Development of a Plant-Based Threshold for Tarnished Plant Bug (Hemiptera: Miridae) in Cotton

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ABSTRACT

The tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), is an important pest of cotton, *Gossypium hirsutum* L., in the mid-southern United States. It is exclusively controlled with foliar insecticide applications, and sampling methods and thresholds need to be revisited. The current experiment was designed to establish a plant-based threshold during the flowering period of cotton development. Experiments were conducted in Mississippi in 2005 and 2006, Arkansas in 2005, and Louisiana in 2005 through 2008. Treatments consisted of various combinations of thresholds based on the percentage of dirty squares that were compared with the current threshold with a drop cloth or automatic weekly applications. Dirty squares were characterized as those with yellow staining on the developing bud resulting from tarnished plant bug excrement. Treatments consisted of 5, 10, 20, and 30% dirty squares. Each plot was sampled weekly, and insecticides were applied when the mean of all replications of a particular treatment reached the designated threshold. At the end of the season, plots were harvested and lint yields were recorded. Differences were observed in the number of applications and yields among the different treatments. The 10% dirty squares threshold resulted in a similar economic return compared with the drop cloth. A threshold of 10% dirty squares resulted in a similar number of insecticide applications, yields, and economic returns compared with that observed with the drop cloth. These results suggest that a threshold of 10% dirty squares could be used to trigger insecticide applications targeting tarnished plant bugs in flowering cotton.

KEY WORDS

*Lygus*, tarnished plant bug, sampling, threshold, cotton

The tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), is an important pest of cotton, *Gossypium hirsutum* L., in the mid-southern United States. Tarnished plant bugs prefer feeding on small to medium-sized flower buds (squares) of cotton compared with other plant structures (Tugwell et al. 1976). While feeding, tarnished plant bugs often defecate, leaving a yellow stain on the outer surface of the developing flower bud (Tugwell et al. 1976). This staining of the flower bud (dirty square) may not always correlate with injury, but it does provide a good indicator of the presence of tarnished plant bugs and their feeding activity in cotton. Feeding generally causes abscission of small squares, resulting in direct yield losses (Layton 2000). On older squares, abscission may not occur, but feeding by tarnished plant bug damages developing flower anthers. Feeding on larger squares that do not abscise generally results in abnormal flowers. If damage to the flower anthers is severe enough, pollination does not occur and this results in small abnormal bolls that often abscise within a few days after pollination (Pack and Tugwell 1976).

Current sampling procedures and thresholds for tarnished plant bugs vary during the season. During preflowering stages, thresholds are based on numbers of tarnished plant bugs using a sweep net and on square retention (Musser et al. 2007). Thresholds for tarnished plant bug range from 8 to 15 bugs per 100 sweeps or 70–85% square retention during the preflowering stages of plant development (Musser 2009b). During the flowering stages, thresholds are based on drop cloth samples, but no consideration is given for a plant-based threshold like that of square retention during the preflowering stages of plant development (Musser 2009b). During the flowering stages, thresholds are based on drop cloth samples, but no consideration is given for a plant-based threshold like that of square retention during the preflowering stages. The threshold for tarnished plant bug during the flowering stages is three bugs per 1.5 m of row (Musser et al. 2009a).

Historically, tarnished plant bugs were considered a relatively minor pest of cotton when compared with the boll weevil, *Anthonomus grandis grandis* (Bohemian), and the tobacco budworm, *Heliothis virescens* (F.) (Layton 2000). Cotton varieties resistant to lepidopteran pests (i.e., Bollgard, Monsanto Co., St. Louis, MO) were first introduced in 1996. These varieties eliminated insecticide applications targeting...
tobacco budworms and reduced applications for other lepidopteran pests. A second generation of resistant cotton varieties was introduced in 2003 (Bollgard II, Monsanto Co., St. Louis, MO) and 2005 (Widestrike, Dow AgroSciences, Indianapolis, IN) that improved control of lepidopteran pests. This further reduced the need for foliar insecticide applications in cotton. Boll weevil eradication had been initiated and was at varying levels of completion in Mississippi, Arkansas, and Louisiana by 2004. Successful implementation of this program across the mid-South further reduced the need for applications of broad-spectrum insecticides such as organophosphates, carbamates, and pyrethroids. Those broad-spectrum insecticides provided coincidental control of tarnished plant bugs, and population densities observed currently in cotton fields are much greater than they were before those advances.

In addition to a reduced spray environment that resulted from transgenic cotton and successful eradication of the boll weevil, development of insecticide resistance in the tarnished plant bug has contributed to their pest status in the mid-South. Tarnished plant bugs in Mississippi, Arkansas, and Louisiana currently have high levels of resistance to the pyrethroid insecticide class. Resistance to this class was first documented in 1995 (Snodgrass 1996) and was widespread in the mid-South by 1999 (Snodgrass and Scott 1999, Snodgrass and Scott 2000). Similarly, resistance to the organophosphate insecticide class, specifically acephate, was first documented in 2001 (Snodgrass and Scott 2002) and was widespread by 2008 (Snodgrass et al. 2009). As would be expected, resistance to acephate confers resistance to other organophosphates and carbamates currently labeled in cotton for most tarnished plant bug populations (Snodgrass et al. 2009). As a result, tarnished plant bugs have become difficult to manage with the few classes of insecticides currently labeled for their management in cotton.

With widespread resistance to the organophosphates and pyrethroids, the neonicotinoid insecticides have become important for tarnished plant bug control during both the preflowering and flowering stages of cotton development. Imidacloprid (Admire Pro, Bayer Crop Science, Raleigh, NC) and thiamethoxam (Centric, Syngenta Crop Protection, Greensboro, NC) are the two most commonly used neonicotinoids for control of tarnished plant bug in cotton. Similarly, the insect growth regulator (IGR), novaluron (Diamond, MANA Inc., Raleigh, NC), and the pyridine carboxamidone, flonicamid (Carbine, FMC Corporation, Philadelphia, PA), are newer insecticides labeled for control of tarnished plant bug. All of these insecticides are relatively slow acting compared with standard organophosphates and pyrethroids (Yamamoto 1996, Maiensisch et al. 2001, Kay 2007, Morita et al. 2007). Therefore, with a twice-a-week scouting program, evaluation of control after an insecticide application and thresholds for subsequent applications may not be appropriate using traditional insect-based scouting procedures. The objective of the current experiment was to determine if a plant-based threshold that used evidence of tarnished plant bug feeding on squares as a trigger could be used to supplement the current threshold during the flowering stages of cotton development. This was determined based on numbers of insecticide applications, yield, and net economic returns for each of the thresholds evaluated.

Materials and Methods

Arkansas and Mississippi Experiments. Experiments were conducted in Mississippi (Stoneville and Greenwood) and Arkansas (Rowher) during 2005 and 2006 seasons to evaluate a plant-based threshold for tarnished plant bugs in flowering cotton. Cotton was planted at one location in Mississippi (Stoneville) and one location in Arkansas (Rowher) during 2005 and at two locations in Mississippi (Stoneville and Greenwood) during 2006. At the Stoneville location, Deltapine 424 B2 F was planted 3 May 2005, and Stoneville 4554 B2 F was planted 30 April 2006. Deltapine 424 B2 F was planted 2 May 2005 at Rowher, AR, and Deltapine 555 BR was planted 25 April 2006 at Greenwood, MS. Plots were 8–16 rows (101.6 cm centers) wide and 12.2–30.5 m long. Treatments were arranged in a randomized complete block design with four replications. The treatments included triggering insecticide applications at three levels of dirty squares (5, 10, and 20%) compared with the currently recommended threshold with a drop cloth (three tarnished plant bugs per 1.5 row m) and a nontreated control. Dirty squares were characterized by yellow staining on the developing flower bud resulting from tarnished plant bug excrement. All general agronomic practices were followed at each location to promote earliness and maximize yields. Before flowering, each test area was scouted weekly and sprayed as necessary for all insect pests.

Beginning at first flower, scouting was initiated to evaluate the threshold treatments. Each plot was scouted once or twice per week using the respective scouting methods (drop cloth or visual observation of squares), and insecticide applications were made based on each threshold. For the plots designated for dirty squares thresholds, 25 one-third to one-half grown squares (~6–12 mm diameter) were randomly removed from each plot and visually examined, and the numbers of dirty squares were recorded. No priority was given for any particular portion of the plant canopy. For the plots designated for the drop cloth threshold and nontreated, one drop cloth sample was taken from each plot. The sample consisted of placing a 0.75-m long drop cloth between two rows of cotton and shaking the plants from each row onto the drop cloth. The numbers of adults and nymphs were counted and recorded. The threshold used for drop cloth samples was three tarnished plant bugs per 1.5 row/m (Musser et al. 2009a). The decision to make an insecticide application was based on the average of all four replications for each threshold. Applications were made the same day that the plots were sampled or the following morning.

At the end of the season, all plots were harvested, and seed cotton weights were determined. Samples of
seed cotton were ginned, and percent lint turnout was recorded for the entire test area. Based on mean percent lint turnout for the entire test area and plot size, yield was converted to kilogram lint per hectare for analyses. All data were analyzed with analysis of variance (ANOVA) (PROC MIXED; SAS Institute 2004). Because there was some inconsistency between years and locations, each year and location combination was treated as a test for statistical analyses. Test (location/year), threshold, and the test by threshold interaction were designated as fixed effects in the model. The replicate by test interaction was the error term for test. Residual error (replicate × test × threshold) was random as well and was the error term for threshold and the test by threshold interaction. Degrees of freedom were estimated with the Kenwood–Roger method. Means were estimated using the LSMEANS statement and adjusted according to the Tukey’s Studentized Range test.

**Louisiana Experiments.** Experiments in Louisiana were conducted at the Macon Ridge location of the Northeast Research Station, near Winnsboro, LA. Bollgard II cotton cultivars were planted during mid-May of 2005, 2006, 2007, and 2008 to minimize the impacts of lepidopteran pests. Plots were eight rows (101.6 cm centers) × 15.2 m. The standard drop cloth threshold treatment was replaced with automatic weekly insecticide applications. Treatments included a nontreated control, weekly insecticide sprays initiated at first flower and continued until crop cutout, and target thresholds of 5, 10, 20, and 30% dirty squares. Treatments were arranged in a randomized complete block design with four to six replications. The insecticides used for these applications included acephate (Orthene 90SP, Valent USA, Walnut Creek, CA) applied at 0.81 kg (active ingredient) ai/ha and thiamethoxam (Centric 40 WG, Syngenta Crop Protection, Greensboro, NC) applied at 0.053 kg ai/ha. All plots were sampled weekly beginning at first flower by examining 50 randomly selected squares from the upper 33% of the cotton plant on the center four rows of each plot. Feeding evidence was determined by visual inspection of the squares externally for yellow staining as described previously and internally for necrotic anthers. Treatments were applied when the average of all four replications reached or exceeded the designated threshold. Plots were mechanically harvested with a spindle-type picker, ginned to determine lint yields, and converted to kilogram lint per hectare. All data were analyzed with ANOVA (PROC MIXED; SAS Institute 2004). Threshold was designated as a fixed effect in the model. Residual error (replicate × threshold) was random and was the error term for threshold. Degrees of freedom were estimated with the Kenwood–Roger method. Means were estimated using the LSMEANS statement and adjusted according to the Tukey’s Studentized Range test.

**Economic Analyses.** To more accurately define the optimum threshold using dirty squares as a trigger for tarnished plant bug management with insecticides, a simple economic analysis was done for each experiment. Economic data used for these analyses were based on an average cotton price of $1.87/kg, average insecticide cost of $23.35/ha, and an average application cost of $7.41/ha (Williams 2011). The price received for cotton was multiplied by the yield for each plot to determine the gross economic return. The mean number of insecticide applications for each treatment was multiplied by the sum of the insecticide cost and application cost to determine the mean cost of control. The net economic return was determined by subtracting the cost of control from the gross economic return. Net economic returns for each experiment (AR/MS and LA) were analyzed with ANOVA (PROC MIXED; SAS Institute 2004). Threshold was designated as a fixed effect in the model. Residual error (test × threshold) was random and was the error term for threshold. Degrees of freedom were estimated with the Kenwood–Roger method. Means were estimated using the LSMEANS statement and adjusted according to the Tukey’s Studentized Range test.

**Results**

Arkansas and Mississippi Experiments. Tarnished plant bug densities in each test peaked during early August each year (Fig. 1). During 2005, tarnished plant bug densities in the nontreated plots exceeded the recommended drop cloth threshold from 21 July to 12 August at Stoneville, MS. Densities of tarnished plant bugs peaked 12 August at a mean (SEM) of 11.5 (3.84) per 1.5 row/m. At the Rowher, AR, location in 2005, tarnished plant bugs in the nontreated plots exceeded the recommended drop cloth threshold on two dates; 26 July and 4 August. Densities peaked 4 August at a mean (SEM) of 14.5 (1.94) per 1.5 row/m. During 2006 at the Stoneville, MS, location, densities of tarnished plant bug in the nontreated plots exceeded the recommended drop cloth threshold from 17 July through 7 August. Densities of tarnished plant bugs peaked 7 Aug at a mean (SEM) of 12.5 (4.05) per 1.5 row/m. At the Greenwood, MS, location in 2006, densities of tarnished plant bug in the nontreated plots exceeded the recommended drop cloth threshold from 5 July through 14 August. Densities of tarnished plant bugs peaked 2 August at a mean (SEM) of 18.8 (5.12) per 1.5 row m.

Numbers of insecticide applications varied among the different thresholds (Fig. 2). The 5% dirty squares threshold triggered significantly more applications than the other thresholds ($F = 5.00; df = 3, 12; F = 0.02$). Across all tests, the mean (SEM) number of applications for the 5% dirty squares threshold was 4.3 (0.5). The 10% dirty squares threshold and the drop cloth threshold triggered significantly more applications than the 20% dirty squares threshold and significantly fewer applications than the 5% dirty squares threshold. The 10% dirty squares threshold and drop cloth threshold triggered a similar number of applications. The mean (SEM) numbers of applications for the 10% dirty squares and drop cloth thresholds were 2.3 (0.8) and 2.8 (0.5), respectively. The 20% dirty
squares threshold resulted in the fewest number of applications with a mean (SEM) of 1.3 (0.5).

There was not a significant test by threshold interaction \( (F = 1.45; \text{df} = 8, 50; P = 0.20) \) for yields, so data were combined across all tests. There were significant differences in yields among the different thresholds (Fig. 3). All threshold treatments resulted in significantly higher yields than the nontreated plots \( (F = 18.57; \text{df} = 4, 64.2; P < 0.01) \). With no insecticide applications, yields in the nontreated plots averaged (SEM) 775.4 (97.8) kg/ha. The thresholds of 5 and 10% dirty squares and the drop cloth threshold (three bugs/1.5 row/m) had significantly higher yields than the 20% dirty squares threshold. Yields for the 5% dirty squares, 10% dirty squares, and drop cloth thresholds averaged (SEM) 1,383.5 (62.1), 1,305.7 (50.2), and 1,269.7 (48.3) kg/ha, respectively. Yields for the 20% dirty squares threshold averaged (SEM) 1,128.4 (66.5) kg/ha.

**Louisiana Experiments.** During this experiment, mean number of applications varied among the different dirty squares thresholds \( (F = 18.57; \text{df} = 3, 12; P < 0.01) \) (Fig. 4). Numbers of applications ranged from 0 (untreated control and 30% dirty squares) to 5.8 (automatic weekly applications). Because no applications were made in the untreated and 30% dirty squares threshold treatments, they were not included in the final analysis of application number. The frequency of applications triggered at 5% dirty squares was similar to those applied on a weekly schedule and those applied at the 10% dirty squares threshold. Fewer applications were triggered in the 10 and 20% dirty squares treatments compared with that for the automatic weekly sprays. Fewer applications were triggered in the 20% threshold than the 10% threshold. The action threshold of 30% dirty squares was never reached during all four years of the study and no sprays were applied to those plots.

**Fig. 1.** Mean (SEM) densities of tarnished plant bug in untreated plots at (A) Stoneville, MS 2005; (B) Rowher, AR 2005; (C) Stoneville, MS 2006; and (D) Greenwood, MS 2006.

**Fig. 2.** Mean (SEM) number of insecticide applications at each of the threshold treatments averaged across years and locations in Mississippi and Arkansas (means followed by the same letter are not significantly different, \( \alpha = 0.05 \)).
Significant differences among treatments in mean cotton lint yields were observed ($F = 4.68; df = 4, 18; P = 0.01$) (Fig. 5). Yields for the 30% damaged squares threshold were combined with the untreated control for the final analysis, because it never triggered an insecticide application in the four years of the experiment. Yields of cotton lint in untreated plots were significantly lower than yields in all insecticide treated plots, except for the 20% dirty squares threshold. No significant differences in yield were detected between the automatic weekly sprays, and the plots triggered at 5, 10, and 20% dirty squares. Yields ranged from 767.3 kg/ha in the untreated to 991.0 kg/ha in the weekly sprays treatment.

Economic Analyses. For the Arkansas and Mississippi experiments, all of the tarnished plant bug threshold treatments resulted in a higher net economic return than the untreated control ($F = 13.67; df = 4, 75; P < 0.01$) (Fig. 6). The 5% dirty square threshold had a significantly higher net economic return than the 20% dirty square threshold. The net economic return for the untreated control averaged (SEM) $1451.22 (183.01)$. Mean (SEM) net economic returns among the threshold treatments ranged from $2071.98 (108.62)$ to $2457.22 (32.05)$.

For the Louisiana experiment, the 10% dirty squares threshold and the weekly insecticide application treatments resulted in higher net economic returns than the untreated control ($F = 3.89; df = 4, 18; P = 0.02$) (Fig. 7). The net economic return for the untreated control averaged (SEM) $1,434.90 (45.58)$. Mean (SEM) net economic returns among the threshold treatments ranged from $1,605.94 (151.95)$ to $1,853.10 (100.65)$.

Discussion

Tarnished plant bugs significantly impacted cotton yields in these experiments. Additionally, treatment of tarnished plant bug based on any threshold generally

![Figure 3](image1.png)

**Fig. 3.** Mean (SEM) yields for each treatment averaged across all experiments conducted in Arkansas and Mississippi in 2005 and 2006 (means followed by the same letter are not significantly different, $\alpha = 0.05$).

![Figure 4](image2.png)

**Fig. 4.** Mean (SEM) number of insecticide applications at each of the threshold treatments averaged across years in Louisiana.
resulted in higher net economic returns than the untreated control indicating that insecticide applications were needed to prevent economic losses during the flowering period. Sampling methods and thresholds to trigger applications during the flowering period across the mid-South are based on insect counts using various sampling methods (Musser et al. 2007). Arkansas, Louisiana, and Mississippi each recommend a threshold of three tarnished plant bugs per 1.5 m of row with a black drop cloth (Bagwell 2008, Catchot 2008, Studebaker 2008). In addition, Louisiana recommends a sweep net threshold (Bagwell 2008), and Mississippi recommends thresholds for sweep nets and visual observation (Catchot 2008) during the flowering period. In contrast, sampling methods and thresholds during the preflowering stages of cotton plant development are based on both insect counts and square retention in each of those states (Musser et al. 2007, 2009b). Currently, a plant-based threshold similar to square retention that monitors plant injury over time does not exist during the flowering period.

In the current experiment, yellow staining on the outer surface of the flower bud (dirty squares) was used as a sampling method to trigger insecticide applications for tarnished plant bugs in cotton. Previous research showed that this method detected recent damage, was relatively efficient, showed less sampler variability (Musser et al. 2007), and provided a better correlation to yield (Gore 2005) compared with other sampling methods. Using a threshold of 10% dirty squares resulted in a similar number of insecticide applications to that with a drop cloth (three tarnished plant bugs per 1.5 row/m) in the Mississippi and Arkansas experiments. Additionally, 10% dirty squares and drop cloth thresholds produced similar yields to each other and the 5% dirty squares threshold. Based on the economic analysis, the 10% dirty squares threshold resulted in a similar net economic return to...
that observed with the drop cloth threshold in the Arkansas and Mississippi Experiments.

In the Louisiana experiments, the numbers of applications were not significantly different between the 5% damaged squares and the 10% damaged squares. The 10% damaged squares threshold triggered significantly fewer insecticide applications than the weekly automatic applications. Based on the economic analysis, only the 10% dirty squares threshold and weekly application treatments provided a greater net economic return than the untreated control.

Based on these results, it appears that a threshold of 5-10% dirty squares will be equivalent to the currently accepted threshold of three tarnished plant bugs per 1.5 m of row with a black drop cloth, and provide the best economic return. Although the 5% dirty squares threshold resulted in a greater economic return in the Mississippi and Arkansas experiments, previous research has shown that lower thresholds with a drop cloth do not provide additional returns for the additional insecticide applications (Musser et al. 2009a). The 10% dirty squares threshold resulted in similar numbers of applications, yields, and economic returns to that with a drop cloth in the Mississippi and Arkansas experiments, and also produced the highest economic return in the Louisiana experiment. Therefore, the 10% dirty squares threshold is the most appropriate plant-based threshold for the current cotton production system. However, other factors such as level of control and yield potential can impact thresholds. Level of control with currently labeled insecticides has been decreasing in recent years because of the development of resistance to multiple insecticide classes (Snodgrass and Scott 2000, 2002). This dirty square threshold may need to be adjusted in the future if levels of control with current insecticides continue to decline or if a new insecticide is labeled that provides better levels of control.

Similarly, this threshold may need to be adjusted based on yield potential of the crop. In the current experiment, the yield potential of the Arkansas and Mississippi experiment was higher than the Louisiana experiment. As a result, the additional sprays triggered by the 5% dirty squares threshold resulted in a greater net economic return than in the Louisiana experiment. This suggests that the threshold may need to be decreased to 5% dirty squares in areas with a higher yield potential (i.e., irrigated land).

This plant-based sampling method and threshold will be important with some of the newer insecticides that may take several days before the maximum level of control is attained, but where feeding rapidly ceases. With a twice per week program, scouting methods and thresholds based solely on insect counts may underestimate the level of control with the newer insecticides and trigger unneeded insecticide applications. This threshold should be used in conjunction with the current drop cloth threshold. With a plant based threshold that measures plant damage and because there is a delay in the time from initial infestation until damage occurs, it can be reasonably expected that the dirty squares threshold will not be reached until at least one sampling event (≈3-5 d) later than the threshold with a drop cloth. Because of that, the current drop cloth threshold should continue to be used by consultants and agricultural pest managers, especially during the early stages of flowering.

Attempts to reduce evidence of tarnished plant bug feeding <5% likely would require insecticide applications be applied at least weekly, if not more often. This would likely not be economically feasible because of excessive input costs. Additionally, insecticides used to control tarnished plant bugs are broad spectrum and disrupt natural enemy complexes. As a result, secondary pests such as cotton aphid, *Aphis gossypii* Glover, and twospotted spider mite, *Tetranychus urticae* Koch, have become more prevalent in cotton in the mid-South (Gore et al. 2010). Unneeded applications resulting from a dirty squares threshold <10% would likely exacerbate problems with second-

![Fig. 7. Mean (SEM) net economic returns for each of the dirty squares threshold treatments, the drop cloth threshold and the untreated control in Louisiana. These figures are based on an average insecticide cost of $23.35/ha plus an application cost of $7.41/ha and a cotton price of $1.87/kg (Williams 2011).](image-url)
ary pests. These results will be used to refine the current integrated pest management (IPM) recommendations for cotton in the mid-southern United States and support, rather than replace, the current threshold of three tarnished plant bugs per 1.5 m of row with a drop cloth.

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