink bug, and green stink bug in 2014. Boll ages were 0 and 3 d old in 2013; and 3, 5, and 7 d old in 2014.

[y] Exact probabilities (*P*) are given, followed by * to denote significant interaction effects (*p* < 0.05) or focus attention on significant main effects when the interaction is not significant.

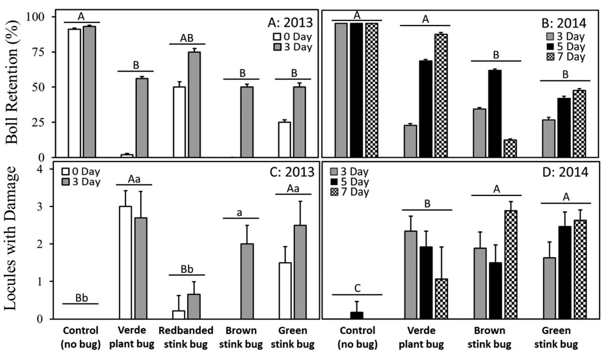

Figure 1. Mean (±SEM) percent boll retention (A: 2013 and B: 2014) and locules with damage (C: 2013 and D: 2014) after selected species of stink bugs and verde plant bugs were individually caged on respective cotton bolls of varying ages for 7 d during mid-bloom. Bars with different capital letters denote significant differences among species, including an uninfested control, averaged across boll ages. Analyses follow Tukey-Kramer's means separation test (α = 0.05). For boll injury in 2013, when the interaction was significant, capital letters denote significant differences in species for 0-d-old bolls, and lower case letters denote differences in species for 3-d-old bolls.

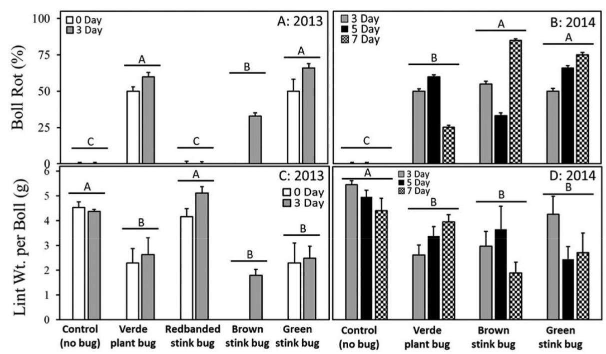

Figure 2. Mean (±SEM) percent boll rot (A: 2013 and B: 2014) and lint weight per boll (C: 2013 and D: 2014) after selected species of stink bugs and the verde plant bug were individually caged on respective cotton bolls of varying ages for 7 d during mid-bloom. Bars with different capital letters denote significant differences among species, including an uninfested control, averaged across boll ages. Analyzed follow Tukey-Kramer's means separation test (α = 0.05).

Boll Retention. In 2013 and 2014, no boll-age-by-species interaction was detected ($p > 0.05$) (Table 1; Figs. 1A, 1B), but boll retention differed across species. Data show that verde plant bug, brown stink bug, and green stink bug caged bolls resulted in significantly lower boll retention compared with bolls caged with no insect in 2013. In 2014, bolls infested with brown stink bug and green stink bug had significantly lower boll retention than bolls infested with verde plant bug or no insect in the cage (Fig. 1B).

Significant boll age effects on boll retention were detected in 2013, but not in 2014 (Table 1). In 2013, 0-d-old bolls had lower boll retention compared with older 3-d-old bolls averaged across species (Fig. 1A). Brewer et al. (2012a) found lower boll retention when younger 0-d-old bolls were caged with the verde plant bug. In the current study, 0-d-old bolls caged with verde plant bug experienced up to 96% boll abscission, and 100% boll abscission when caged with the brown stink bug. Similarly, Glover et al. (2019) showed significant decreases in boll retention of younger bolls resulting from the infestation of verde plant bug at mid-bloom. As these results were highly conclusive, the 0-d-old boll age treatment was not repeated in 2014 and 5- and 7-d-old boll age treatments were added.

Boll Injury. In 2013, both the species-by-boll-age interaction and main effects were significant (Table 1; Fig. 1C). Looking across species at 3-d-old bolls, a Tukey's test indicated bolls caged with verde plant bug, brown stink bug, and green stink bug experienced more injury than bolls infested with redbanded stink bug or bolls with no insect. Inspecting the interaction, 0-d-old control bolls (no injury observed) and bolls caged with redbanded stink bug (0.2 ± 0.4 injured locules per boll) experienced minimal boll injury, whereas bolls infested with green stink bug (1.5 ± 0.4) and verde plant bug (2.8 ± 0.4) experienced more injury. All 0-d-old bolls caged with the brown stink bug in 2013 abscised (0% boll retention, Fig. 1A); therefore, subsequent boll injury measurements were not collected. Control bolls at 3 d did not exhibit any damage and bolls caged with redbanded stink bug experienced minimal boll injury (0.6 ± 0.4 injured locules per boll), whereas bolls infested with brown stink bug (2.0 ± 0.21), green stink bug (2.4 ± 0.38), and verde plant bug (2.6 ± 0.2) experienced more injury (Fig. 1C).

In 2014, the interaction between species and boll age was not significant ($p > 0.05$) for boll injury; however, differences were detected across insect species, but not across boll age (Table 1; Fig. 1D). A Tukey's test indicated bolls infested with insects experienced significantly greater boll injury when compared to uninfested control bolls. Boll injury ratings were smaller for verde plant bug (1.0 ± 0.4) compared with brown stink bug (2.0 ± 0.3) and green stink bug (2.3 ± 0.4) when averaged across boll age in 2014.

Overall, verde plant bug and stink bugs infested bolls consistently experienced increased boll injury when compared with uninfested bolls, and more variation in boll injury was associated with species differences than boll age. The redbanded stink bug was less damaging to bolls when compared with the other stink bugs and verde plant bug. However, bolls infested with the redbanded stink bug experienced decreased boll retention and boll injury. Although boll injury was more variable across boll age than previously found, these results were consistent with reports of verde plant bug injury occurring primarily on younger bolls (Brewer et al., 2013). Additionally, Glover et al. (2019) reported boll injury rates similar to rates observed in the current study, further supporting the susceptibility of younger less mature bolls.

Cotton Boll Rot. When visually inspecting open bolls at harvest, up to 66% of bolls had symptoms of boll rot in 2013 and 85% in 2014; variability was always detected across species (Table 1; Figs. 2A, 2B). Boll rot reported here was significantly higher than previous findings of occurrence and magnitude of cotton boll rot symptoms when bolls were exposed to verde plant bugs (Brewer et al., 2012b). A significant species-by-boll-age interaction was not detected either year ($p > 0.05$); however, species differences in occurrence of cotton boll rot were detected (Table 1). In 2013, a Tukey's test indicated that bolls caged with verde plant bug, brown stink bug, and green stink bug had significantly more boll rot than bolls caged with redbanded stink bugs or control bolls. Boll rot was never detected in bolls caged with redbanded stink bug or control bolls. These results were inconsistent with Glover et al. (2019), who reported relatively low incidence of boll rot (no greater than 10%) when caging whole cotton plants during mid-bloom with the redbanded stink bug, whereas cotton boll rot incidence was much higher in cages infested with other stink bug species. The lack of boll rot in bolls caged with the redbanded stink bug and the relatively high incidence of boll rot for other species in the current study can be associated with differences in habitat reservoirs for the disease pathogen (i.e., redbanded stink bug was collected in soybean, whereas the other species were collected in sorghum and cotton) or the efficiency in transmitting the disease across species.

In 2014, a Tukey's test indicated that bolls caged with the brown stink bug and green stink bug experienced significantly more cotton boll rot (up to 85%) compared with bolls infested with the verde plant bug (up to 62%). Boll rot was never detected in the control bolls (Fig. 2B). In 2013, a significant boll age main effect was detected (Fig. 2A), but boll age was not a significant effect in 2014 ($p > 0.05$; Table 1).

Yield. In 2013 and 2014, the species-by-boll-age interaction was not significant ($p > 0.05$) (Table 1; Figs. 2C, 2D). In 2013, yield weight varied across species but not across the two boll ages. A Tukey's test indicated a significant decline in lint averaged across boll age when exposed to verde plant bug, brown stink bug, and green stink bug when compared with redbanded stink bug and the uninfested controls. Bolls infested with redbanded stink bug had lint weight comparable to the uninfested bolls, suggesting boll response to herbivory from this species could be less severe and could be associated with low levels of boll rot as seen for this species. Reduction in lint weight on a per-boll basis (Fig. 2C) reflected boll injury and cotton boll rot observed here (Figs. 1C, 2A), similar to that observed in whole plant cage studies except for redbanded stink bug (Glover et al., 2019). Although the interaction was not significant in 2014, species significantly affected yield (Table

1). In 2014, significant reductions in lint weights were observed when bolls were infested with any species compared with uninfested bolls (Fig. 2D). In comparison, differences in yield detected across boll age were not readily apparent.

In this 2-yr study, the same species were used as in Glover et al. (2019) to examine the extent that boll age and insect species contributed to differences in specific damage and yield when cotton was infested at mid-bloom. Differences in boll retention, boll injury, boll rot, and yield were detected across species in each year. Results from this study comparing 0-, 3-, 5-, and 7-d-old bolls reflect past studies that demonstrated verde plant bug readily fed on large squares and < 10-d-old bolls (Brewer et al., 2012a); further, verde plant bug feeding decreased boll retention. In contrast, southern green stink bugs injured bolls up to 14 d old (Greene et al., 1999). From a management viewpoint, this can have implications on pesticide selection, application timing, and on the window of field monitoring activities that is needed when sampling for these insects. The decline in boll retention and increased boll injury (Fig. 1) support the interpretation that these factors, along with boll rot, are the main causes of observed yield decline (Brewer et al., 2013; Glover et al., 2019). The observed variation in the frequency of cotton boll rot in this 2-yr study suggests potential differences in plant response or in transmission efficiency across species. Further research to define the severity of species-specific disease relationships under varying plant-water stress conditions would be valuable, particularly because it could be an important driver of yield decline.

The similarities in measured responses among bolls exposed to insects further explain and support the blooming period of cotton development as containing the largest array of susceptible boll ages. Furthermore, the narrow range of yield reduction observed in these experiments across stink bug and plant bug infested bolls support the construction of a common economic injury level across several of these species, particularly for brown stink bug and green stink bug (Glover et al., 2019). In contrast, redbanded stink bug caused less damage than other species. The authors acknowledge that frequency of feeding for insects was unknown and the lack of boll rot observed in bolls caged with the redbanded stink bug might be explained by significantly less feeding. Verde plant bug caged bolls resulted in similar reductions in yield when compared with stink bug infested bolls in this study, whereas Glover et al. (2019) in a whole-cage experiment showed that verde plant bug injury and yield loss were on average less when compared to the brown stink bug and green stink bug infested plants. On balance, the degree of yield depression, boll injury, and cotton boll rot caused by these boll-feeding sucking insects, except redbanded stink bug, was in a range that can allow for joint management of this sucking bug complex affecting cotton bolls.

ACKNOWLEDGMENTS

Special thanks to D. Anderson (Texas A&M AgriLife Research, Corpus Christi) for assistance in field plot maintenance and data collection. We thank our local county extension agents and crop consultants for help in locating insect collection sites, and local growers for allowing collection of insects on their property.

REFERENCES

Allen, K.C., R.G. Luttrell, and C.D. Parker, Jr. 2009. Influence of within-season densities of Heliothines and tarnished plant bugs on variability in end-of season cotton yield mapping. J. Cotton Sci. 13:11–22.

Armstrong, J.S., L.D.A. Camelo, H.G. Thorvilson, and L.D. Thompson. 2005. Comparison of *Lygus elisus* Van Duzee and *Lygus hesperus* Knight (Hemiptera: Miridae) feeding injury to pre-bloom cotton. J. Entomol. Sci. 40:143–148.

Armstrong, J.S., M.J. Brewer, R.D. Parker, and J.J. Adamczyk, Jr. 2013. Verde plant bug (Hemiptera: Miridae) feeding injury to cotton bolls characterized by boll age, size, and damage ratings. J. Econ. Entomol. 106: 189-195.

Beerwinkle, K.R., J.R. Coppedge, and T.M. O'Neil. 1997. 'KISS' – a new portable pneumatic 'Keep It Simple Sampler' for row crop insects. p. 1330–1332 *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 7-10 Jan. 1997. Natl. Cotton Counc. Am., Memphis, TN.

Brewer, M.J., D.J. Anderson, and J.S. Armstrong. 2012a. Comparison of cotton square and boll damage and resulting lint and seed loss caused by verde plant bug, *Creontiades signatus.* Southwest. Entomol. 37:437–447.

Brewer, M.J., D.J. Anderson, and J.S. Armstrong. 2013. Plant growth stage-specific injury and economic injury level for verde plant bug, *Creontiades signatus* (Hemiptera: Miridae), on cotton: effect of bloom period of infestation. J Econ. Entomol. 106:2077–2083.

Brewer, M.J., J.A. Armstrong, E.G. Medrano, and J.F. Esquivel. 2012b. Association of verde plant bug, *Creontiades signatus* (Hemiptera: Miridae), with cotton boll rot. J. Cotton Sci. 16:1–8.

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

Esquivel, J.F. 2019. Stink bug rostrum length vs. stylet penetration potential. Entomol. Exp. Appl. 167:323–329.

Esquivel, J.F., and L.L. Hinze. 2019. The cotton boll: The relationship of species and genotype with temporal development of boll wall thickness. Crop Sci. 59:1200–1210.

Esquivel, J.F., Droleskey, R.E., Ward, L.A., and Harvey, R.B. 2019. Morphometrics of the southern green stink bug [*Nezara viridula* (L.) (Hemiptera: Pentatomidae)] stylet bundle. Neotrop. Entomol. 48:78–86.

Glover, J.P., M.J. Brewer, M.N. Parajulee, and G.A. Sword. 2019. Plant response and economic injury levels for a boll-feeding sucking bug complex on cotton. J. Econ. Entomol. 112:1227–1236.

Glover, J.P., M.J. Brewer, M.N. Parajulee, and G.A. Sword. 2020. Transmission of cotton seed and boll rotting bacteria by the verde plant bug (Hemiptera: Miridae). J. Econ. Entomol. (in press).DOI: https://doi.org/10.1093/jee/toz334.

Greene, J.K., S.G. Turnipseed, M.J. Sullivan, and G. A. Herzog. 1999. Boll damage by southern green stink bug (Hemiptera: Pentatomidae) and tarnished plant bug (Hemiptera: Miridae) caged on transgenic *Bacillus thuringiensis* cotton. J. Econ. Entomol. 92:941–944.

Greene, J.K., S.G. Turnipseed, M.J. Sullivan, and O.L. May. 2001. Treatment thresholds for stink bugs (Hemiptera: Pentatomidae) in cotton. J. Econ. Entomol. 94:403–409.

Jenkins J.N., J.C. McCarty, Jr., and W.L. Parrott. 1990. Fruiting efficiency in cotton: boll size and boll set percentage. Crop Sci. 30:857–860.

Kerby, T.A., F.M. Bourland, and K.D. Hake. 2010. Physiological rationales in plant monitoring and mapping, p. 304-317 *In* J.M. Steward, D.M. Oosterhuis, J.J. Heitholt, and J.R. Mauney (eds.), Physiology of Cotton. Springer, Dordrecht, The Netherlands.

Khan, M., A. Quade, and D. Murray. 2006. Mirid damage assessment in Bollgard II- critical damage stage and action thresholds at different stages in irrigated and rain grown cotton, p. 543–554 *In* Proc. 13th Australian Cotton Conference. Gold Coast, Australia.

Lu, Y., K. Wu, Y. Jiang, B. Xia, P. Li, H. Feng, K.A.G. Wyckhuys, and Y. Guo. 2010. Mirid bug outbreaks in multiple crops correlated with wide-scale adoption of Bt cotton in China. Science 328:1151–1154.

Luttrell, R.G., T.G. Teague, and M.J. Brewer . 2015. Cotton insect pest management. p. 509-546 *In* D.D. Fang and R.G. Percy (eds.) Cotton, 2nd Ed. Alliance of Crop, Soil, and Environmental Science Soc., Monogr. 57. Madison, WI.

McPherson, J.E., and R.M. McPherson. 2000. Stink Bugs of Economic Importance in America North of Mexico. CRC Press, Boca Raton.

Medrano, E.G., J.F. Esquivel, R.L. Nichols, and A.A. Bell. 2009. Temporal analysis of cotton boll symptoms resulting from southern green stink bug feeding and transmission of a bacterial pathogen. J. Econ. Entomol. 102:36–42.

Medrano, E.G., A.A. Bell, J.K. Greene, P.M. Roberts, J.S. Bacheler, J.J. Marois, D.L. Wright, J.F. Esquivel, R.L. Nichols, and S. Duke. 2015. Relationship between piercing-sucking insect control and internal lint and seed rot in southeastern cotton (*Gossypium hirsutum* L.). J. Econ. Entomol. 108:1540–1544.

Medrano, E. G., A. A. Bell, and S. E. Duke. 2016. Cotton (*Gossypium hirsutum* L.) boll rotting bacteria vectored by the brown stink bug, *Euschistus servus* (Say) (Hemiptera: Pentatomidae). J. Appl. Microbiol. 121:757–766.

Morgan, G. 2018. Cotton.tamu.edu. Texas A&M AgriLife Extension, College Station

Available online at http://cotton.tamu.edu/index.html (verified 19 Feb. 2020).

National Weather Service. 2019. Observed monthly rainfall for South Texas. National Oceanic and Atmospheric Administration. Available online at www.weather.gov/crp/monthlyrainfall (verified 19 Feb. 2020).

Neter, J., W. Wasserman, and M.H. Kutner. 1985. Applied Linear Statistical Models: Regression, Analysis of Variance, and Experimental Designs, 2nd ed. Richard D. Irwin, Homewood, IL.

Quinn, G.P., and M.J. Keough. 2002. Experimental Design and Data Analysis for Biologists. Cambridge University Press, Cambridge, UK.

Soria, M.F., P.E. Degrande, A.R. Panizzi, and M.D. Toews. 2017. Economic injury level of the neotropical brown stink bug *Euschistus heros* (F.) on cotton plants. Neotrop. Entomol. 46:324–335.

Suh, C.P., J.K. Westbrook, and J.F. Esquivel. 2013. Species composition of stink bugs in cotton and other major row crops in the Brazos River Bottom production area of Texas. Southwest. Entomol. 38:561–570.

Vyavhare, S.S., M.O. Way, and R.F. Medina. 2014. Stink bug species composition and relative abundance of the redbanded stink bug (Hemiptera: Pentatomidae) in soybean in the Upper Gulf Coast of Texas. Environ. Entomol. 43:1621–1627.