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Susceptibility of Flowering Cotton to Damage and Yield Loss from Tarnished Plant Bug (Hemiptera: Miridae)

W. Wood,[1] J. Gore,[1,2] A. Catchot,[3] D. Cook,[1] D. Dodds,[4] and L. J. Krutz[1]

[1]Delta Research and Extension Center, Mississippi State University, P.O. Box 197, Stoneville, MS 38776 (wwood@drec.msstate.edu; jgore@drec.msstate.edu; dcook@drec.msstate.edu; j.krutz@msstate.edu), 2Corresponding author, e-mail: jgore@drec.msstate.edu, [3]Department of Entomology, Mississippi State University, Box 9775, Mississippi State, MS 39762 (acatchot@entomology.msstate.edu), and [4]Department of Plant and Soil Sciences, Mississippi State University, Box 9555, Mississippi State, MS 39762 (darrind@ext.msstate.edu)

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Abstract

The tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), is a major pest of cotton in the midsouthern United States, including the states of Arkansas, Mississippi, Louisiana, western Tennessee, and southeastern Missouri. Insecticides provide the primary form of control for this pest, and numerous applications are required annually to control the tarnished plant bug. Little information exists regarding when to terminate insecticide applications targeting tarnished plant bugs in cotton. Numerous sprays are made late in the season to protect a small percentage of the overall yield. Experiments were conducted at the Mississippi State University Delta Research and Extension Center to determine the impact of tarnished plant bug infestation timings on cotton yield. Two separate planting dates were utilized to determine the weeks of flowering that tarnished plant bugs can cause significant yield losses. There was a significant planting date by treatment interaction. Overall, yields were greater in the first planting date than the second planting date. In both planting dates, the first 4 wk of flowering were the most critical for tarnished plant bug control, and this is when the greatest yield losses occurred. Also, when no insecticide applications were made after the fourth week of flowering, no significant yield loss was observed. These data demonstrate the importance of scouting and adhering to treatment thresholds during the early flowering period. These data also suggest that thresholds may be able to be modified or eliminated after the fourth week of flowering, but more research is needed to confirm this.

Key words: cotton, yield loss, *Lygus lineolaris*, insecticide termination, IPM

The tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), is the most important insect pest of cotton in the midsouthern United States (Musser et al. 2009). This region consists of Louisiana, Mississippi, Arkansas, western Tennessee, and extreme southeastern Missouri. The cost of control and significant yield losses this insect can cause have driven many growers away from planting cotton in the Mid-South. An average of six insecticide applications were made targeting the tarnished plant bug during the 2013 growing season in Mississippi. In 2013, 76,497 bales were lost in Mississippi due to damage from the tarnished plant bug (Williams 2014). Nationally, *Lygus* infestations were reported in 38% of cotton hectares and caused 0.8% of cotton losses (Williams 2014). Since 2011, an average of $277 per hectare has been spent on insect control in Mississippi, and this is unsustainable for cotton growers. These costs are the result of multiple pests, such as twospotted spider mite, *Tetranychus urticae* (Koch); tobacco thrips, *Frankliniella occidentalis* (Pergande); and bollworm, *Helicoverpa zea* (Boddie). Of that $277, $197 (71%) can be attributed to tarnished plant bug control (Williams 2012, 2013, 2014). Similar control costs were observed in Louisiana, Arkansas, Tennessee, and Missouri. The inflated cost of control for tarnished plant bug can be attributed to high levels of insecticide resistance, which necessitates numerous insecticide applications when large populations move into cotton during the reproductive stages (Snodgrass 1996, Snodgrass and Scott 2000, Snodgrass et al. 2009). Several cultural control methods such as intercropping, destruction of host plants, and nectariless cotton (Stewart and Layton 2000) serve as inexpensive ways to reduce input costs. Also, recent research indicates that foliar applications to control tarnished plant bug can be significantly reduced by utilizing an early planting date and an early maturing variety (Adams et al. 2013). These data showed the benefits of "earliness" to safeguard yield with early planting dates and early maturing varieties. Given high input costs and low cotton prices, improved management practices are needed to safeguard yield from tarnished plant bug populations and increase profitability of cotton production.

Several studies have shown the amount of damage and yield loss that can be caused by *Lygus* populations infesting cotton fields during the squaring period (Black 1973, Tugwell et al. 1976, Layton

1995, Zink and Rosenheim 2005). However, little is known about the impact of tarnished plant bug infestations within the separate weeks of the flowering period on cotton yields. Also, questions remain regarding the effect of tarnished plant bug infestation in cotton during the flowering period as affected by planting date. Reducing the number of insecticide applications during the flowering period could prove highly beneficial to growers. Finally, it is not known exactly when cotton yields are no longer affected by tarnished plant bugs and thus when insecticide application can be terminated during the flowering period. The current recommendation in the Mississippi State University insect control guide is to terminate insecticide applications targeting the tarnished plant bug at nodes above white flower 5 plus 350 heat units (Catchot et al. 2013). Determining the effect of tarnished plant bug infestations in flowering cotton on yield and when to terminate insecticide applications targeting tarnished plant bug at different planting dates could prove economically valuable to growers. The objective of this experiment was to determine when tarnished plant bugs cause the greatest yield losses in cotton.

Materials and Methods

Experimental Design

An experiment was conducted at the Delta Research and Extension Center in Stoneville, MS, in 2013 and 2014 to determine the effect of tarnished plant bug in flowering cotton planted at two separate dates. A full-season, smooth leaf, 'Bollgard II' cotton variety (Deltapine 1050 B2RF) was planted at 113,668 seeds/ha at both planting dates. Plots consisted of eight 1.0-m-wide rows that were 21.3 m in length. Treatments were in a split-plot arrangement within a randomized complete block design with four replications. The main-plot factor was planting date and included 26 April 2013, 28 May 2013, 2 May 2014, and 1 June 2014. The sub-plot factor was insecticide application timing. The timings included automatic insecticide applications initiated or terminated at different times during the flowering period. Prior to flowering, the entire test area was sprayed to manage all insect pests based on current thresholds in the Mississippi State University Extension Service Insect Control Guide (Catchot et al. 2013).

Once flowering began across the area of one of the planting dates, treatments were initiated for each specific planting date only. For the initiation treatments, plots were sprayed at designated weeks of flowering. The weeks of flowering when insecticide applications were initiated or terminated included the second, fourth, sixth, and eighth weeks. Once sprays were initiated, those treatments were sprayed once a week until physiological maturity, which was defined as nodes above white flower 5 plus 350 heat units. For the termination treatments, plots were sprayed once a week, beginning at first flower, until the designated termination timing. When a treatment was terminated, that specific treatment did not receive additional insecticide applications for tarnished plant bug control for the remainder of the season. The termination treatments included the same weeks of flowering as the initiation treatments. In addition, untreated control and season-long control treatments were included. The untreated control was not sprayed with any insecticide that has activity against tarnished plant bug after first flower. Sprays in the season-long control were initiated at first flower and continued through physiological maturity.

Treated plots were sprayed using insecticide mixtures at their highest labeled rates to maximize control of tarnished plant bug. Insecticides utilized were acephate (1.12 kg ai/ha, Orthene 90S, Valent Corporation, Walnut Creek, CA), sulfoxaflor (0.08 lb ai/ha, Transform WG, Dow AgroSciences, Indianapolis, IN), thiamethoxam (0.07 lb ai/ha, Centric 40 WG, Syngenta Crop Protection, Greensboro, NC), and acephate (1.12 lb ai/ha) tank mixed with bifenthrin (0.11 lb ai/ha). Every attempt was made to rotate insecticide modes of action throughout the season. All sprays were made with a John Deere 6700 Hi-Clearance sprayer calibrated to deliver 112 L/ha through TX-10 hollow cone nozzles at 345 KPa.

Data Collection and Analysis

For all in-season insect and plant samples, only rows four through six of the eight row plots were sampled. Plots were sampled twice per week to determine tarnished plant bug densities. In some cases, weather or timing of insecticide sprays prevented the collection of two samples per week. Tarnished plant bug densities were determined by taking two drop cloth samples in each plot with a 0.76-m black drop cloth. Samples were taken by laying the cloth between two cotton rows near the center of the plot and vigorously shaking all of the plants on each row onto the cloth. One sample resulted in 1.52 m of row being sampled. Musser et al. (2007) determined that a black drop cloth was one of the most effective and efficient methods of monitoring tarnished plant bug densities, and current economic injury levels and economic thresholds are based on this method (Musser et al. 2009). Square (flower bud) retention and nodes above white flower counts were also collected once per week in all plots. Square retention was determined by the counting of first position squares retained in the top three nodes of 16 plants per plot. Nodes above white flower counts were determined by counting the number of main stem nodes from the upper-most first position white flower and the apical meristem (Bourland et al. 1992).

All data except nodes above white flower were subjected to analysis of variance using the PROC MIXED procedure in SAS 9.3 (Littell et al. 1996). In the initial analysis, planting date, treatment, week of sample, and their interactions were considered fixed effects. Replication nested in year, replication by planting date nested in year, and replication by planting date by week nested in year were considered random and served as error terms for planting date, week of sample, and treatment. Additional analyses were conducted based on significance of the three-way interaction. Degrees of freedom were estimated using the Kenward–Roger method. Means and standard errors were estimated using LSMEANS and separated according to Tukey's studentized range test. Differences were considered significant at $\alpha = 0.05$. The relationship between week of flowering and nodes above white flower was analyzed with a simple linear regression analysis (PROC REG, SAS Institute 1989) across all planting dates, years, and treatments. Week of flowering was the independent variable and nodes above white flower was the dependent variable. This was done to determine when the cotton in these trials reached the recommended time to terminate insecticide applications based on heat unit accumulation beyond nodes above white flower 5 (Catchot 2013).

At the end of the season, sequential harvesting was conducted in a 3-m subsection of each plot to quantify crop maturity. All open bolls (fruit) in a 3-m section of each plot were hand-harvested each week. Hand-harvest was conducted weekly until all mature bolls were harvested from the 3-m area. When the entire test area reached 80% open bolls, harvest aids were applied based on Mississippi State University Extension Service recommendations. Rows two and three of each plot were harvested mechanically and seedcotton weights were recorded. Lint yields were determined using an average of 38% lint percentage of seedcotton weights.

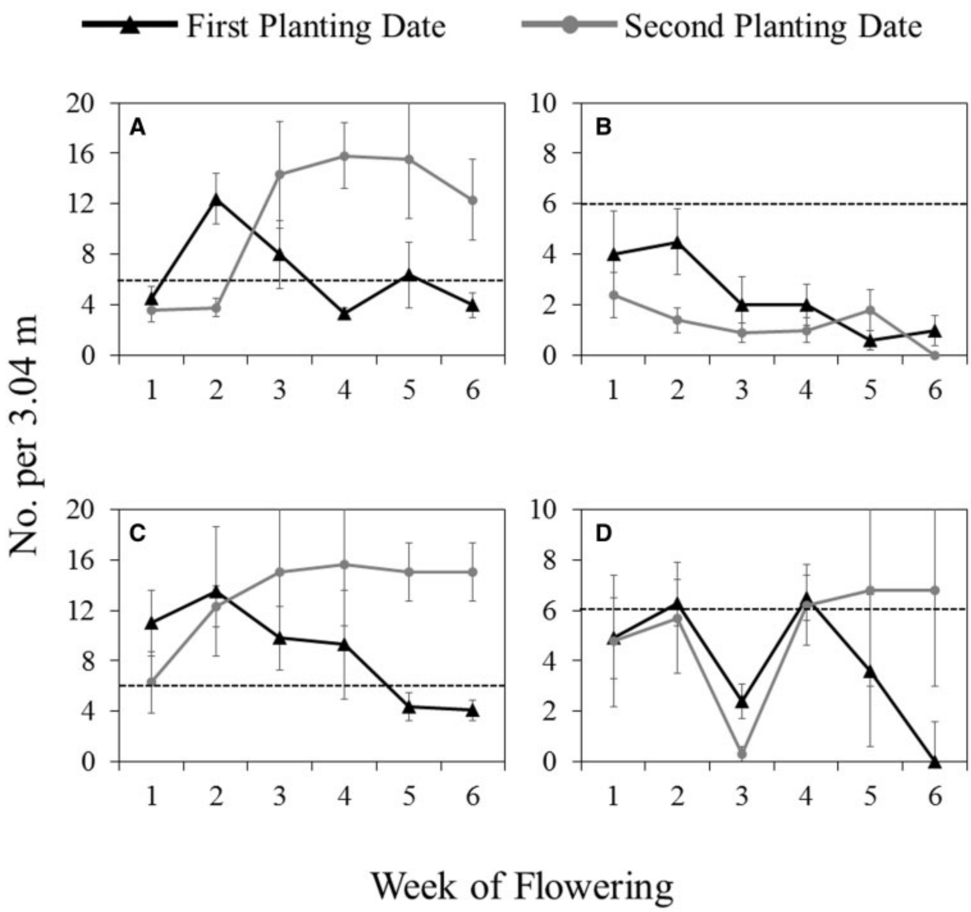

Fig. 1. Mean (SEM) number of nymphs per two drop cloth samples for the season-long control and the untreated control treatments during the first 6 wk of flowering at each planting date in 2013 and 2014 in Stoneville, MS. The solid dashed line denotes the recommended action threshold of six tarnished plant bugs per two drop cloth samples. A = untreated control in 2013, B = season-long control in 2013, C = untreated control in 2014, and D = season-long control in 2014.

Yield data were subjected to analysis of variance using the PROC MIXED procedure in SAS 9.3 (Littell et al. 1996). Planting date, treatment, and their interactions were considered fixed effects in the model. Replication nested in year and replication by planting date nested within year were considered random effects in the model and served as the error terms for planting date and treatment, respectively. Degrees of freedom were estimated using the Kenward–Roger method. Means and standard errors were estimated using LSMEANS and means were separated using Tukey's studentized range test. Differences were considered significant for $\alpha = 0.05$.

Results and Discussion

Tarnished plant bug populations were moderate to high during the 2013 and 2014 growing seasons. Tarnished plant bug densities in the untreated control remained at or above threshold (six per two drop cloth samples [3.04 m]) for the majority of the growing season during both years (Fig. 1). Tarnished plant bug densities in the season-long control treatment remained at or below the threshold during both years, except for late in the flowering period at the second planting date in 2014. Bollworm and twospotted spider mite, *Tetranychus urticae* Koch, were the only other insect pests observed over the 2 yr of the experiment. Bollworms and twospotted spider mite infestations were controlled before they reached economically damaging levels with applications of chlorantraniliprole (Prevathon, E.I. DuPont de Nemours, Wilmington, DE) and fenpyroximate (Portal, Nichino America, Wilmington, DE), respectively. These products are known to have no activity against tarnished plant bug.

There was a significant planting date by week of sample by treatment interaction for numbers of tarnished plant bug nymphs ($F = 2.54$; df = 45, 1150, $P < 0.01$). The effect of planting date was not significant ($F = 2.97$; df = 1, 7.18; $P = 0.13$); however, the effect of week of sampling was significant ($F = 2.58$; df = 5, 55, $P = 0.04$). To better facilitate interpretation of the results and to evaluate the impact of planting date across treatments, a separate analysis was performed by week of sample. There were no significant effects for the number of tarnished plant bug nymphs during the first week of flowering (Table 1; Fig. 2A). Treatment was the only effect that was significant for the second and third weeks of flowering. All termination treatments and the season-long control had significantly fewer tarnished plant bugs than all of the initiation treatments and the untreated control during the second week of flowering (Fig. 2B). A similar trend was observed during the third week of flowering, except where treatments were initiated during the second week of flowering. Where treatments were initiated during the second week of flowering, similar numbers of tarnished plant bug nymphs were observed between the season-long control and the termination treatments (Fig. 2C). All termination treatments were sprayed during the first 2 wk of flowering, and populations remained low in all of those treatments through the third week of flowering. In contrast, none of the initiation treatments were sprayed during that time, with the

Table 1. Analysis of variance for tarnished plant bug nymphs when analyzed by week of sample

Week of flowering	Treatment	F-value	df	$P > F$
First	Planting date	0.47	1, 6.99	0.52
	Treatment	1.70	9, 206	0.09
	Planting date × treatment	0.80	9, 206	0.61
Second	Planting date	4.37	1, 13.5	0.06
	Treatment	13.33	9, 236	<0.01
	Planting date × treatment	0.44	9, 236	0.91
Third	Planting date	0.22	1, 7.8	0.65
	Treatment	29.48	9, 246	<0.01
	Planting date × treatment	1.26	9, 246	0.26
Fourth	Planting date	1.03	1, 8.83	0.34
	Treatment	15.45	9, 170	<0.01
	Planting date × treatment	2.56	9, 170	0.01
Fifth	Planting date	11.94	1, 12.8	<0.01
	Treatment	24.71	9, 202	<0.01
	Planting date × treatment	6.84	9, 202	<0.01
Sixth	Planting date	12.78	1, 5.5	0.01
	Treatment	10.88	9, 93.4	<0.01
	Planting date × treatment	3.33	9, 93.4	<0.01

exception of the treatment for initiation of sprays during the second week of flowering. These were sprayed one time and population densities declined in that treatment by the third week of flowering.

There was a significant planting date by treatment interaction for tarnished plant bug nymphs during each of the fourth through sixth weeks of flowering (Table 1). In general, treatments that were sprayed the previous week had similar numbers of tarnished plant bug nymphs between the first and second planting dates during the fourth week of flowering (Fig. 2D). In contrast, tarnished plant bug densities were generally higher in the second planting date for all unsprayed plots. During the fifth and sixth weeks of flowering, all plots that were currently being sprayed had similar numbers of tarnished plant bug nymphs among planting dates, except where treatments were initiated during the fourth week of flowering (Fig. 2E and F). This does not include treatments that had already been terminated (T2) or had not been initiated (I6 and I8).

Tarnished plant bug populations migrate from other hosts, such as senescing corn, and move into cotton as flowering begins (Snodgrass et al. 2009). When insecticide applications targeting tarnished plant bugs were delayed until the fourth week of flowering or later, tarnished plant bug populations averaged two times the recommended threshold. Where insecticide applications were delayed during the early to mid-flowering period, tarnished plant bug populations exceeded those where insecticide applications were terminated at similar weeks within the flowering period. Failure to control tarnished plant bugs during the first 4 wk of flowering or delaying insecticide applications at this time can lead to populations that rapidly increase within several days.

There was a significant planting date by week of sample by treatment interaction for percent square retention ($F = 1.90$; df = 36, 1123, $P < 0.01$). Planting date was not significant ($F = 0.56$; df = 1, 57.9; $P = 0.46$), but week of sample was significant ($F = 4.84$; df = 5, 57.1, $P < 0.01$). Similar to tarnished plant bug nymph populations, a separate analysis was performed by week of sample to evaluate the impact of planting date across treatments on percent square retention. There were no significant effects for percent square retention during the first and second weeks of flowering (Table 2). There was a significant planting date by treatment interaction for the third, fourth, and fifth weeks of flowering. Similar to tarnished plant bug nymph populations, few differences were observed between the two planting dates for treatments where insecticide applications were made (Fig. 3). For treatments where no insecticide applications were made, percent square retention was generally lower for the second planting date compared with the first planting date (Fig. 3). In general, square retention did not rebound to acceptable levels (>85%) when insecticide applications were delayed during the early flowering period (initiation treatments). For the termination treatments, square retention generally remained above 85%, except during the fifth and sixth week of flowering, where insecticide applications were terminated during the second week of flowering (Fig. 3E and F).

For nodes above white flower counts, the planting date by week of sample by treatment interaction was not significant ($F = 0.75$; df = 45, 714, $P = 0.89$). There was a significant planting date by week interaction (data not shown, $F = 29.82$; df = 5, 715, $P < 0.01$). There was no significant planting date by treatment ($F = 0.72$; df = 9, 714, $P = 0.69$) or week by treatment ($F = 0.70$; df = 45, 714, $P = 0.93$) interaction, or a significant main effect of treatment ($F = 1.20$; df = 9, 714, $P = 0.29$) for nodes above white flower. This suggests that tarnished plant bug management did not have a significant effect on maturity of the cotton based on nodes above white flower counts. There was a significant relationship between week of sample and nodes above white flower ($F = 1063.43$; df = 1, 846, $P < 0.01$). Based on the regression equation, nodes above white flower decreased by 0.69 nodes per week, with an intercept of 7.5 nodes (Fig. 4). Nodes above white flower 5 plus 350 HU is the current recommendation to terminate insecticides targeting tarnished plant bugs (Russell 1999), and this occurred, on average, at the end of the fifth week of flowering in both planting dates and across both years in this trial based on the regression equation.

There was no significant interaction between treatment and year for a delay in cotton maturity ($F = 1.38$; df = 9, 54; $P = 0.21$) for the first planting date based on the sequential harvest and time to 80% open bolls. Year did not affect maturity ($F = 3.05$; df = 1, 6; $P = 0.13$), but treatment did significantly affect cotton maturity ($F = 5.82$; df = 9, 54; $P < 0.01$). In general, where tarnished plant bug control was implemented during the early flowering period, no differences were observed compared with the season-long control (data not shown). Where insecticide applications were delayed or terminated during the early flowering period, cotton achieved 80% open boll quicker than the season-long control. These data are misleading, and it would appear that tarnished plant bug advanced cotton maturity in plots where they were not adequately controlled. Although previous research has shown a delay in cotton maturity from tarnished plant bug feeding during the pre-flowering period (Terry 1992, Jones et al. 1996), these data suggest that plants do not have time to compensate for injury when it occurs during the flowering period. For the later planting date, there was no significant interaction between treatment and year on cotton maturity ($F = 0.37$; df = 9, 54; $P = 0.94$). Treatment ($F = 1.19$; df = 9, 54; $P = 0.32$) or year ($F = 0.88$; df = 1, 6; $P = 0.38$) did not have a significant effect on cotton maturity. While past research has shown that tarnished plant bug damage during the squaring period will delay maturity (Layton 1995), feeding damage during the flowering period did not cause a delay in maturity in the current experiment. This is likely the result of cotton having time to compensate for injury that occurs during the pre-flowering stages. Generally, cotton needs additional time to compensate for early-season fruit loss, which results in delayed maturity. In the current experiment, cotton did not have

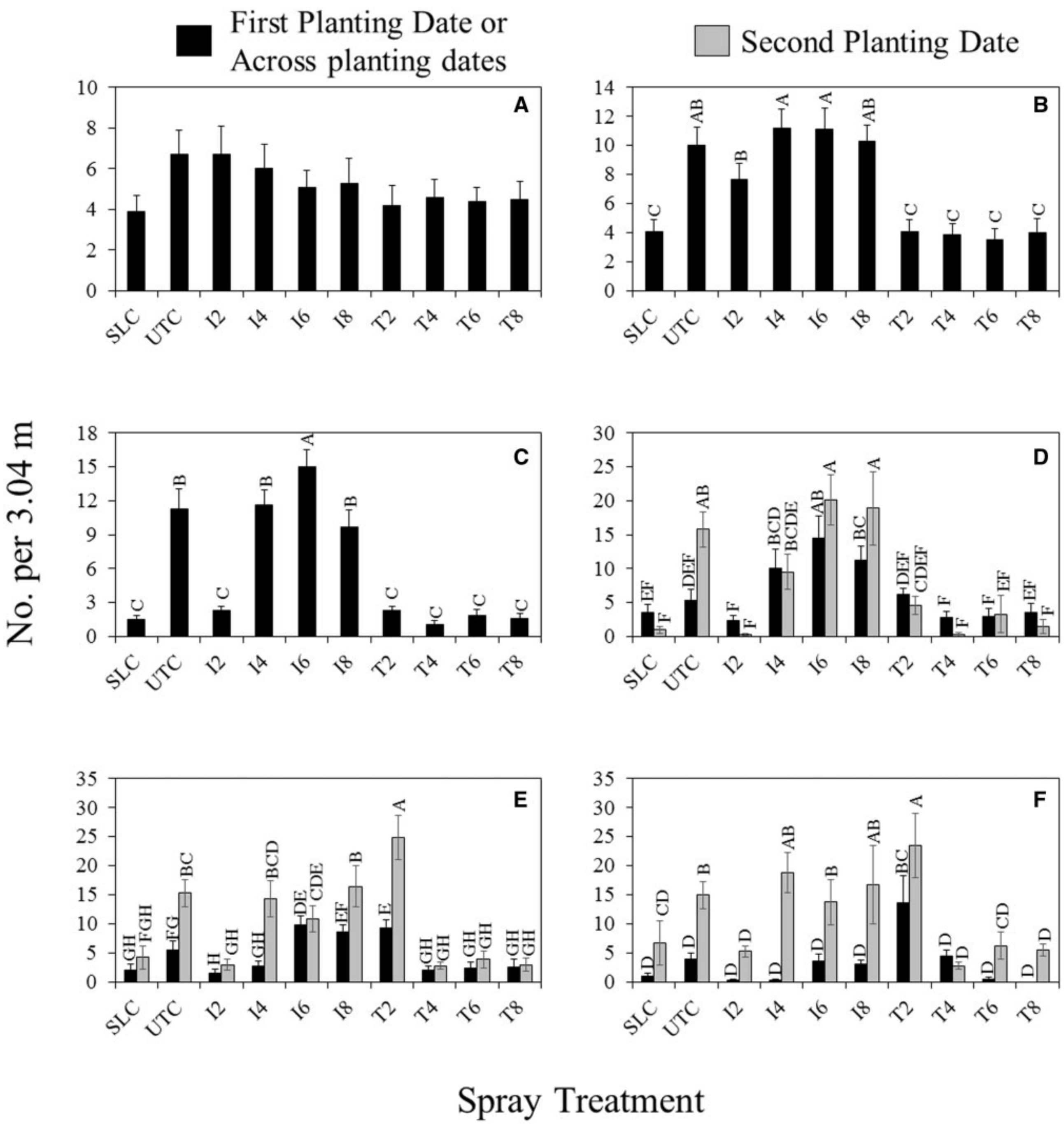

Fig. 2. Mean (SEM) number of tarnished plant bug, *L. lineolaris*, nymphs per two drop cloth samples averaged across planting dates (A-C) or for each planting date (D-F). Graphs A through F represent weeks 1 through 6 of flowering, respectively, for all treatments averaged across 2013 and 2014 in Stoneville, MS (SLC = season-long control, UTC = untreated control, I = initiation of treatments at the specified weeks of flowering, and T = termination of treatments at the specified weeks of flowering). Means followed by the same letter within a graph are not significantly different, $\alpha = 0.05$.

sufficient time to compensate for injury that occurred during the flowering period, and significant yield losses were observed rather than a delay in maturity.

There was a significant planting date by treatment interaction for cotton yield ($F = 2.16$; df = 9, 126; $P = 0.03$). Overall, cotton yields from the early planting date were significantly greater than cotton yields from the late planting date (Fig. 5). For both planting dates, terminating insecticide applications beyond the fourth week of flowering did not result in significant yield losses relative to the season-long control. Although terminating insecticide applications after the second week of flowering resulted in greater yields than the untreated control, significant yield reductions were observed relative to the season-long control. For the early planting date, delaying insecticide applications until the second week of flowering did not result in a significant yield reduction relative to the season-long control. In contrast, delaying insecticide applications until the second week of flowering resulted in a significant yield reduction compared with the season-long control for the late planting date when tarnished plant bug densities were greater and yield potential was lower. Regardless of planting date, delaying insecticide applications

Table 2. Analysis of variance for percent square retention when analyzed by week of sample

Week of flowering	Treatment	*F*-value	df	*P* > *F*
First	Planting date	0.20	1, 6.99	0.67
	Treatment	0.74	9, 206	0.68
	Planting date × treatment	1.35	9, 206	0.21
Second	Planting date	1.30	1, 12.6	0.28
	Treatment	1.31	9, 235	0.23
	Planting date × treatment	1.03	9, 235	0.41
Third	Planting date	1.02	1, 4.3	0.37
	Treatment	16.22	9, 241	<0.01
	Planting date × treatment	2.81	9, 241	<0.01
Fourth	Planting date	0.03	1, 9	0.86
	Treatment	20.38	9, 169	<0.01
	Planting date × treatment	2.53	9, 169	0.01
Fifth	Planting date	2.82	1, 13.6	0.12
	Treatment	35.20	9, 203	<0.01
	Planting date × treatment	4.85	9, 203	<0.01
Sixth[1]	Planting date	–	–	–
	Treatment	11.49	9, 70	<0.01
	Planting date × treatment	–	–	–

[1]Square retention data were only collected from the first planting date during the sixth week of flowering.

until the fourth week of flowering or later resulted in significant yield reductions relative to the season-long control.

Yield losses in treatments that were vulnerable to tarnished plant bug damage during the early flowering period suggest that these weeks are the most critical time to protect cotton. According to the results from this experiment, it appears that the second week through the end of the fourth week of flowering is the critical period

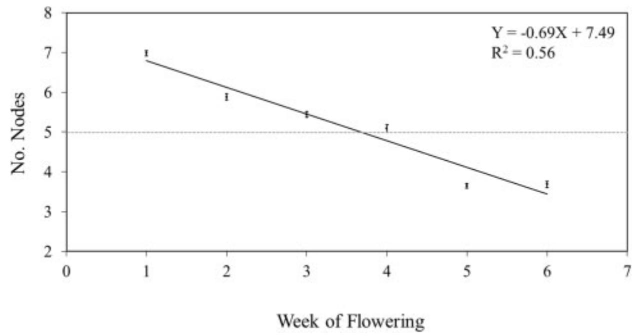

Fig. 4. Linear regression for nodes above white flower of cotton averaged across all planting dates and treatments in 2013 and 2014 in Stoneville, MS.

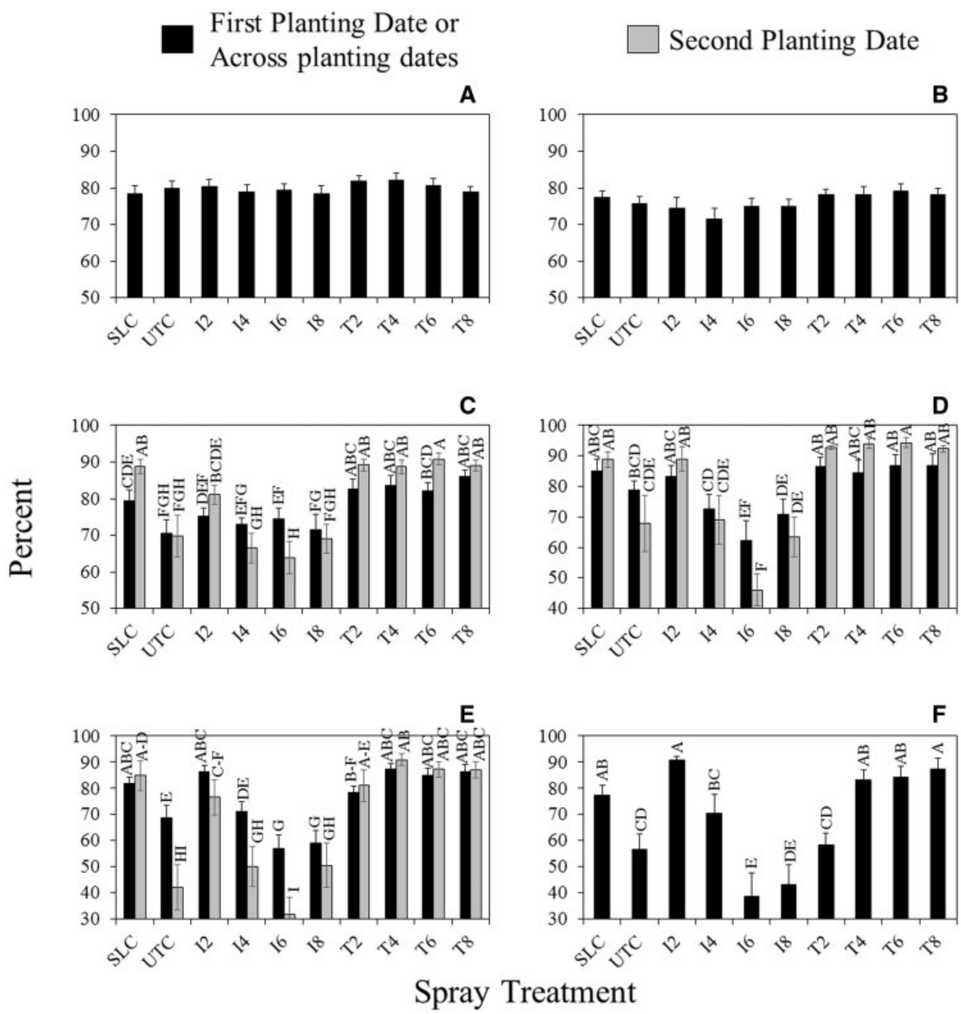

Fig. 3. Mean (SEM) square retention averaged across planting dates (A-B) or for each planting date (C-E). Graphs A through F represent weeks 1 through 6 of flowering, respectively, for all treatments averaged across 2013 and 2014 in Stoneville, MS (SLC = season-long control, UTC = untreated control, I = initiation of treatments at the specified weeks of flowering, and T = termination of treatments at the specified weeks of flowering). Means followed by the same letter within a graph are not significantly different, $\alpha = 0.05$.

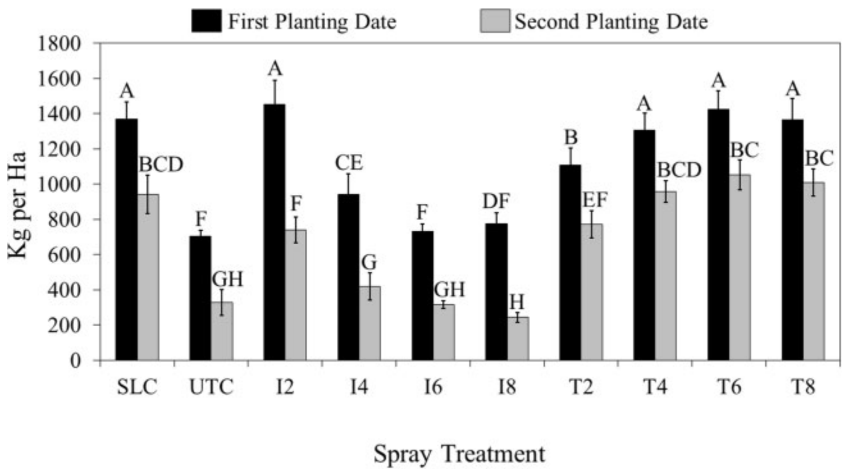

Fig. 5. Impact of tarnished plant bug, *L. lineolaris*, spray treatments on mean (SEM) cotton yields for early- and late-planted cotton in Stoneville, MS. Means followed by a common letter are not significantly different, $\alpha = 0.05$.

when thresholds should strictly be followed to minimize yield losses, because the plants were not able to compensate for fruit loss during this period. In addition, the impact on yield was more severe at the later planting date likely owing to higher populations of tarnished plant bugs at that time. An early planting date will likely result in greater yield potential owing to less insect pressure during the reproductive period of the crop, which can result in fewer insecticide applications required (Adams et al. 2013).

Although current recommendations to terminate insecticide applications for tarnished plant bug are based on nodes above white flower counts and heat unit accumulation, results from this study show that if no insecticide applications are made after the end of the fourth week of the flowering period, no significant yield loss or delay in maturity will occur. However, tarnished plant bug populations did not rebound to above threshold densities, which may have impacted these results. Where insecticide applications were terminated at the fourth week of flowering, which was on average 1 wk prior to the current recommendation of nodes above white flower 5 plus 350 HU, there was no significant yield loss observed. There is potential to lower our current recommendation, but because tarnished plant bug populations did not exceed threshold after the fourth week of flowering in these plots, more research is needed in large-plot trials across a range of environments. The current insecticide termination recommendation is adequate in safeguarding yield from tarnished plant bug damage, but these data suggest that growers will not suffer severe losses if they terminate applications up to 1 wk earlier than the current recommendation.

Musser et al. (2009) observed that cotton yield loss was strongly linked to tarnished plant bug densities during the late flowering period rather than the early flowering period. This is contradictory to results from this trial that show that the early to middle flowering period is the most critical time when yield losses can occur. These results further highlight the need to effectively manage tarnished plant bugs during the early flowering period.

Overall, there appears to be a greater deficit to delaying applications too long during the early flowering period compared with terminating insecticide applications too early. This was evident in terms of tarnished plant bug densities, square retention, and yield. The results of this study show that the current termination recommendation is adequate in protecting cotton yield from late-season tarnished plant bugs, and that late-season insecticide applications targeting tarnished plant bugs are not needed. Results also show the need to strictly adhere to thresholds during the first 4 wk of the flowering period because significant yield losses can occur due to tarnished plant bug infestations. Given that $197 per hectare is spent solely to control tarnished plant bugs (Williams 2012), every management practice that could reduce input costs or safeguard yield is needed to improve sustainability of cotton production in the Mid-South.

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