

Tarnished Plant Bug (Hemiptera: Miridae) Thresholds and Sampling Comparisons for Flowering Cotton in the Midsouthern United States

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ABSTRACT The tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois) (Hemiptera: Miridae), has become the primary target of foliar insecticides in cotton, *Gossypium hirsutum* L., throughout the Midsouth over the past several years. This prompted a reevaluation of existing action thresholds for flowering cotton under current production practices and economics. A trial was conducted at 19 locations throughout the Midsouth during 2006 and 2007. Threshold treatments ranged from a weekly automatic insecticide application to a very high threshold of 10 tarnished plant bugs per 1.5 row-m on a black drop cloth. Individually, all locations reached the lowest threshold, and eight locations had a significant yield loss from tarnished plant bugs. Across all locations, lint yield decreased 0.85 to 1.72% for each threshold increase of one tarnished plant bug per 1.5 row-m. Yield loss was most closely correlated to pest density during the latter half of the flowering period. The relationship between plant bug density or damage and yield was similar for drop cloth, sweep net, and dirty square sampling methods, but the correlations among these sampling methods were not high. Incorporating actual insecticide application data from the trial and average production and economic factors for Midsouth cotton, the economic threshold, if monitoring once per week, should be between 1.6 and 2.6 tarnished plant bugs per 1.5 row-m during the flowering period. More frequent monitoring or situations where insecticide applications are more efficacious may alter this threshold.

KEY WORDS *Lygus lineolaris*, economic injury level (EIL), economic threshold, *Gossypium hirsutum*

The heteropteran pest complex in cotton, *Gossypium hirsutum* L., across the midsouthern United States consists primarily of the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois) (Hemiptera: Miridae), with more sporadic populations of clouded plant bug, *Neurocolpus nubilis* (Say) (Hemiptera: Miridae); cotton fleahopper, *Pseudatomoscelis seriatus* (Hemiptera: Miridae); southern green stink bug, *Nezara viridula* (L.) (Hemiptera: Pentatomidae); green stink bug,

Acrosternum hilare (Say) (Hemiptera: Pentatomidae); and brown stink bug, *Euschistus servus* (Say) (Hemiptera: Pentatomidae). Tarnished plant bug made up 94% of the sampled bugs in cotton during the flowering period across this region during a recent study (Musser et al. 2007), indicating that most heteropteran damage can be attributed to tarnished plant bugs. Before 1995, tarnished plant bugs were generally controlled by insecticides directed at other pests during the flowering period of cotton; therefore, economic damage from tarnished plant bugs during flowering was relatively uncommon. However, with >80% of Midsouth cotton now being planted to transgenic cotton expressing one or more toxins derived from *Bacillus thuringiensis* (Bt) (Williams 2008) and the eradication of the boll weevil, *Anthonomus grandis grandis* Boheman (Coleoptera: Curculionidae), many of the foliar applications for other pests during flowering have been eliminated. One consequence of this change is that tarnished plant bugs have become dominant pests during flowering in Mississippi, Louisiana, Arkansas, Tennessee, and Missouri during the past 5 yr. Control costs and crop losses associated with tarnished plant bugs have increased dramatically during the flowering period, with an average of 7.5 insecticide

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applications targeted at this pest in the Delta region of Mississippi during 2007 (Williams 2008).

Both adult and immature tarnished plant bugs feed on cotton during the flowering period. Feeding primarily occurs on the reproductive structures where they insert their mouthparts into plant tissues, introduce toxic saliva at the feeding site, and extract the juices from the damaged tissue (Layton 2000). Cotton has an indeterminate growth habit, so flower buds (squares), flowers, and fruit (bolls) are present during most of the flowering period. Tarnished plant bugs feed on all these structures, but preferentially feed on squares (Tugwell et al. 1976). When the square is small (pinhead square), feeding often leads to abscission within a few days. Tarnished plant bugs can cause squares to abscise at the rate of 0.6–2.1 squares per insect per day (Gutierrez et al. 1977, Mauney and Henneberry 1979, Wilson 1984). Feeding on larger squares may not result in abscission, but damage will be evident as yellow staining on the square and brown or black anthers in the flower. When <30% of the anthers are damaged, there is little to no effect on yield (Pack and Tugwell 1976), but higher rates of damage can lead to aborted and malformed bolls (Layton 2000). On bolls, tarnished plant bug feeding causes a dark, sunken lesion at the feeding site on the outside of the boll and a pin-point sized black spot inside the boll (Pack and Tugwell 1976). Within 2 d after feeding, the endocarp will develop a wart-like growth around the feeding site. Feeding on bolls can result in stained lint, undeveloped locules, or damaged seed within the boll. Tarnished plant bugs can damage bolls eight d after anthesis (Greene et al. 1999), but lint yield in bolls is safe from damage after the boll has accumulated 250–300 heat units (degree-day [DD]60s) after anthesis (Horn et al. 1999, Russell et al. 1999).

In an integrated pest management (IPM) system, economic injury levels (EILs) and associated economic thresholds form the basis for therapeutic insect control, primarily insecticide applications. The key components that determine the EIL are pest management costs, market value of the crop, injury by the insect, crop damage due to insect injury, and the reduction in the pest population from the control practice (Pedigo et al. 1986). Therefore, true EILs are not static but fluctuate with changes in any of these factors. The goal of this trial is to more clearly understand the injury and damage components of the EIL for tarnished plant bugs in flowering cotton in the current production system. These results can then be combined with economic scenarios to permit more profitable pest management decision-making. Although economic thresholds traditionally evaluate a single point in time, this trial evaluates the impact of multiple action thresholds maintained over a five to seven wk flowering period. Therefore, unlike typical threshold estimations, this trial includes the pest control impacts of natural enemy mortality that may occur from insecticide applications.

Tarnished plant bugs have traditionally been considered a pest before flowering in cotton (Layton 2000), largely because this was the period when in-

secticides targeted at tarnished plant bugs were most frequently applied. Most of the research has therefore focused on monitoring and control of tarnished plant bug before flowering (Wilson 1984, Williams et al. 1987, Carder et al. 2000, Williams and Tugwell 2000). Tarnished plant bug injury after the initiation of anthesis was seldom considered to cause economic losses (Layton 2000), so limited research has examined tarnished plant bug management during the flowering period.

In the western United States, the western tarnished plant bug, *Lygus hesperus* Knight, is the dominant plant bug species infesting cotton. Behavior and damage seem to be similar for both species of plant bugs, with comparable thresholds for control of both species. Although published thresholds are in the range of one to three plant bugs per row-m on a drop cloth or eight to 15 plant bugs per 100 sweeps during the flowering period (University of California 1996, Catchot 2008, Stewart et al. 2008, Studebaker 2008), there is little research with controlled insect densities to support these recommendations. Scales and Furr (1968) found that weekly releases of 25 adults per 100 plants beginning at the first week of flowering caused no significant impact on total yield. However, yield for the second harvest was significantly reduced, indicating that squares developing during the flowering period were damaged by the infestation. Black (1973) found that infestations needed to reach nearly 350,000 insects per ha during flowering before economic damage was observed. In contrast, yield loss was observed at densities of 47,000 insects per ha during the squaring period. Gutierrez et al. (1979) found that insecticidal control of *L. hesperus* actually caused more harm to cotton by reducing beneficial insect populations than was attained by reducing the plant bug densities. Tugwell et al. (1976) found no yield loss during the seventh–ninth weeks of squaring when infesting with 1.2 tarnished plant bugs per plant. Similarly, Jubb and Carruth (1971) found no cotton yield losses from *L. hesperus* at a density of one nymph per plant but did observe delayed crop maturity, increased plant height, and a lower lint:seed fraction. In the same study, an infestation with male adults had no impact on cotton development. Barman (2006) found a density of three *L. hesperus* per plant maintained for 3 wk during the flowering period caused a yield reduction, but a rate of one plant bug per plant had no effect. These studies indicate that plant bug thresholds during the flowering period should be much higher than those currently recommended. However, numerous field studies with natural populations show yield losses from tarnished plant bug feeding during the flowering period at much lower densities than obtained in the controlled experiments (Scott et al. 1999, Robbins et al. 2000, Gore and Catchot 2005, Cook et al. 2006). Tarnished plant bugs on cotton in the midsouthern United States are currently the target of numerous insecticide applications during the flowering period. Therefore, more data are needed to document the impacts of tarnished plant bug feeding on cotton during flowering. During 2006 and 2007, experiments were conducted throughout

Table 1. Mean yield and tarnished plant bug (TPB) threshold data for individual locations throughout the Midsouth, 2006–2007

State	County or parish	Yr	Mean lint yield (kg /ha)	Highest threshold reached	Threshold factor statistics			% TPB equiv. from TPB ^a
					F	df	P > F	
AR	Crittenden	2006	1,651	Low	0.11	1, 15	0.75	100
AR	Lee	2006	1,603	High	0.02	1, 15	0.89	100
LA	W. Feliciana	2006	1,049	Very high	4.10	1, 15	0.06	87
MS	Leflore	2006	1,479	Very high	4.92	1, 15	0.04	100
TN	Lauderdale	2006	1,347	High	8.92	1, 15	0.01	82
TN	Madison	2006	1,404	Medium	0.67	1, 15	0.43	12
AR	Crittenden	2007	1,921	Very high	8.08	1, 14	0.01 ^b	100
AR	Desha	2007	1,338	Very high	4.36	1, 14	0.06 ^c	100
AR	Lee	2007	1,421	Very high	0.11	1, 15	0.74	100
AR	Mississippi	2007	1,636	High	3.53	1, 15	0.08	100
AR	Poinsett	2007	1,109	Medium	0.81	1, 13	0.38	88
LA	Franklin	2007	914	High	62.80	1, 15	<0.01	94
LA	W. Feliciana	2007	1,255	High	10.07	1, 15	<0.01	91
MO	Pemiscot	2007	807	Low	0.92	1, 15	0.35	79
MO	Pemiscot	2007	1,308	Medium	0.71	1, 15	0.41	65
MS	Hinds	2007	1,387	High	0.11	1, 14	0.74	90
MS	Lee	2007	1,577	Low	0.14	1, 14	0.72	46
TN	Lauderdale	2007	1,357	High	2.86	1, 14	0.11	58
TN	Madison	2007	738	Low	0.07	1, 15	0.80	37

^a Based on drop cloth samples.

^b When paired with the significant squared threshold term ($F = 5.72$; $df = 1, 14$; $P = 0.03$).

^c When paired with the significant squared threshold term ($F = 3.36$; $df = 1, 14$; $P = 0.09$).

the Midsouth cotton region to evaluate tarnished plant bug action thresholds during the cotton flowering period by manipulating natural population densities.

Materials and Methods

Data by Location. Large field plots (24 rows × 30 m minimum) arranged in a randomized complete block with four replications were used for this trial. The trial was conducted at eight and 15 locations during 2006 and 2007, respectively. However, due to a variety of reasons, complete data were only collected from six and 13 locations during 2006 and 2007, respectively. Therefore, data analysis included data from these 19 locations (Table 1). At all locations, transgenic Bt cotton was planted to reduce insecticide applications to control lepidopteran pests. The specific cultivars planted varied by location but were always common varieties adapted to the local area. Cotton was planted during recommended planting times for each area and managed uniformly using recommended crop production practices over all plots at a location except for tarnished plant bug management. Insects were sampled weekly. Before first bloom, tarnished plant bug densities exceeding the local action threshold were treated with a neonicotinoid insecticide across all plots at a location. Beginning at first bloom and continuing weekly throughout the flowering period, a black drop cloth (76 by 91 cm) was used to estimate tarnished plant bug densities. The drop cloth was placed between two adjacent rows of cotton and all cotton plants on both sides were vigorously beaten over the drop cloth (1.5 row-m per sample) to dislodge all insects. Two samples were taken in each plot. Insecticide applications were triggered based on the mean pest density in the four replicates of a treatment and applied to all replicates of the treatment. The

treatments were as follows: weekly: automatic insecticide application every 7 d; low: an action threshold of one tarnished plant bug per 1.5 row-m; medium: an action threshold of three tarnished plant bugs per 1.5 row-m; high: an action threshold of five tarnished plant bugs per 1.5 row-m; and very high: an action threshold of 10 tarnished plant bugs per 1.5 row-m. Other phytophagous heteropterans damage cotton in the same manner as tarnished plant bug, and damage from all similar pests was assumed to be additive. Although tarnished plant bug was the dominant species in most locations, other Heteroptera were included in the treatment thresholds. To account for different rates of feeding by the multiple species, all species were converted to tarnished plant bug equivalents. Cotton fleahoppers were counted as one tarnished plant bug, clouded plant bugs counted as 1.5 tarnished plant bugs, and stink bugs counted as three tarnished plant bugs, based on relative action thresholds currently recommended in Midsouth cotton (Catchot 2008, Stewart et al. 2008, Studebaker 2008). Treatments during the flowering period were made with one of two organophosphate insecticides (minimal rates of 0.42 kg [AI]/ha dicrotophos or 0.56 kg [AI]/ha acephate). Monitoring and insecticide applications were applied weekly as needed until the cotton plants had five main stem nodes above the uppermost first position white flower and had accumulated an additional 350 heat units (Bagwell and Tugwell 1992). At this point tarnished plant bug no longer causes economic injury (Horn et al. 1999, Russell et al. 1999, Teague et al. 2001). The impact of action thresholds on yield was analyzed for each site individually using the GLM procedure (SAS Institute 1999).

Overall Data. Pest management decisions were based on average pest density over the four replicates, so each replicate was not actually independent. There-

fore, data pooled over locations used mean data from each location, with each location considered a replication. The insect and yield data were then analyzed using the GLM procedure. Yield was evaluated as both kilograms per hectare and as a percentage of the yield obtained in the weekly threshold treatment. Statistical analyses were very similar for both yield measures, so results are only reported as percentage of yield loss. The threshold factor was analyzed as a numerical variable, with the weekly threshold set equal to a threshold of zero plant bugs per drop cloth sample.

Data were initially analyzed using the predetermined action threshold as the measure of tarnished plant bug density. However, plant bug densities at the time of treatment were sometimes much higher than the action threshold or were far below the action threshold when not treated. To overcome this variability in the relationship between the action threshold and tarnished plant bug densities, the data also were analyzed using the highest and lowest possible seasonal thresholds that would have not changed the treatment decisions. For example, if the medium threshold plots at a location had average counts of one, four, two, eight, five, and two tarnished plant bugs per drop cloth sample for the 6 wk of flowering, respectively, the plots were sprayed on weeks 2, 4, and 5. The predetermined action threshold was three plant bugs per drop cloth, but the threshold could have been as high as four plant bugs per drop cloth or as low as 2.1 plant bugs per drop cloth and the plots would have been sprayed at exactly the same times. These seasonal maximal and minimal thresholds were independently determined for each treatment at each location. To provide the broadest possible interpretation of the results, the impact of plant bugs on yield were analyzed using the original action thresholds, the highest possible (maximal) thresholds and the lowest possible (minimal) thresholds. When a treatment was never sprayed, the maximal threshold was set at the actual threshold. When a treatment was sprayed every week, the minimal threshold was set equal to the actual threshold or, in the case of the weekly treatment, the maximal threshold. Data were analyzed using PROC GLM to determine the yield impact of different levels of tarnished plant bug pressure. Differences were considered significant for $\alpha = 0.10$ for individual locations where the power of the analysis was low. Differences among data pooled from multiple locations were considered significant at $\alpha = 0.05$.

Other Sampling Methods. Treatment decisions were based on tarnished plant bug densities estimated using a black drop cloth. However, other sampling methods may be equally efficient in estimating tarnished plant bug densities (Musser et al. 2007). In this study, tarnished plant bug densities also were estimated by sweep net sampling and a sample of dirty squares each week. A sweep net sample consisted of 25 sweeps per plot with a 38-cm-diameter sweep net. A dirty square sample was an examination of 25 randomly selected medium-sized squares per plot for the presence of external yellow staining that is typical of heteropteran feeding on squares. Sampling methods

Table 2. Distribution of the number of insecticide applications for tarnished plant bugs triggered by various thresholds during the cotton flowering period at 19 locations across the Midsouth, 2006–2007

Threshold	No. applications								Mean no. applications
	0	1	2	3	4	5	6	7	
Weekly	0	0	1	2	4	3	6	2	5.00
Low	0	2	6	5	5	1	0	0	2.84
Medium	3	6	9	1	1	0	0	0	1.53
High	7	9	1	1	1	0	0	0	0.95
Very high	13	3	2	1	0	0	0	0	0.53

were compared in two ways. First, correlations were established between drop cloth estimates and the other sampling methods using PROC CORR (SAS Institute 1999). The second comparison examined the relationship between mean tarnished plant bug densities during the flowering period for each sampling method and lint yield using PROC GLM (SAS Institute 1999).

Economic Injury Levels. EILs were calculated using the formula presented by Pedigo et al. (1986) based on yield loss rates estimated from actual, maximal, and minimal treatment thresholds plus application frequency for the three treatment thresholds. Various economic scenarios were considered over the entire flowering period to examine the sensitivity of the thresholds to plausible changes in lint value, control costs and potential yield. Because the proportionate reduction in pest populations was already factored into the field-based yield loss estimates, this factor was not explicitly included in the model.

Results

Data by Location. Average lint yields over all thresholds ranged from 1,049 to 1,726 kg/ha at the six locations in 2006 and from 738 to 1,921 kg/ha at the 13 locations in 2007 (Table 1). Overall average yield was 1,425 and 1,218 kg/ha in 2006 and 2007, respectively. Tarnished plant bug densities reached the low threshold at least once at all locations both years. During 2006, tarnished plant bug densities reached the medium, high, and very high thresholds at five, four, and two locations, respectively, and during 2007, these thresholds were reached at 10, eight, and three locations, respectively. The weekly threshold treatment received an average of 5.0 insecticide applications with the other thresholds being sprayed less frequently (Table 2). The threshold used had a significant impact on yield at three locations during 2006 and five locations during 2007 (Table 1). All of these locations reached the high or very high threshold at least once during the trial. Most insecticide applications were triggered during the third and fourth weeks of flowering (Fig. 1). The heteropteran complex in this trial was primarily tarnished plant bugs. In drop cloth samples, tarnished plant bugs comprised 87% of tarnished plant bug equivalents, whereas tarnished plant bugs made up 76% of tarnished plant bug equivalents in sweep net samples. At most locations tarnished

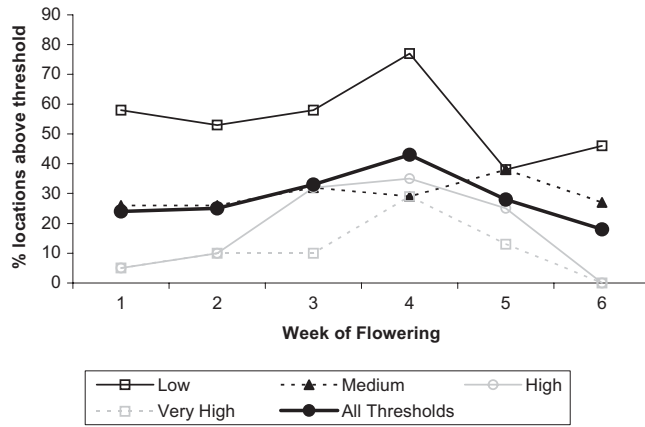


Fig. 1. Frequency of locations triggering insecticide applications at selected thresholds during the weeks of flowering.

plant bugs comprised the majority of insects, but at five locations, other bugs made up 30% or more of the complex as measured in tarnished plant bug equivalents (Table 1). These locations were all northern locations (Missouri, Tennessee, and northern Mississippi) and had a mixture of clouded plant bugs, cotton fleahoppers, and stink bugs. With the exception of the Lauderdale, TN, location during 2007, stink bugs never made up >13% of the tarnished plant bug equivalents at any of the 12 locations reaching the high threshold, so interpretation of these results should be appropriate for plant bug damage.

Overall Data. Using the predetermined action thresholds on data from all locations, the threshold impact on yield in 2006 was significant ($F = 7.72$; $df = 1, 23$; $P = 0.011$), with an estimated lint yield loss of $0.76 \pm 0.27\%$ for every increase in the threshold of one plant bug per drop cloth. The yield response in 2007 was similar ($F = 11.15$; $df = 1, 51$; $P = 0.002$), with an estimated lint yield loss of $0.89 \pm 0.27\%$ for each increase in the threshold of one plant bug per drop cloth. Combining the data from both years, the esti-

mated lint yield loss was $0.85 \pm 0.20\%$ for each increase in the threshold of one plant bug per drop cloth ($F = 17.85$; $df = 1, 75$; $P < 0.001$) (Fig. 2; Table 3). These estimates include several locations where actual pest density never approached the higher thresholds, so these yield loss estimates from tarnished plant bugs are conservative.

For the data to more closely reflect actual pest densities, maximal and minimal thresholds were analyzed in relation to lint yield. Both the minimal and maximal thresholds resulted in larger yield loss estimates than using actual thresholds with yield loss estimates of 1.72 ± 0.41 and $1.38 \pm 0.34\%$ for each increase in the threshold of one plant bug per drop cloth by minimal and maximal thresholds, respectively (Fig. 3; Table 3). As with the actual thresholds, the yield loss rate predicted using minimal and maximal thresholds were consistent over both years (Table 3).

The flowering period was divided into early flowering (the first 3 wk of flowering) and late flowering (the period from the fourth week of flowering onward) to gain a better understanding of which part of the flowering period was most strongly associated with

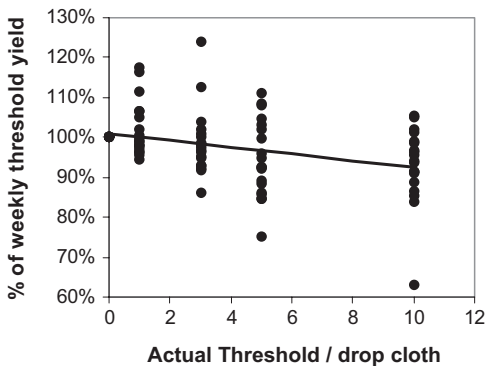


Fig. 2. Percentage of weekly threshold yield shown as a function of the tarnished plant bug threshold used during the flowering period. Each point represents the mean yield at one location in the Midsouth (19 locations total in 2006 and 2007). Line is the best fit ($F = 17.85$; $df = 1, 75$; $P < 0.0001$).

Table 3. Yield loss rate estimates \pm SEM and statistics for tarnished plant bug densities measured with actual, maximal, and minimal thresholds during various management windows

Threshold	Estimate (%)	F	df	P
Overall actual	-0.85 ± 0.20	17.85	1, 75	<0.0001
Overall max	-1.38 ± 0.34	16.99	1, 73	<0.0001
Overall min.	-1.72 ± 0.41	18.00	1, 75	<0.0001
2006 actual	-0.76 ± 0.27	7.72	1, 23	0.0107
2006 max	-1.04 ± 0.49	4.61	1, 23	0.0426
2006 min.	-1.62 ± 0.64	6.29	1, 23	0.0196
2007 actual	-0.89 ± 0.27	11.15	1, 51	0.0016
2007 max	-1.53 ± 0.44	12.26	1, 49	0.0010
2007 min.	-1.76 ± 0.51	11.87	1, 51	0.0011
Overall max-early flower ^a	-1.05 ± 0.45	5.45	1, 74	0.0223
Overall min.-early flower ^a	-1.26 ± 0.48	6.77	1, 75	0.0112
Overall max-late flower ^b	-1.51 ± 0.33	20.40	1, 73	<0.0001
Overall min.-late flower ^b	-2.09 ± 0.48	19.13	1, 75	<0.0001

^a First 3 wk of flowering.

^b After the third week of flowering.

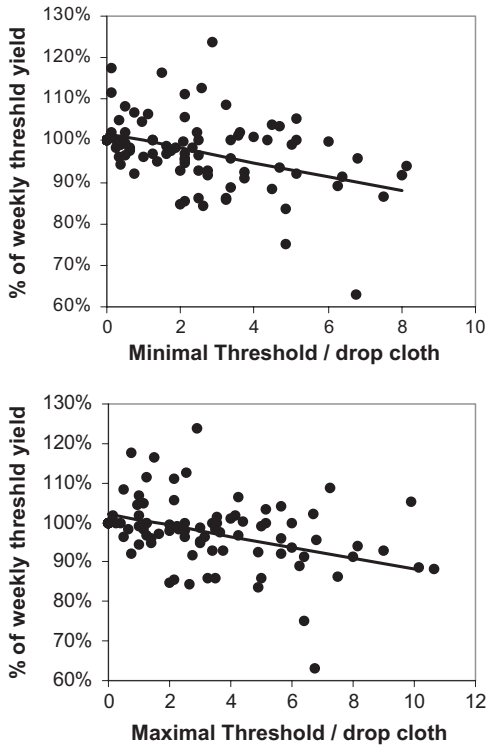


Fig. 3. Percent of weekly threshold yield as a function of the maximal and minimal thresholds that could have been used during the trial without changing application frequency or application timing during the flowering period. Each point represents the mean yield for one threshold at a single location in the Midsouth (19 locations total in 2006 and 2007). Line is the best fit for each data set.

yield loss. Using both minimal and maximal thresholds for tarnished plant bug densities during these flowering periods, a steeper yield loss from tarnished plant bugs was realized during the late flowering period compared with the early flowering period (Table 3).

Higher thresholds greatly reduced the number of insecticide applications required (Table 2). The best fit equation initially drops rapidly for small changes in the threshold and nearly plateaus at thresholds above

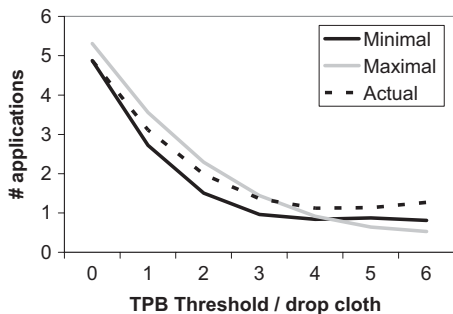


Fig. 4. Estimated frequency of insecticide applications needed using minimal, maximal, and actual tarnished plant bug thresholds during the flowering period.

Table 4. Comparison of sampling methods in estimating yield loss

Sampling method	% lint loss estimate ^a	F	df	P
Drop cloth ^b	-2.47 ± 0.73	11.53	1, 75	0.0011
Sweep net ^c	-3.56 ± 1.12	10.08	1, 47	0.0026
Dirty squares ^d	-1.25 ± 0.37	11.29	1, 63	0.0013

^a Percentage of lint loss ± SEM resulting from a mean increase of 1 in the sample (e.g., lint yield where total tarnished plant bugs per drop cloth averaged 2 would be expected to be 2.47% lower than where total tarnished plant bugs per drop cloth averaged 1).

^b A sample was 1 drop of a drop cloth that sampled 1.5 row-m.

^c A sample was 25 sweeps with a sweep net.

^d A sample was examination of 25 squares for external damage.

five tarnished plant bugs per drop cloth. This trend was fairly consistent regardless of the threshold type (Fig. 4).

Other Sampling Methods. Average densities from sweep net and dirty square sampling methods had an equally strong relationship to lint yield as average densities on a drop cloth (Table 4). Tarnished plant bug density estimates from drop cloth samples were highly correlated to sweep net estimates, but the correlation between drop cloth and dirty square samples was much weaker (Table 5). Estimates of sampling equivalencies each week of flowering were fairly consistent between sweep nets and drop cloths after the first week of flowering as the proportion of the population that were nymphs remained constant during the remainder of the flowering period. However, the number of dirty squares equivalent to the drop cloth counts was not as consistent each week (Fig. 5).

Economic Injury Levels. The results of the three threshold models (Fig. 6) show that the total estimated costs from tarnished plant bugs (yield loss + control costs) were similar using maximal and minimal thresholds, but the actual thresholds showed less yield loss, and therefore a higher density where costs were minimized. The relationships between the models were maintained over changes in assumptions (data not shown). To demonstrate how changes in assumptions influence the EIL, the maximal threshold model was used with a number of scenarios (Fig. 7). In situations of higher yield potential, higher commodity

Table 5. Comparisons of tarnished plant bug sampling methods during 6 wk of cotton flowering

Flowering wk	% nymphs ^a		Drop cloth correlation (R)	
	Drop cloth	Sweep net	Sweep net	Dirty squares
1	79	35	0.48	0.39
2	89	47	0.65	0.33
3	81	42	0.73	0.02
4	88	50	0.53	0.60
5	89	52	0.80	0.21
6	89	36	0.81	0.54
Overall	85	45	0.69	0.26

^a Percentage of total tarnished plant bugs in the nymph stage. The rest of the tarnished plant bugs sampled were adults.

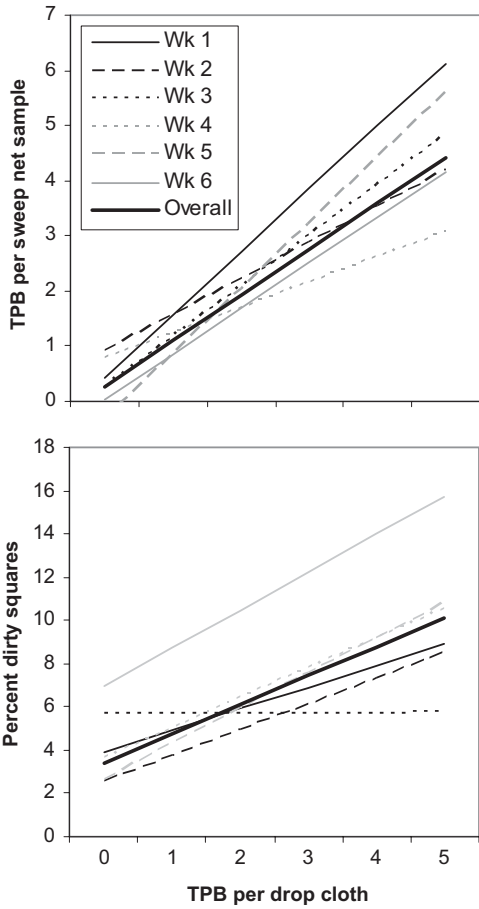


Fig. 5. Relationship of sweep net and dirty square sampling methods to drop cloths for tarnished plant bugs (TPB) over the first 6 wk of flowering.

prices or lower insecticide costs, the EIL was reduced from 1.9 plant bugs/drop cloth in Fig. 6 to as low as 0.9 plant bugs per drop cloth. In situations where yield potential or commodity prices were reduced, or insecticide costs increased, the threshold increased to as high as 3.9 plant bugs per drop cloth.

Discussion

Contrary to the findings of numerous trials that used released populations (Scales and Furr 1968, Jubb and Carruth 1971, Tugwell et al. 1976), natural populations of tarnished plant bugs feeding during the flowering period had a significant impact on cotton yield. EILs for average conditions were estimated to be between 1.6 and 2.6 tarnished plant bugs per drop cloth (Fig. 6). Because of the way these were estimated, the true EIL is likely between these two points. Changes in the yield potential or economic factors could shift the EIL to as low as 0.9 or as high as 3.9 tarnished plant bugs per 1.5 row-m. The economic threshold used to trigger management decisions is generally lower than the EIL to prevent the grower from reaching the EIL (Stern et al. 1959). However, because these data were collected in a manner similar to a commercial situation, the data already reflect the lag time in application and insecticide effectiveness that is used to justify a threshold lower than the EIL. Therefore, the reported EILs can be used as economic thresholds without further adjustment. One adjustment that may be needed in some situations is to evaluate the impact of insecticide applications on other cotton pests. In a few locations, twospotted spider mite, *Tetranychus urticae* Koch (Acari: Tetranychidae), populations were higher in the plots sprayed weekly than in the less-frequently sprayed threshold treatments. At one location in Tennessee, the weekly insecticide treatment had obvious mite injury on 67% of the plants, but no other treatment had mite injury on >12% of the plants. Increased spider mite densities from insecticide applications are

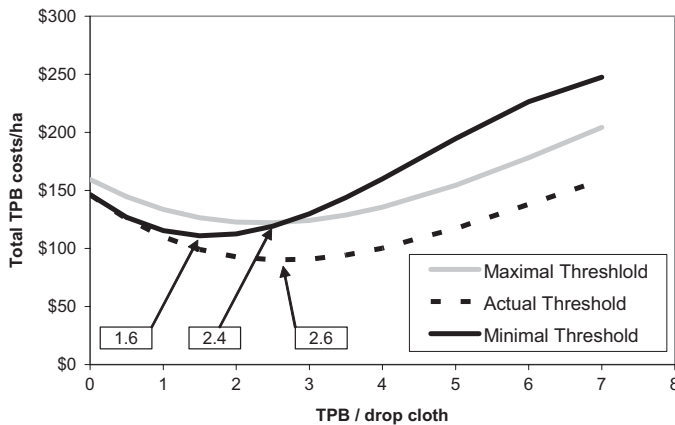


Fig. 6. Total cost of tarnished plant bugs (TPB) in yield loss + insecticide costs for various thresholds using the yield loss and insecticide applications predicted from the actual, minimal, and maximal thresholds. The numbers in boxes represent the thresholds that have the lowest total cost for each of the threshold models. Assumptions for these estimates are 1350 kg/ha lint yield (without TPB), \$1.45/kg lint value and insecticide costs of \$30/ha per application over a 5-wk flowering period.

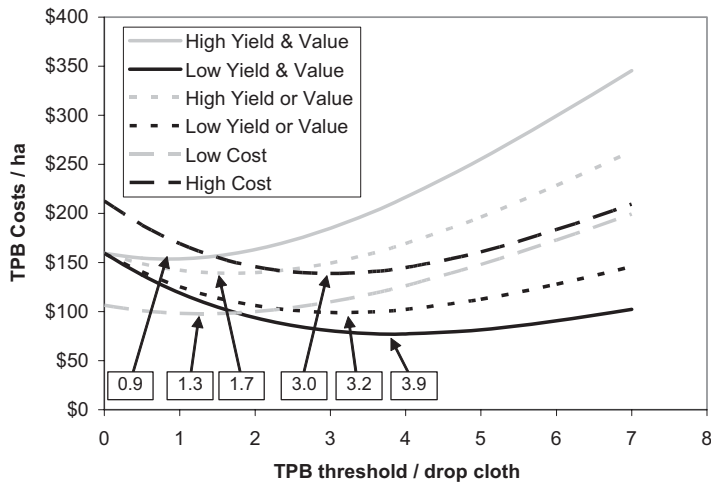


Fig. 7. Total cost of tarnished plant bugs (TPB) in yield loss + insecticide costs for various thresholds by using the yield loss and insecticide applications predicted from the maximal threshold for six scenarios. The numbers in boxes represent the thresholds that have the lowest total cost for each of the scenarios. Unless specified, assumptions for these estimates are 1350 kg/ha lint yield (without TPB), \$1.45/kg lint value and insecticide costs of \$30/ha per application over a 5-wk flowering period. Specific assumptions: high yield, 1,800 kg lint/ha; low yield, 900 kg lint/ha; high value, \$1.90/kg for lint; low value, \$1.00/kg for lint; high cost, \$40/ha per treatment; and low cost, \$20/ha per treatment.

consistent with the findings of numerous other studies (Gerson and Cohen 1989, Ayyappath et al. 1996, James and Price 2002). Where secondary pests such as spider mites are present, the impact of tarnished plant bug management decisions on these nontarget pests should be considered to minimize the likelihood of creating a secondary pest problem by addressing the primary pest. This could include raising the threshold or selecting insecticides that would be less likely to increase secondary pest problems.

The results of this trial were shaped by two factors that may vary in some situations. The first factor was sampling frequency. All the locations in this trial were sampled and sprayed once per week according to their action threshold. This frequency was longer than desirable for a pest like tarnished plant bug that can build populations rapidly through movement and oviposition. As a result, populations just under the threshold 1 wk would occasionally greatly exceed the action threshold the following week. A shorter scouting interval should increase the threshold because pests should not have time to reach very high densities. The second factor that could not be controlled was the efficacy of the insecticides used. Resistance to organophosphate insecticides has been reported for tarnished plant bug in the Midsouth, particularly in the Delta region (Snodgrass and Elzen 1995, Snodgrass 1996). Although efficacy is declining, organophosphate insecticides remain among the most efficacious insecticides available (Burriss et al. 2008, Catchot et al. 2008, Fontenot et al. 2008, Smith and Catchot 2008) and are still the standard insecticide class recommended during the flowering period in the Midsouth (Catchot 2008, Stewart et al. 2008, Studebaker 2008). In a region without insecticide resistance, or if a more efficacious insecticide were to become available, the

frequency of sprays required to maintain the lower thresholds would likely be lower than in this trial. This should reduce the EIL because insecticide costs would be lower. However, it is also possible that a more effective insecticide would reduce yield loss for a given threshold and therefore raise the EIL, because the plant would have more opportunity to compensate for a brief period of damage rather than having to continually overcome feeding damage from the survivors of an insecticide application. Furthermore, new, effective products often are more expensive per application which would raise the EIL. Because multiple factors would be impacted and the degree of impact cannot be predicted, the overall impact from a more effective insecticide on the EIL is difficult to predict.

The thresholds proposed here are static throughout the flowering period. However, yield loss was more strongly associated with tarnished plant bug densities during the late flowering period than the early flowering period (Table 3). Cotton can compensate for injury to fruiting structures early in the flowering period (Jubb and Carruth 1971, Holman and Oosterhuis 1999, Barman 2006), and this may be the reason for this observation. The other possible explanation is that the highest densities on the higher thresholds occurred during the mid-to-late season window (Fig. 1), resulting in a bigger impact on yield because that was the window of greatest insect pressure. More research is required to refine the economic threshold for specific periods within the flowering period. A dynamic threshold that changes within defined windows of during this time is likely to be variety and environment-specific. Longer season varieties in favorable environments will likely compensate for early injury better than short-season varieties under stress-

ful conditions. Future developments in cotton production may change the threshold where chemical control strategies are most economical. However, the damage from tarnished plant bug to cotton during the flowering period can clearly reduce yield, so effective monitoring needs to be implemented, and control strategies need to be applied when triggered by economic thresholds to maximize profits.

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