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ARTHROPOD MANAGEMENT AND APPLIED ECOLOGY

Termination of Insecticide Applications for Tarnished Plant Bug (Hemiptera: Miridae) Management in Cotton

Whitney Crow*, Jeff Gore, Angus L. Catchot, Donald R. Cook, Scott D. Stewart, Nick J. Seiter, Glenn Studebaker, Gus Lorenz, David Kerns. Sebe Brown, Moneen M. Jones, Fred Musser, and Tyler Towles

ABSTRACT

Tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), is the most important insect pest of cotton, *Gossypium hirsutum* L., in the states of Arkansas, Louisiana, Mississippi, Tennessee, and Missouri. Foliar insecticide sprays are an important tactic within an integrated pest management (IPM) program for this pest which occurs from early flower bud development to cut out, a stage where the plant has reached the capacity for supporting fruiting positions and equivalent to when there are five nodes above the uppermost first position white flower (NAWF 5). Currently, NAWF and heat unit accumulation monitoring is limited, resulting in a need for a more simplified insecticide termination method that has the potential for wider adoption. Experiments were conducted in 2015 and 2016 in the previously mentioned states to determine when to terminate insecticide sprays for tarnished plant bug based on week of flowering. Treatments included terminating sprays after the second through sixth weeks of flowering, a season-long control, and an untreated control. In general, insecticides reduced densities of tarnished plant bugs in the sprayed treatments. When analyzed by location, treatments that resulted in cotton yields similar to the season-long control ranged from weeks two through five of flowering. These data suggest that treatments can be terminated after the fifth week of flowering. Data from this study indicate applications terminated after the fifth week of flowering would be similar to the current recommended termination timing of NAWF 5 plus 350 heat units. Results from this experiment will be used to better define a simplified IPM strategy for tarnished plant bug in cotton.

Input costs have consistently increased in cotton production over the last 20 years. Technology fees associated with transgenic varieties, widespread adoption of insecticide seed treatments, and pest resistance have all contributed to this increase. Most notably, weed species resistant to glyphosate (Koger et al., 2004; Nandula et al., 2008; Nandula et al., 2012) have increased the need for more intense weed management programs that include pre-plant and in-season applications of herbicides that provide residual control of problem weeds. Additionally, several species of insects have developed resistance to foliar insecticides. They include tobacco thrips, *Frankliniella fusca* (Hinds) (Huseth et al., 2016); tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois) (Snodgrass 1996); bollworm, *Helicoverpa zea* (Boddie) (Graves et al., 1963,); and tobacco budworm, *Heliothis virescens* (F.) (Brown et al., 1998; Martin et al., 1995). Of those species, the tarnished plant bug is the most important insect pest of cotton grown in the mid-southern states of Arkansas, Louisiana, Mississippi, Missouri, and Tennessee (Williams, 2016).

Tarnished plant bugs prefers to feed on small to medium sized flower buds (squares) (Tugwell et al., 1976). Feeding on these structures generally causes them to abscise leading to direct yield losses (Layton, 2000). Previous research demonstrated that fruit (bolls)

W. Crow*, J. Gore, and D.R. Cook, Mississippi State University, Delta Research and Education Center, 82 Stoneville Road, PO Box 197, Stoneville, MS 38776; A.L. Catchot, F. Musser, and T. Towles, Mississippi State University, 100 Old Highway 12, Starkville, MS 39762; S.D. Stewart, The University of Tennessee, West Tennessee Research and Education Center, 605 Airways Blvd., Jackson, TN 38301; N.J. Seiter, University of Arkansas, Southeast Research and Education Center, PO Box 35508, Monticello, AR 71656; G. Studebaker, University of Arkansas, Northeast Research and Extension Center, PO Box 48, Keiser, AR 72351; G. Lorenz, University of Arkansas, Lonoke Research and Education Center, 2001 Hwy 70 East, Lonoke, AR 72086; D. Kerns, Texas A&M University, College Station, TX 77843; S. Brown, LSU AgCenter, Macon Ridge Research Station, 212A Macon Ridge Rd , Winnsboro, LA 71295; and M.M. Jones, University of Missouri, Fisher Delta Research Center, PO Box 160, Portageville, MO 63873.
*Corresponding author: wdc165@msstate.edu

less than 173 heat units beyond anthesis, that are fed upon may abscise and that weights may be reduced for bolls less than 326.5 heat units beyond anthesis (Russell, 1999). Considerable research has been conducted to define the most economical sampling methods and action thresholds for this pest at different stages of cotton development (Gore et al., 2012; Musser et al., 2007, Musser et al., 2009a, Musser et al., 2009b). In general, insecticide sprays are recommended when an average of eight tarnished plant bugs are caught per 100 sweeps during the first two weeks of squaring and 15 per 100 sweeps from the third week of squaring to bloom (Musser et al., 2009b). During bloom, a black drop cloth is recommended, and the threshold at this time is three tarnished plant bugs per drop cloth sample (0.76 m of row) (Musser et al., 2009a).

Multiple insecticide applications are needed in the mid-southern states (Williams, 2016) to minimize yield losses from tarnished plant bug (Gore et al., 2012, Wood et al., 2016). This pest species has developed widespread resistance to pyrethroids (Snodgrass, 1996) and organophosphates (Snodgrass et al., 2009), making it difficult to manage with foliar insecticides. Additionally, field performance failures with neonicotinoids targeting tarnished plant bug have become common. Zhu and Luttrell (2014) demonstrated overexpression of esterase and P450 detoxification enzymes in tarnished plant bug and suggested that some field populations of tarnished plant bug may have developed multiple/cross-resistance to both acephate and imidacloprid in cotton-growing areas.

Considerable research has investigated several cultural practices to be incorporated into an overall integrated pest management plan to complement management with insecticides and minimize economic losses. Planting date and varietal maturity can be important factors in reducing insecticide applications targeting tarnished plant bug in cotton. Yield losses attributed to tarnished plant bug were significantly greater in a late maturing cotton variety and at later planting dates compared with an early maturing cotton variety and earlier planting dates (Adams et al., 2013). Additionally, fewer insecticide applications were required when using the current thresholds in earlier planting dates and earlier maturing variety. Nitrogen rate also has an impact on management of tarnished plant bug in cotton. Samples (2014) determined that cotton yields were maximized at a nitrogen application rate of 90 kg ha^{-1}, with one to two fewer insecticide applications required at this rate compared with higher rates. Leaf pubescence is another factor associated with variety selection that has reduced the impact of tarnished plant bug in cotton (Wood et al., 2017). Cotton varieties with greater numbers of leaf trichomes sustained less injury from tarnished plant bug than varieties with fewer trichomes, resulting in greater levels of square retention and yield.

Some cultural practices are being integrated into pest management programs by growers and pest managers, but insecticidal control remains an important component in managing tarnished plant bug. An important and recurring question is when to terminate insecticide applications for tarnished plant bug to maximize profits but prevent late season yield losses. This consideration is important for pest managers because insecticide resistance increases throughout the season (Snodgrass and Scott, 2000), making late-season control even more difficult. As a result, two- and three-way tank mixes with multiple insecticides at the highest labeled rates are often needed to reduce populations of tarnished plant bug, making a single application much more expensive than earlier in the season (Thrash et al., 2013). Currently, termination of insecticide sprays for tarnished plant bug is based on nodes above white flower counts and heat unit accumulation (Bernhardt et al., 1986). This strategy defines cut out as being when the last harvestable bolls, represented by a cohort of first position white flowers, are five mainstem nodes below the plant terminals, or five nodes above white flower (Bourland et al., 1992). Termination of insecticide applications is based on the point in plant development (determined by heat unit accumulation beyond anthesis) when a boll is safe from injury from a particular insect pest (Bagwell and Tugwell, 1992). Termination of insecticide applications using this approach has been defined for boll weevil, *Anthonomus grandis grandis* Boheman, (Bagwell, 1994); bollworm, *Helicoverpa zea* (Boddie), (Bagwell, 1994; Gore et al., 2000); beet armyworm, *Spodoptera exigua* (Hübner), fall armyworm, *S. frujiperda* (J.E. Smith), (Adamczyk et al., 1998); stink bugs (Greene et al., 1999); and tarnished plant bug (Horn 2003; Russell, 1999). This strategy for terminating insecticide applications is well defined but is not always used by pest managers because they rarely know when cotton reaches five nodes above white flower (NAWF) and are reluctant to monitor heat unit accumulations over time. Recent research used weeks of flowering as an indicator of when tarnished plant bug caused the greatest yield losses in cotton (Wood et al., 2016). By initiating or terminating insecticide applications at two-week intervals, the authors determined that the second through fourth weeks of flowering was the most critical window for managing tarnished plant bug in flowering cotton. The objective of this research was to validate current termination strategies for tarnished plant bug across a broad geography and to determine if a more user-friendly method for terminating insecticide applications could be identified.

MATERIALS AND METHODS

Experiments were conducted across multiple locations in the mid-southern region of the United States (U.S.), to determine when flowering cotton is no longer susceptible to yield loss caused by tarnished plant bug feeding. Locations in 2015 included two locations at the Delta Research and Extension Center in Stoneville, MS; West Tennessee Research and Education Center in Jackson, TN; the Rohwer Research Station in Rohwer, AR; the Northeast Research and Extension Center in Keiser, AR; the Lon Mann Cotton Research and Experiment Station in Marianna, AR; and two locations at the Macon Ridge Research Station in Winnsboro, LA. Locations in 2016 included a grower farm in Sidon, MS; West Tennessee Research and Education Center in Jackson, TN; the Rohwer Research Station in Rohwer, AR; the Lon Mann Cotton Research and Experiment Station in Marianna, AR; the Northeast Research Station in St. Joseph, LA; the Macon Ridge Research Station in Winnsboro, LA; and the Fisher Delta Research Center in Portageville, MO. All experiments were planted between 25 April and 20 May according to the recommended timing at each respective location. Cotton varieties varied among locations, but a mid-maturity dual-gene Bt cotton variety (Bollgard II®, Monsanto Co., St. Louis, MO, or Widestrike™, Corteva Agrisceince, Indianapolis, IN) was planted at each location to minimize injury from lepidopteran pests. Plots were managed to minimize infestations of weeds and other insects, and to maximize yields at each location. Insect pests other than tarnished plant bug were managed across the entire test area based on established thresholds using insecticides without known activity against tarnished plant bug. Experimental treatments were applied only during the flowering period, and prior to flowering, tarnished plant bugs were managed across the entire test area with currently recommended insecticides based on the current action threshold for pre-flowering cotton (Musser et al., 2009b)

All experiments were designed as a randomized complete block with four replications. Plots consisted of four rows measuring 12.2 m in length, with the exception of the Jackson, TN where plots consisted of eight rows measuring 10.6 m in length. Treatments included termination of insecticide applications targeting tarnished plant bug after the second, third, fourth, fifth, sixth, seventh, or eighth week of flowering in 2015. Based on the results from 2015, treatments for termination after the seventh and eighth weeks of flowering treatments were not included in 2016. During 2015, plots in all of the studies were beyond cutout during the fifth and sixth weeks of flowering and were well beyond the effective flowering period. Additionally, yields of termination treatments after the fifth week of flowering were not different than the season-long control. A season-long control was included that was automatically sprayed weekly in 2015 or sprayed based on the current action threshold of three tarnished plant bugs per drop cloth sample (Musser et al., 2009a) in 2016. Additionally, an untreated control was included in each test, and, after first bloom, it was not treated with insecticides known to have activity against tarnished plant bug. Once flowering began across all plots, all other treatments were sprayed once per week through the designated weeks of termination. Insecticides were chosen to maximize control and generally included tank mixtures of organophosphates or neonicotinoids with pyrethroids at their highest labeled rates or sulfoxaflor (Transform WG™, Dow AgroSciences, Indianapolis, IN) during the flowering period and neonicotinoids or sulfoxaflor during the pre-flowering period.

Once flowering and scheduled insecticide spraying was initiated, populations of tarnished plant bug were sampled weekly. Two drop-cloth samples were obtained from each plot. A black drop cloth measuring 0.76m in length was placed between the center two rows, and all plants from each row within the length of the drop cloth were vigorously shaken over the cloth to dislodge tarnished plant bugs. This method resulted in a total of 3.0 m of row being sampled in each plot at each sample date. The numbers of adults and nymphs per 3.0 m were recorded. All weeks of flowering were not sampled at each location, but samples were collected during the peak-flowering period at all locations. In addition to tarnished plant bug densities, nodes above white flower counts were made at some locations to compare results with previous research this was accomplished by counting the number of main stem nodes above the uppermost first position white flower. At the end of the season, when the entire test area reached 80% open boll, plots were chemically defoliated and mechanically harvested with a spindle-type commercial cotton picker modified for small-plot research. Seed cotton weights were recorded for each plot.

Seasonal mean densities of tarnished plant bug nymphs per 3.0 m, averaged across all sample dates within a location and year, were analyzed with a general linear mixed model analysis of variance (PROC GLIMMIX, SAS Institute Version 9.3, Cary, NC). In the model, week of insecticide termination was designated as the fixed effect, and replication was designated as the random effect. Densities of tarnished plant bug nymphs were analyzed by location and year to show relative insect pressure among termination treatments at each location and because overall densities varied among years and locations. Additionally, means and standard errors for sample dates were calculated for tarnished plant bug nymphs at each location and year, for the untreated control and the season-long control treatments to show general trends of populations over time. Densities of adult tarnished plant bugs were not included in the analyses because they are highly mobile, use of drop cloths are not as efficient for measuring adult densities (Musser et al., 2007), and adults represented anywhere from 3 to 30% within a given location however, they only represented 10% of the total populations across all trials.

For seed cotton yields, two separate general linear mixed model analyses of variance (PROC GLIMMIX, SAS Institute Version 9.3, Cary, NC) were conducted. The first analysis was done by location and year to determine the earliest week of flowering that termination of insecticide applications resulted in similar yields to the season-long control, and the latest week of flowering that termination of insecticide applications resulted in similar yields to the untreated control in each test. In that analysis, week of insecticide termination was designated as the fixed effect, and replication was designated as the random effect. A separate analysis was performed across all locations and years. In that analysis, week of insecticide termination was designated as the fixed effect. Replication and replication by location nested in year were designated as the random effects in the model. The Kenward-Roger method was used to estimate degrees of freedom, and means were separated using the LSMEANS statement. Differences were considered significant at $\alpha = 0.05$. Counts of NAWF were not analyzed but used to estimate the approximate NAWF 5 plus 350 heat units, the current recommendation for terminating insecticide applications (Mississippi State University Extension 2017).

Linear regression analysis of counts of NAWF (PROC GLM, SAS Institute, Version 9.3, Cary, NC) was used (week of flowering as the independent variable) to determine when plots reached NAWF 5 and to determine the nodes above white flower counts at different weeks of flowering. This analysis was done only on the season-long treatment, and 95% confidence limits were calculated as an estimate of variability among locations. The regression equation from this analysis was used to determine the mean week that plots reached NAWF 5. Local weather data was not used to estimate heat unit accumulation beyond nodes above white flower five. Gore et al., (2000) observed an average accumulation of 25 heat units per day in a study conducted in northeast Louisiana, so this value was used to calculate heat unit accumulation in the current study. This analysis was done to compare the results of this study to previous research.

RESULTS AND DISCUSSION

Previous research investigating the termination of insecticide applications for various insect pests in cotton was based on NAWF counts and heat unit accumulation. Specific boll ages, based on heat unit accumulation, when cotton bolls are safe from yield losses have been determined for boll weevil (Bagwell, 1994), bollworm (Bagwell, 1994; Gore et al., 2000), beet armyworm and fall armyworm (Adamczyk et al., 1998); stink bug (Willrich et al., 2005); and tarnished plant bug (Horn, 2003; Russell, 1999). Some discrepancy exists about when to terminate insecticide applications for tarnished plant bug. In terms of number of stylet penetrations and depth of those penetrations, data suggest that applications could be terminated when cotton reached NAWF 5 plus 250 heat units (Horn, 2003). In contrast, Russell (1999) found that bolls were not safe from yield losses until they accumulated 326.5 heat units beyond anthesis. Based on those data, the recommendation has been to terminate insecticide applications once cotton reached NAWF 5 plus 326.5 heat units. While this strategy has been well defined, it has not necessarily been widely adopted because most producers rarely know when cotton has reached NAWF 5 let alone monitored accumulated heat units. Woods et al., (2016) recently conducted research utilizing weeks of flowering as an indicator for the termination of tarnished plant bug management. The authors determined that the most critical window for management of tarnished plant bugs in flowering cotton would be the second to the fourth weeks of flowering. Through continued research on the critical flowering window, the purpose of this research was to determine the optimal termination timing not only to minimize the need for later season insecticide applications, but to simplify the current recommendation.

In the current study, densities of tarnished plant bug varied across individual trials (Figs. 1 & 2). Tarnished plant bug densities in the untreated control remained well above the current threshold of six tarnished plant bugs per 3.0 m throughout most of the sampling period with the exception of LA and MO locations. The greatest populations occurred in Stoneville, MS; Marianna, AR; Rohwer, AR; and Jackson, TN, in 2015 (Fig. 1), and in Marianna, AR; Rohwer, AR; and Jackson, TN, in 2016 (Fig. 2). In general, insecticide sprays in the season-long control (2015) and threshold (2016) treatments effectively reduced densities of tarnished plant bug, with a few exceptions (Figs. 1 & 2). In locations such as Jackson, TN or Mariana, AR levels of tarnished plant bug were exceptionally high, so insecticide applications lowered densities, but not necessary to a level below threshold.

During 2015, significant differences in seasonal mean tarnished plant bug densities were observed among insecticide termination treatments at each location, except at Winnsboro, LA(a) (Table 1). All insecticide termination treatments and the season-long control had significantly fewer tarnished plant bug nymphs than the untreated control at Keiser, AR; Rohwer, AR; and Jackson, TN. Termination of insecticide sprays after the fifth week of flowering, fourth week of flowering, fifth week of flowering, and third week of flowering resulted in fewer tarnished plant bug nymphs than the untreated control at Stoneville, MS(a); Stoneville, MS(b); Winnsboro, LA(b); and Marianna, AR; respectively (Table 1).

Significant differences in seasonal mean tarnished plant bug densities were observed for insecticide termination treatments at all sites except for St. Joseph, LA, and Winnsboro, LA, in 2016 (Table 2). All insecticide termination treatments and the threshold treatment (SLC) had significantly fewer tarnished plant bug nymphs than the untreated control at Marianna, AR; Portageville, MO; Rohwer, AR; and Jackson, TN. Termination of insecticide sprays after the fifth week of flowering resulted in fewer tarnished plant bug nymphs than the untreated control at Sidon, MS, but the season-long control treatment was not significantly different than the untreated control (Table 2).

Overall, insecticide sprays provided acceptable control of tarnished plant bug populations in these trials, despite widespread resistance to most classes of insecticides (Snodgrass 1996, Snodgrass and Scott 2000, Snodgrass et al., 2009). Because of known resistance, high rates of organophosphates or neonicotinoid insecticides were tank mixed with high rates of pyrethroids (usually bifenthrin) when insecticide sprays were made. Additionally, sulfoxaflor (Transform WDG, Corteva Agriscience, Indianapolis, IN) was commonly used because it provides good control of tarnished plant bug (Siebert et al., 2012), and no insecticide resistance has been documented for this insecticide to date.

In the overall analysis of yields, significant differences were observed among treatments ($F = 49.5$; $df = 6, 308.1$; $P < 0.01$). All termination treatments and the season-long control resulted in greater cotton yields than the untreated control (Fig. 3). Termination of insecticide applications after the second through fourth weeks of flowering resulted in significantly lower cotton yields than the season-long control. On average, the only treatments that resulted in cotton yields similar to those of the season-long control were when insecticide applications were terminated after the fifth and sixth weeks of flowering. In the individual trial analysis, significant differences were observed at seven of eight locations in 2015 and at four out of eight locations in 2016 (Table 3). Across all locations, the fifth week of flowering was the latest week where insecticide termination resulted in cotton yields similar to the season-long control. At some locations, termination of insecticide applications after the second through fourth weeks of flowering resulted in cotton yields that were similar to the season-long control. However, for most locations tarnished plant bug densities peaked between weeks three and four suggesting that cotton is safe from significant yield losses from tarnished plant bug after the fifth week of flowering. These data also suggest that, in some situations, insecticide applications can be terminated after the fourth week of flowering without a significant yield penalty, especially in areas where good control can be achieved with currently labeled insecticides. In areas where management with foliar insecticides is more difficult due to widespread resistance, terminating insecticide applications after the fourth week of flowering may result in some yield loss.

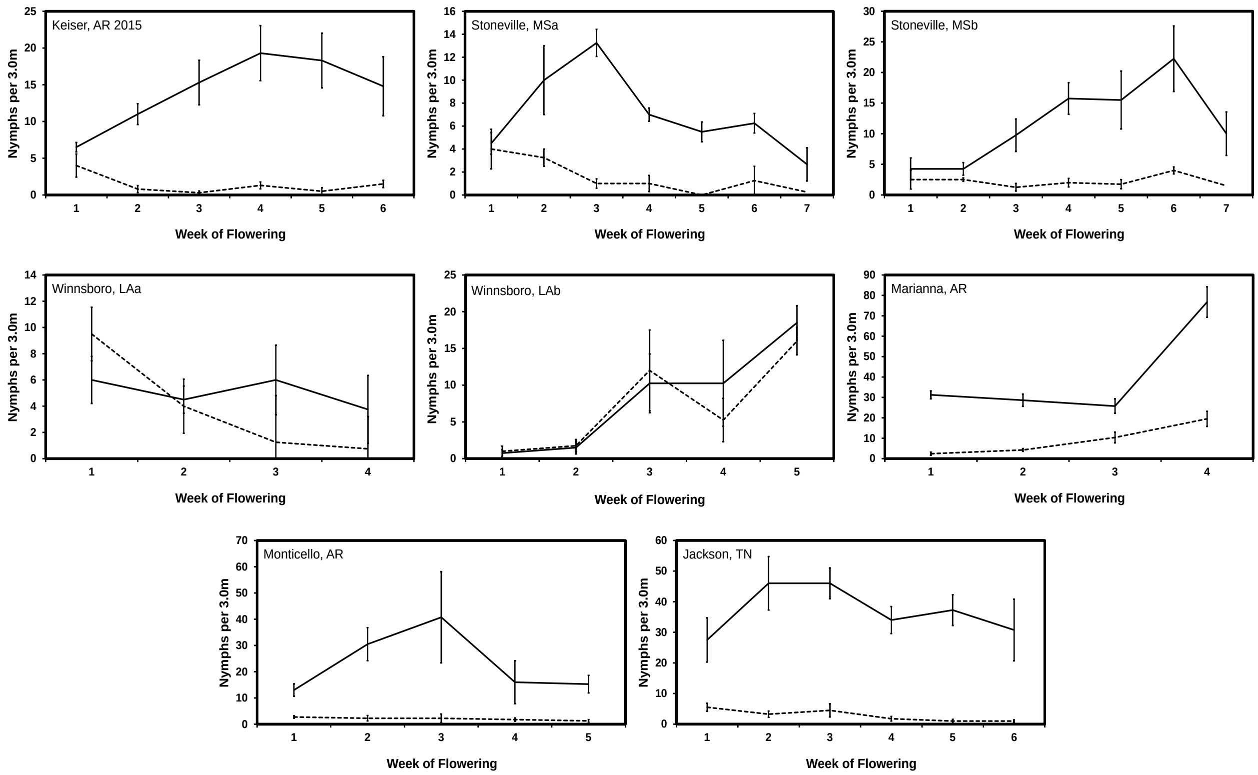

Figure 1. Mean (SEM) densities of tarnished plant bug, *L. lineolaris,* in the untreated control (solid line) and season-long control (dotted line) in cotton at each location in 2015.

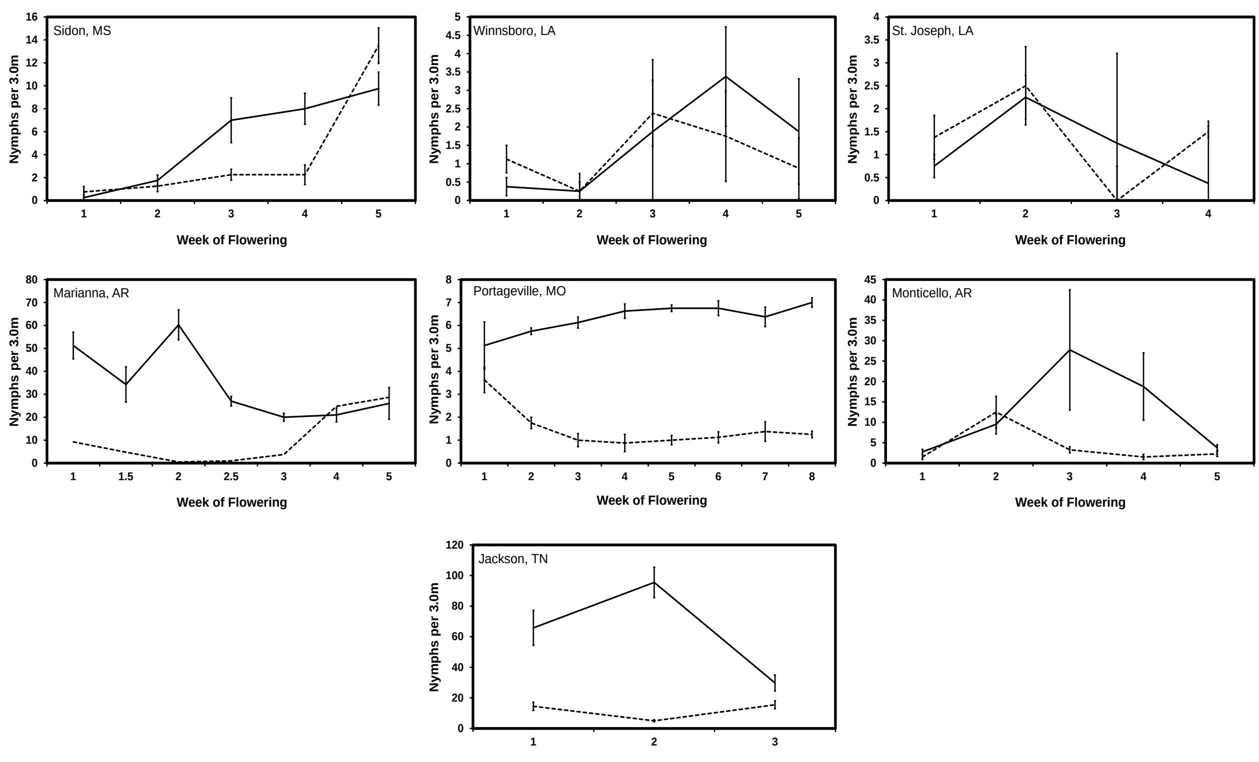

Figure 2. Mean (SEM) densities of tarnished plant bug, *L. lineolaris* in the untreated control (solid line) and season-long control (dotted line) in cotton at each location in 2016.

Table 1. Seasonal mean (SEM) densities of tarnished plant bug nymphs per 3.0 m of row (two drop cloth samples) in cotton at each location in 2015

Termination Treatment[1]	Keiser, AR	Stoneville, MS(a)	Stoneville, MS(b)	Winnsboro, LA(a)	Winnsboro, LA(b)	Marianna, AR	Rohwer, AR	Jackson, TN
UTC	14.2 (2.5)a[2]	7.2 (0.6)bc	11.7 (1.1)ab	5.1 (2.0)a	8.3 (0.4)ab	40.6 (3.5)a	23.1 (3.7)a	36.9 (3.3)a
Second	5.2 (1.0)b	9.8 (0.7)a	13.6 (1.0)a	7.0 (0.5)a	12.0 (2.4)a	41.7 (2.5)a	9.6 (1.7)b	14.2 (1.4)b
Third	3.8 (0.8)bc	9.2 (0.9)ab	9.7 (1.4)b	3.8 (0.6)a	5.9 (1.4)bc	32.0 (3.9)b	5.8 (2.5)bc	9.8 (2.8)c
Fourth	3.2 (0.6)bc	6.8 (1.4)c	6.8 (0.9)c	5.9 (1.5)a	5.4 (1.0)bc	12.7 (0.6)c	2.0 (0.7)c	3.6 (1.1)d
Fifth	2.2 (0.2)c	3.7 (0.6)d	4.7 (0.4)d	5.4 (0.7)a	3.9 (0.7)c	---	1.6 (0.8)c	1.6 (0.2)d
Sixth	2.0 (0.5)c	1.5 (0.4)e	2.3 (0.2)e	4.1 (0.4)a	4.2 (0.9)c	---	2.6 (0.9)c	2.2 (0.3)d
Seventh	1.3 (0.2)c	2.3 (0.3)de	2.8 (0.8)de	4.0 (0.9)a	4.9 (2.0)bc	---	1.7 (0.7)c	1.9 (0.5)d
Eighth	---	1.0 (0.2)e	2.2 (0.4)e	---	---	---	---	1.3 (0.4)d
SLC	1.4 (0.3)c	1.5 (0.3)e	2.2 (0.2)e	3.9 (0.4)a	7.2 (1.5)bc	9.4 (1.1)c	2.1 (0.3)c	2.8 (0.4)d
F	21.3	24.7	40.2	1.3	4.0	33.4	18.9	82.0
df	7, 21	8, 24	8, 24	7, 24	7, 21	4, 15	7, 21	8, 24
P > F	<0.01	<0.01	<0.01	0.30	0.01	<0.01	<0.01	<0.01

[1] UTC represents untreated control. Week of flowering after which insecticide sprays for tarnished plant bug were terminated. SLC represents season-long control where applications were made weekly.

[2] Means within a column followed by the same letter are not significantly different at α = 0.05 according to Fisher's Protected LSD

Table 2. Seasonal mean (SEM) densities of tarnished plant bug nymphs per 3 m of row (two drop cloth samples) in cotton at each location in 2016

Termination Treatment[1]	Sidon, MS	St. Joseph, LA	Winnsboro, LA	Marianna, AR	Portageville, MO	Rohwer, AR	Jackson, TN
UTC	5.4 (0.4)a[2]	1.2 (0.2)a	1.6 (0.2)a	34.7 (2.2)a	6.3 (0.2)a	12.5 (3.6)a	63.7 (3.8)a
Second	5.5 (1.1)a	1.4 (0.2)a	1.1 (0.2)a	11.8 (1.2)b	3.9 (0.1)b	3.0 (0.5)b	12.7 (1.4)b
Third	4.2 (0.8)a	1.7 (0.7)a	1.6 (0.5)a	12.3 (2.2)b	3.2 (0.2)c	2.2 (0.5)b	10.0 (1.7)b
Fourth	4.6 (0.9)a	0.7 (0.2)a	1.0 (0.2)a	---	2.5 (0.2)d	2.3 (0.5)b	8.8 (1.2)b
Fifth	2.2 (0.5)bc	0.7 (0.2)a	0.6 (0.1)a	---	2.1 (0.2)de	3.2 (0.8)b	11.2 (1.1)b
Sixth	1.9 (0.3)c	0.7 (0.1)a	1.0 (0.4)a	---	1.7 (0.1)ef	3.4 (0.5)b	8.5 (0.4)b
SLC	4.0 (0.2)ab	1.3 (0.3)a	1.3 (0.4)a	9.6 (1.2)b	1.5 (0.2)f	4.2 (0.7)b	11.7 (1.8)b
F	4.7	1.6	1.3	44.7	111.0	6.6	111.8
df	6, 18	6, 18	6, 18	3, 12	6, 18	6, 18	6, 21
P > F	<0.01	0.19	0.31	<0.01	<0.01	<0.01	<0.01

[1] Week of flowering after which insecticide sprays for tarnished plant bugs were terminated. UTC represents Untreated Control. SLC represents season-long control where applications were made weekly.

[2] Means within a column followed by the same letter are not significantly different at α = 0.05 according to Fisher's Protected LSD

Table 3. Week of flowering that cotton yields in tarnished plant bug insecticide termination treatments were statistically similar to the season-long control and the untreated control and at each experimental location in 2015 and 2016 (SLC represents Season-Long Control, UTC represents Untreated Control)

2015	Location	Same as SLC	Same as UTC[1]	F	df	*P* > F
	Keiser, AR	4	4	3.1	6, 18	0.03
	Marianna, AR	3	2	4.5	4, 15	0.01
	Rohwer, AR	3	2	6.8	6, 18	<0.01
	Stoneville, MS(a)	5	3	36.7	6, 21	<0.01
	Stoneville, MS(b)	5	2	19.2	6, 18	<0.01
	Jackson, TN	3	--	9.0	6, 21	<0.01
	Winnsboro, LA(a)	4	5	3.5	6, 18	0.02
	Winnsboro, LA(b)	NS[2]	NS	2.6	6, 18	>0.05
2016	**Location**	**Same as SLC**	**Same as UTC[1]**	**F**	**df**	***P* > F**
	Rohwer, AR	2	--	6.6	6, 18	<0.01
	Marianna, AR	NS	NS	3.4	3, 7	0.08
	Sidon, MS	3	--	10.0	6, 21	<0.01
	Jackson, TN	2	3	3.6	6, 18	0.02
	Winnsboro, LA	NS	NS	2.1	6, 18	0.11
	St. Joseph, LA	NS	NS	0.8	6, 21	0.58
	Portageville, MO	3	2	2.8	6, 21	0.04

[1]The dashed lines in the table indicate locations where all termination treatments resulted in significantly greater yields than the untreated control (UTC).

[2] NS represents not significant.

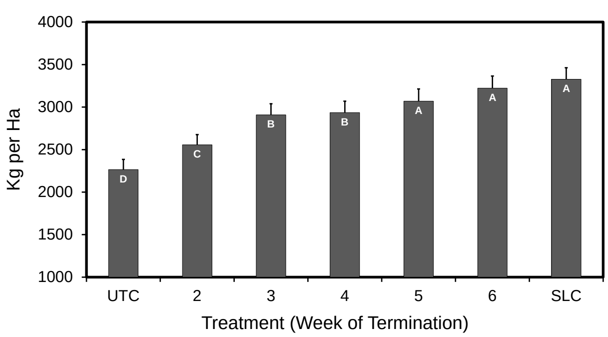

Figure 3. Mean ± (SEM) seed cotton yields averaged across all locations and years based on the week of flowering that tarnished plant bug applications were terminated. Bars with a common letter are not significantly different according to Fisher's Protected LSD, α = 0.05 (SLC represents season-long control; UTC represents untreated control).

Previous research for numerous insect pests has focused on determining when to terminate insecticide applications based on NAWF counts and heat unit accumulation. In general, cotton growers and pest managers in the southern U.S. do not monitor NAWF counts and heat unit accumulations. As a result, a more user-friendly method for estimating when to terminate insecticide applications for tarnished plant bug based on weeks of flowering or on a specific NAWF measure is needed. Based on the season-long control regression analysis, NAWF decreased by 0.83 nodes per week, with an intercept of 7.4. Based on this information, plots in the current study reached NAWF 5 at 2.9 weeks after first flower. With an average daily heat unit accumulation of 25 heat units per day (Gore et al., 2000), plots in the current study would have reached NAWF 5 plus approximately 350 heat units (14 days) at or near the end of the fifth week of flowering. These results are similar to those reported previously of NAWF 5 plus 326.5 heat units being the point when insecticide applications can be terminated for tarnished plant bug (Russell 1999). On average, termination at the end of week five lines up with the current recommendation of NAWF 5 plus 350 heat units.

These results confirm previous research but now provide a more user-friendly method for determining when to terminate insecticide applications. In many situations in the mid-southern U.S., cotton pest managers and growers may make one to two additional insecticide applications late in the season because they did not record when the crop reached NAWF 5. Based on our research, cotton is safe from tarnished plant bug injury after the fifth week of flowering. In situations where widespread resistance is not an issue and populations can be effectively controlled, insecticide applications can be terminated after the fourth week of flowering without the risk of significant yield losses. Based on the regression equations with NAWF counts, plots in the season-long control were at a mean (95% confidence limits) of 4.1 (3.8 – 4.4) NAWF at the end of the fourth week of flowering and 3.2 (2.8 – 3.6) NAWF at the end of the fifth week of flowering. These values provide growers and pest managers a measurement that they can record at any given time during the flowering period to determine when to terminate sprays for tarnished plant bug. The average cost of an insecticide, or tank mixture of insecticides targeting tarnished plant bug is \$22.70 ha^{-1} plus an application cost of \$12.35 ha^{-1} for a total of \$35.05 ha^{-1} for one application (Williams 2016). Approximately 405,000 ha of cotton were planted in the states of Arkansas, Louisiana, Mississippi, Missouri, and Tennessee in 2016. Assuming a conservative estimate of saving one application, terminating insecticide applications based on these recommendations would save growers over \$14 million each year in the region.

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