The *Journal of Cotton Science 23:21–27 (2019)*
http://journal.cotton.org, © The Cotton Foundation 2019

AGRONOMY AND SOILS

Impact of Irrigation Timing on Tarnished Plant Bug Populations and Yield of Cotton

Clinton Wilks Wood*, Jeff Gore, Angus Catchot , Don Cook, Darrin Dodds, and Jason Krutz

ABSTRACT

The tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), is the most significant insect pest of cotton, *Gossypium hirsutum* (L.), in the mid-southern United States (Arkansas, Louisiana, Mississippi, Missouri, and Tennessee). Past research has shown the impact that planting date, nitrogen rate, and variety selection has on tarnished plant bug populations, but a paucity of data exists on the effect irrigation timing has on tarnished plant bug. Experiments were conducted at the Mississippi State University Delta Research and Extension Center in Stoneville, MS to determine if insecticide applications targeting the tarnished plant bug could be reduced in response to irrigation timings. Treatments were in a strip-block arrangement, with the main plot factor being irrigations initiated at squaring, first flower, peak flower, and a non-irrigated control. The sub-plot factor was tarnished plant bug management that consisted of insecticide applications made weekly, at threshold, and a non-treated control. Overall, insecticide applications for tarnished plant bug increase yield. Irrigation initiated at squaring resulted in tarnished plant bugs exceeding the recommended treatment threshold significantly more than when irrigations were initiated later in the growing season. Also, when irrigation was postponed until peak flower, no yield loss or delay in maturity was observed. These results indicate that irrigation timing could be a potential cultural control practice that reduces the number of insecticide applications targeting tarnished plant bug populations in Mid-South cotton.

Insecticide resistance has become prevalent in tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), populations in the mid-southern United States (Arkansas, Louisiana, Mississippi, Missouri, and Tennessee) (Snodgrass et al. 2009, Snodgrass 1996), and three to seven pesticide applications are often made to prevent economic losses (Williams 2014). In general, the risk of yield losses from tarnished plant bug is lower during the pre-bloom period compared with the bloom period (Musser et al. 2009); however, yield losses can be severe if tarnished plant bugs are not adequately controlled throughout the entire season (Layton 2000). Several agronomic practices have been shown to reduce tarnished plant bug populations in cotton or diminish their impacts on final yields. Most notably, promoting early maturity of the crop through planting date and variety selection can significantly reduce the number of insecticide applications for tarnished plant bug and their impact on yield (Adams et al. 2013). In Mississippi, planting cotton prior to 15-May was shown to reduce the number of insecticide applications compared to later planting dates (Adams et al. 2013), and yield losses from tarnished plant bug averaged 26% for an early maturing variety compared with 45% for a late maturing variety. Fertilization also can impact tarnished plant bug management in cotton. Fewer insecticide applications were needed where 90 kg of nitrogen was applied per hectare compared to higher rates, without losing yield (Samples 2014).

Little is known about the impact of irrigation on tarnished plant bug populations, despite the fact that approximately 65% of cotton planted in Mississippi is irrigated (Perry et al. 2012). In general, cotton is considered a relatively drought tolerant crop; however, adequate water is needed for proper growth and development (Burke and Ulloa 2017). A reduction in photosynthesis, as well as fruit abscission and yield loss, may occur if cotton becomes severely drought stressed. Demands for water are greatest during the reproductive and early boll maturation periods with 53% of total water use occurring from first square to peak flower (Janat 2008), which is when tarnished plant bug infestations tend to be most prevalent. Drought stress and insect pests such as the tarnished plant bug can

---

C.W. Wood*^{1}, J. Gore, D. Cook, and J. Krutz, Delta Research and Extension Center, Mississippi State University, P.O. Box 197, Stoneville, MS 38776; A. Catchot, Department of Biochemistry, Molecular Biology, Entomology and Plant Pathology, Mississippi State University, Box 9655, Mississippi State, MS 39762; and D. Dodds, Department of Plant and Soil Sciences, Mississippi State University, Box 9555, Mississippi State, MS 39762.
^{1}(formerly)
*Corresponding author: wilks.wood@cookspest.com

result in significant yield loss; however, the interaction between these factors has not been studied.

Little is also known about the attractiveness of cotton to tarnished plant bug under different irrigation regimes. Previous research has shown that tarnished plant bug is attracted to vigorously growing cotton compared to stressed cotton (Willers et al. 1999, Willers and Akins 2000). It is hypothesized that tarnished plant bug populations will not be as attracted to drought stressed cotton during the squaring period which can result in decreased tarnished plant bug populations compared to those found in cotton irrigated according to standard practices. Understanding the interaction between irrigation strategy, tarnished plant bug populations, and the impact of these factors on final cotton yield must be understood to develop more cost-efficient production practices. Therefore, the objective of this study was to determine if insecticide applications targeting the tarnished plant bug could be reduced in response to irrigation timings.

MATERIALS AND METHODS

An experiment was conducted at the Delta Research and Extension Center in Stoneville, MS to evaluate the effect furrow irrigation timing has on tarnished plant bug populations. Phytogen 499 WRF was planted on 20 May 2013 and 9 May 2014, at 113,668 seeds/ha. Seed were commercially treated with a premix of imidacloprid and abamectin along with select fungicides. Plots consisted of eight 1.01-m rows that were 15.2-m long. Treatments were in a strip-block arrangement in a randomized complete block design with four replications. The main-plot factor was irrigation timing which consisted of a non-irrigated control, irrigation beginning at early squaring, first flower, or peak flower. Plots were furrow irrigated, where water was pumped through 30.5 cm diameter polyethylene tubing laid perpendicular to the cotton rows. Holes were punched in the polyethylene tubing to allow water to run down every furrow. Plots were arranged across the field to allow furrow irrigation to easily be controlled and prevent inadvertent irrigation of non-irrigated rows. After irrigation was initiated for a specific treatment, subsequent irrigation events for that treatment were based on soil moisture sensor readings. Three IRROMETER Watermark moisture sensors (IRROMETER Company Inc., Riverside, CA) were set at depths of 15, 30, and 61 centimeters. These sensors measure soil water tension by reading the amount of water absorbed through a granular matrix. The sensors were set in the fourth row of the middle tier of each replication and were monitored weekly. Irrigation was initiated when soil moisture readings from the three sensors averaged over -100 centibars, indicating a depletion in adequate soil moisture. Irrigation events were completed when the soil was adequately saturated based on soil moisture sensors.

The sub-plot factor was tarnished plant bug management within each irrigation timing. Tarnished plant bug management included weekly insecticide application, applications made based on the recommended treatment thresholds, and a non-treated control. Rows four through seven of all plots were sampled twice per week to determine tarnished plant bug adult and nymph densities. During the pre-flowering stages (squaring), tarnished plant bug densities were determined by taking 25 sweeps with a standard 38-cm diameter sweep net. During the flowering period, tarnished plant bug densities were determined by taking two drop cloth samples with a 0.76-m black drop cloth in each plot. For the weekly spray treatment, insecticide applications were made every week beginning at first square and continued until physiological cutout. For the threshold treatment, insecticide applications were made when tarnished plant bugs exceeded threshold beginning at first square and continued until physiological cutout. An insecticide application was applied to the appropriate plots based on the recommended threshold (Catchot 2013). The thresholds were eight tarnished plant bugs per 100 row sweeps during the squaring period and three tarnished plant bugs per 1.52-m of row once flowering began. Insecticide mixtures that provide maximum control of tarnished plant bug were used for all spray treatments. Insecticides utilized were acephate (Orthene 90S, Valent Corporation, Walnut Creek, CA), sulfoxaflor (Transform WG, Dow AgroSciences, Indianapolis, IN), thiamethoxam (Centric 40 WG, Syngenta Crop Protection, Greensboro, NC), and acephate tank mixed with bifenthrin (Brigade, FMC Corporation, Princeton, NJ). The non-irrigated and the squaring irrigation timing were the only treatments sampled throughout the entire sampling period. It was assumed that tarnished plant bug numbers in the first flower and peak flower treatments prior to irrigation initiation would not be different from the non-irrigated treatment because those plots had not yet received irrigation treatments. As such, sampling did not begin in those treatments until irrigations were initiated. To account for differences in the numbers of samples and the potential impact on yields, yields were determined from different rows than those that were sampled as indicated above. Final plant heights and nodes above white flower counts were taken at week six of the flowering period. Nodes above white flower data were determined by counting the number of mainstem nodes from the highest first-positon white flower to the apical meristem. All sampling methods were terminated after the sixth week of flowering at physiological cutout. At the end of the season, rows two and three of every plot, were harvested mechanically with a spindle type picker modified for small plot harvest and seed cotton weights were recorded. Lint yield was calculated as 38% of the seed cotton weights.

All data were analyzed with Analysis of Variance, PROC MIXED (Littell et al. 1996). Regarding tarnished plant bug densities in the non-irrigated and irrigation initiated at squaring treatments, data were analyzed as a repeated measures analysis of variance with week, irrigation timing, and spray treatments as fixed effects and week as the repeated effect. All irrigations had been initiated by week six, therefore data for non-irrigated, squaring, first flower and peak flower irrigations were analyzed for weeks five and six. It was during these weeks that all plots in the trial were sampled. In weeks five and six, data were analyzed with irrigation timings and spray treatments as fixed effects in the model. Replication nested within year served as the random statement, and the Kenward-Rogers degrees of freedom method was used. Final yield data were analyzed by year due to extreme differences in rainfall between the two years. Year, irrigation timing, and spray treatment were considered fixed effects. Replication nested within year served as the random statement, and the Kenward-Rogers degrees of freedom method was used. Means were separated using the LSMEANS statement. Differences were considered significant for α=0.05.

RESULTS AND DISCUSSION

Differences in rainfall between 2013 and 2014 impacted the results of this experiment, and the summer of 2013 was characterized by relatively dry conditions; whereas, there was ample rainfall in June and July of 2014 (Table 1). However, tarnished plant bug populations were moderate to high during both growing seasons. No three-way interaction (*F*=0.88; df=2, 317; *P*=0.41) between irrigation timing, spray treatment and sample week was present for tarnished plant bug densities in the irrigation treatment initiated at squaring and the non-irrigated control. There was an interaction between spray treatment and week (*F*=3.14; df=10, 317; *P*<0.01) for mean number of tarnished plant bugs in drop cloth samples. Except for the first sampling time, the non-treated control had significantly more tarnished plant bugs than all other treatments (Fig.1). The weekly spray treatment had the fewest number of tarnished plant bugs at first flower and at peak flower. During squaring, second week of flowering, third week of flowering, and fifth week of flowering, tarnished plant bug numbers in the threshold spray treatment was not significantly different than the weekly spray treatments (Fig. 1).

Table 1. Rainfall and heat unit accumulation (DD60, Landivar and Benedict 1996) by month and year for 2013 and 2014 at Stoneville, MS (http://www.deltaweather.msstate.edu/).

Month and Year	Precipitation (cm)	DD60
May 2013	14	311
June 2013	9.3	547
July 2013	4.9	560
August 2013	5.1	647
Total	33.3	2,065
May 2014	14.4	355
June 2014	14.6	598
July 2014	12.2	542
August 2014	5	609
Total	46.2	2,104

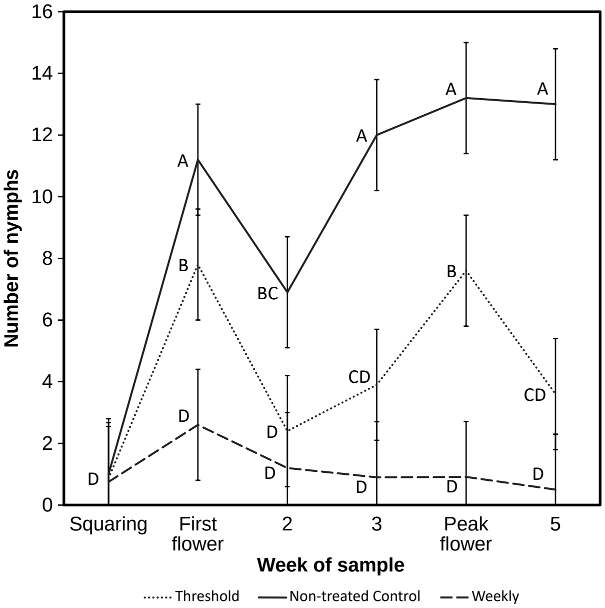

Figure 1. Effect of spray treatment regime and week of sampling on mean (SEM) number of tarnished plant bugs per 3.04-m of row by week across 2013 and 2014 in Stoneville, MS. Means separated by common letter are not significantly different at α=0.05.

There was a significant interaction between irrigation timing and spray treatment for tarnished plant bug numbers (*F*=5.98; df=2, 317; *P*<0.01). The control treatment for both irrigation timings had significantly more nymphs than the weekly and threshold spray treatments (Fig. 2). In the non-irrigated treatment, there was no difference in the number of tarnished plant bugs between the threshold and weekly spray treatments. In contrast, there was a significant difference in tarnished plant bug densities between the threshold spray treatment and the weekly spray treatment for the squaring irrigation treatment (Fig. 2).

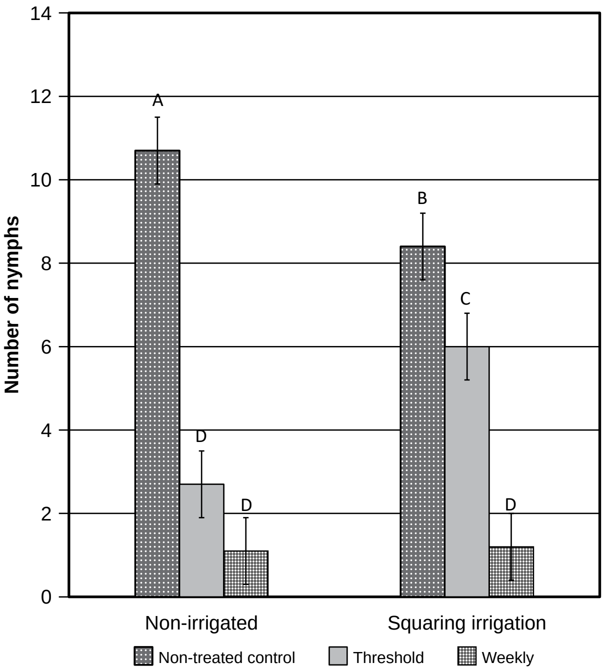

Figure 2. Impact of irrigation treatment and spray treatment regime on mean number of tarnished plant bugs per 3.04-m of row across 2013 and 2014 in Stoneville, MS. Means separated by a common letter are not significantly different at α=0.05.

For the threshold spray regime, irrigation significantly affected the number of times tarnished plant bug populations exceeded threshold (*F*=7.63; df=3, 21; *P*<0.01). When irrigation was initiated at squaring, tarnished plant bug populations exceeded threshold more often than all other irrigation treatments (Table 2).

For tarnished plant bug numbers with all irrigation treatments included, there was a significant interaction between irrigation timings and spray treatment (*F*=2.96; df=6, 178; *P*<0.01). The non-treated control had more tarnished plant bug nymphs than the threshold and weekly spray treatment for all irrigation timings (Table 3). No differences were observed among the irrigation timings within the non-treated control or weekly spray treatments. For the threshold spray regime, there were significantly more tarnished plant bugs when irrigation was initiated at squaring than where irrigation was initiated at first flower, peak flower, and the non-irrigated control (Table 3).

Table 2. Mean ± SEM number of times that different irrigation treatments exceeded the recommended threshold for tarnished plant bug in the threshold spray regime in Stoneville, MS (averaged for 2013 and 2014).

Irrigation Initiation	Number of Times Exceeded Threshold
Non-Irrigated	1.6±0.37 b
Squaring	3.6±0.65 a
First Flower	1.9±0.39 b
Peak Flower	1.5±0.32 b

Means followed by common letter are not significantly different at α=0.05.

Table 3. Mean ± SEM number of tarnished plant bugs per 3.04-m of row by irrigation and insecticide spray regimes averaged across weeks 5 and 6 of the flowering period for 2013 and 2014 in Stoneville, MS.

Irrigation Initation	Non-Treated	Weekly	Threshold
Non-Irrigated	13.4±2.9 a	0.5±0.2 d	1.8±0.6 cd
Squaring	12.7±1.7 a	0.8±0.3 cd	9.2±4.1 b
First Flower	15.1±1.8 a	1.1±0.4 cd	4.3±0.7 c
Peak Flower	13.1±2.6 a	0.7±0.3 cd	1.8±0.6 cd

Means followed by common letter are not significantly different at α=0.05.

There was no interaction between irrigation timing and spray treatment for final cotton heights (*F*=0.51; df=6, 56; *P*=0.79). Spray treatment did not affect cotton height (*F*=1.45; df=2, 56; *P*=0.24), but irrigation did affect final plant height (*F*=3.70; df=3, 21; *P*=0.02). Plants were taller when irrigation was initiated at squaring compared with plants in the non-irrigated treatment (Fig. 3). Plant heights for the first flower irrigation regime (115.79±5.1 cm) and the peak flower irrigation regime (117.7±5.1 cm) were not significantly different from either of the other treatments.

Irrigations in the Mid-South are typically delayed as long as possible to allow for early season field operations such as herbicide and nitrogen application (Perry et al. 2012). Also, growers believe water stress early in the growing season will enhance root development (Perry et al. 2012). Water needs are low during the early growing season, but demand increases drastically during the reproductive stages (Table 1). Many growers in the Mid-South initiate irrigations when squaring begins. Yet, initiating irrigation during the squaring period caused tarnished plant bugs to exceed the threshold significantly more than if irrigations had been postponed until later in the growing season. Irrigation initiated at squaring resulted in significantly taller plants, and that may have affected sampling efficiency or the level of control that was achieved with foliar insecticide applications. There seems to be a relationship between attractiveness of cotton after irrigation initiation and tarnished plant bug feeding as seen by the number of tarnished plant bugs in the squaring irrigation treatment. Making cotton more attractive during the pre-flowering stage may compound damage observed from tarnished plant bug as there are many examples of tarnished plant bugs causing yield loss during this time frame (e.g., Layton 2000, Tugwell et al. 1976).

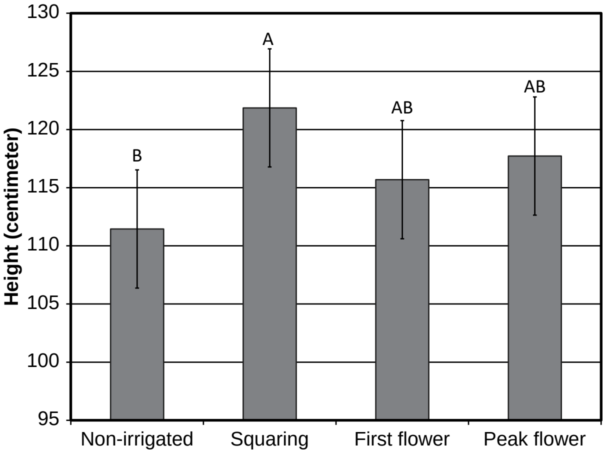

Figure 3. Impact of irrigation initiation timings on final mean (±SEM) plant heights averaged across 2013 and 2014 in Stoneville, MS. Means separated by common letter are not significantly different at α=0.05.

There was no interaction between irrigation timing and spray treatment on nodes above white flower (*F*=1.11; df=6, 40; *P*=0.37). Spray treatment had an effect on the number of nodes above white flower (*F*=9.45; df=2, 40; *P*<0.01). Cotton in the non-treated control (3.28±0.32) had significantly more nodes above white flower than cotton in the threshold treatment regime (2.93±0.32), and cotton in the threshold regime had more nodes above white flower than the weekly spray treatment (2.59±0.32) (Fig. 4). Irrigation timing also had an effect on the number of nodes above white flower (*F*=3.37; df=3, 15; *P*=0.04). Irrigation initiated at squaring (3.18±0.33) and at first flower (3.14±0.33) resulted in cotton with significantly more nodes above white flower than cotton in which irrigation was initiated at peak flower (2.62±0.32). Non-irrigated cotton (2.8±0.32) had a similar number of nodes above white flower to cotton in which irrigation was initiated at all other timings (Fig. 5). These data indicate that greater tarnished plant bug control minimized delays in maturity and that, when irrigations were postponed, no delay in maturity was observed.

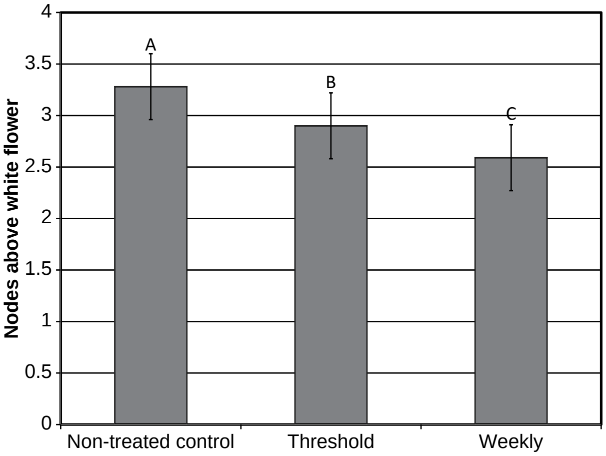

Figure 4. Impact of tarnished plant bug spray regime on mean (SEM) nodes above white flower counts averaged across 2013 and 2014 in Stoneville, MS. Means separated by common letter are not significantly different at α=0.05.

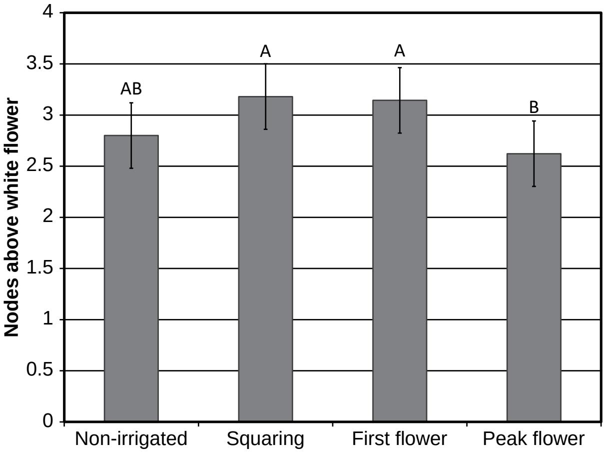

Figure 5. Impact of irrigation timing on mean (SEM) nodes above white flower counts averaged across 2013 and 2014 in Stoneville, MS. Means separated by common letter are not significantly different at α=0.05.

There was a significant year by spray treatment interaction (*F*=3.88; df=2, 48; *P*=0.02) and a year by irrigation timing interaction (*F*=4.31; df=3, 18; *P*<0.01) for lint yield. Therefore, yields were analyzed by year. There was more rainfall in 2014 compared to 2013 with a total of 31.8 cm of rain from June-August in 2014 compared with only 19.3 cm during that same time frame in 2013 (http://www.deltaweather.msstate.edu/).

There was no irrigation timing by spray treatment interaction (*F*=1.61; df=6, 24; *P*=0.18) for mean lint yield during 2013. Irrigation initiation timing had a significant effect on lint yield (*F*=9.86; df=3, 9; *P*<0.01) (Table 3). Irrigation initiated at squaring (1,568±41 kg/ha), first flower (1,497±41 kg/ha) and peak flower (1,472±41 kg/ha) resulted in greater yields than cotton that was non-irrigated (1,085±41 kg/ha) in 2013. Spray treatment also had an effect on lint yield (*F*=81.86; df=2, 24; *P*<0.01) (Table 4). Cotton sprayed weekly (1,634±35 kg/ha) and sprayed based on threshold (1,537±35 kg/ha) yielded significantly greater than the non-treated control treatment (1,047±35 kg/ha) in 2013.

There was no significant irrigation timing by spray treatment interaction (*F*=1.69; df=6, 24; *P*=0.16) for lint yield during 2014. In addition, irrigation timing did not have an effect on lint yield (*F*=0.18; df=3, 9; *P*=0.90) in 2014. Spray treatment did have a significant effect on lint yield (*F*=62.18; df=2, 24; *P*<0.01) (Table 4). Cotton yields were greater when sprayed weekly compared to when sprays were based on threshold as well as non-treated control, and yields was significantly greater when sprayed based on threshold compared to the non-treated control.

The effect of environmental conditions between the two years can be observed in lint yields between the irrigation treatments. Fewer irrigations were needed during the summer of 2014 compared to the summer of 2013, and irrigation had a significant impact on yield in 2013 but not in 2014. In 2013, irrigation events were triggered four times in the squaring treatment, three times in the first flower treatment, and once in the peak flower treatment. In 2014, the squaring treatment received two irrigation events, first flower treatment received one, and the peak flower irrigation treatment was not irrigated. Also, when irrigation was postponed until the point of peak flower, no significant decrease in yield was observed.

CONCLUSION

Based on these data, a grower may be able to reduce insecticide applications without a penalty in yield by postponing irrigations until peak flower or not irrigating at all when sufficient rainfall occurs. However, the amount of stress placed on a cotton plant not receiving supplemental irrigation should be considered. Postponing irrigation reduced the number of times tarnished plant bugs exceeded threshold, but lush, freshly irrigated plants were nearby to dry non-irrigated plants. This may have influenced tarnished plant bug densities because they were able to freely move among the plots and select preferred feeding sites. Initiating irrigation at peak flower reduced the number of times tarnished plant bugs exceeded threshold and resulted in similar yields compared to when irrigation was initiated at squaring. A grower

Table 4. Impact of irrigation and insecticide spray regimes on mean ± SEM lint yields (kg/ha) for 2013 and 2014 in Stoneville, MS.

		2013		
Irrigation Initiation	**Non-Treated**	**Weekly**	**Threshold**	**Mean**
Non-Irrigated	**859±89**	**1,250±72**	**1,150±45**	**1,085±63 b**
Squaring	**1,186±193**	**1,837±94**	**1,675±94**	**1,568±111 a**
First Flower	**1,050±73**	**1,719±91**	**1,722±19**	**1,497±101 a**
Peak Flower	**1,089±125**	**1,723±177**	**1,621±174**	**1,472±118 a**
Mean	**1,047±65 b**	**1,634±79 a**	**1,537±74 a**	
		2014		
Irrigation	**Non-Treated**	**Weekly**	**Threshold**	**Mean**
Non-Irrigated	**1,558±147**	**1,994±131**	**1,941±125**	**1,831±91**
Squaring	**1,611±84**	**2,256±46**	**1,801±84**	**1,889±89**
First Flower	**1,598±57**	**2,104±45**	**1,869±86**	**1,857±71**
Peak Flower	**1,587±58**	**2,108±97**	**1,959±58**	**1,885±76**
Mean	**1,586±43 c**	**2,112±46 a**	**1,889±44 b**	

Means within a column or row followed by common letter are not significantly different at α=0.05.

may save money by not only reducing the number of irrigations, but also by reducing the number of insecticide applications. The current price to pump 2.54 centimeters per hectare of water is $8.23, and a single insecticide application averages $30 per hectare, eliminating one irrigation and one insecticide application on 250 hectares of cotton could save $12,500, all while not sustaining a significant yield penalty (Mississippi State University 2013). The longevity of the growing season in the mid-southern U.S. also needs to be considered as results may not be the same in areas with shorter growing environments, so more research is still needed in separate regions and environments. Nonetheless, using simple cultural control methods, such as the manipulation of irrigation, can reduce the input costs associated with cotton production in Mississippi.

ACKNOWLEDGEMENTS

Funding for this research was provided by Cotton Incorporated and the growers of Mississippi. This material is based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, Hatch Project under 223813, MIS-721140.

REFERENCES

Adams, B. A. Catchot, J. Gore, D. Cook, F. Musser, and D. Dodds. 2013. Impact of planting date ad varietal maturity on tarnished plant bug (Hemiptera: Miridae) in cotton. J. Econ. Entomol. 106(6): 2378-2383.

Burke, J. J., and M. Ulloa. 2017. Stress response of commercial cotton cultivars to reduced irrigation at flowering and maximization of yields under sub-optimal subsurface drip irrigation. J. Cotton Sci. 21: 229-241.

Catchot, A. L. 2013. Insect control guide for agronomic crops. Mississippi State University Extension Service. Mississippi State, MS.

Gore, J., A. Catchot, F. Musser, J. Greene, B. R. Leonard, D. R. Cook, G. L. Snodgrass, and R. Jackson. 2012. Development of a plant-based threshold for tarnished plant bug (Hemiptera: Miridae) in cotton. J. Econ. Entomol. 105(6): 2007-2014.

Janat, M. 2008. Response of cotton to irrigation methods and nitrogen fertilization: yield components, water-use efficiency, nitrogen uptake, and recovery. Communications in Soil Science and Plant Analysis. 39: 2282-2302.

Landivar, J. A., and J. H. Benedict. 1996. Monitoring system for the management of cotton growth and fruiting. Tex. Agric. Exp. Stn. Bull. B02. College Station, TX.

Layton, M. B. 2000. Biology and damage of the tarnished plant bug, *Lygus lineolaris,* in cotton. Southwest. Entomol. Suppl. No. 23: 7-19.

Littell, R. C., G. A. Milliken, W. W. Stroup, R. D. Wolfinger, and O. Schabenberger. 1996. SAS system for mixed models. SAS Institute, Cary, NC, p. 814.

Mississippi State University. 2013. Delta 2014 Planning Budgets, Department of Agricultural Economics Budget Report 2013–05, December, 2013. http://www.agecon.msstate.edu/whatwedo/budgets/docs/14/MSUDELTA14.pdf (accessed 11/28/2018).

Musser, F.R., J. Robbins, D. Cook, G. Studebaker, J. Greene, E. Burris, R. Bagwell, S. Stewart, A. Catchot and G. Lorenz. 2007. Comparison of direct and indirect sampling methods for tarnished plant bug (Hemiptera: Miridae) in flowering cotton. J. Econ. Entomol. 100: 1916-1923.

Musser, F. R., A. L. Catchot, S. D. Stewart, R. D. Bagwell, G. M. Lorenz, K. V. Tindall, G. E. Studebaker, B. R. Leonard, D. S. Akin, D. R. Cook, and C. A. Daves. 2009. Tarnished plant bug (Hemiptera: Miridae) thresholds and sampling comparisons for flowering cotton in the midsouthern United States. J. Econ. Entomol. 102: 1827-1836.

Perry, C. and E. Barnes. 2012. Cotton irrigation management for humid regions. Cotton Incorporated. Cary, NC.

Samples, C., D. Dodds, A. Catchot, J. Gore, J. Varco, and B. Golden. 2014. Evaluating the relationship between cotton (*Gossypium hirsutum L.*) crop management factors and tarnished plant bug (*Lygus lineolaris*) populations. M. S. Thesis, Mississippi State University, Starkville, MS.

Snodgrass, G. L. 1996. Glass-vial bioassay to estimate insecticide resistance in adult tarnished plant bugs (Heteroptera: Miridae). J. Econ. Entomol. 89: 1053-1059.

Snodgrass, G. L., J. Gore, C. A. Abel, and R. Jackson 2009. Acephate resistance in populations of the tarnished plant bug (Heteroptera: Miridae) from the Mississippi River Delta. J. Econ. Entomol. 102: 699-707.

Tugwell, P., S. C. Young, B. A. Dumas, and J. R. Phillips. 1976. Plant bugs in cotton: importance of infestation time, types of cotton injury, and significance of wild hosts near cotton. Arkansas Agricultural Experiment Station Report. Report Series 227. University of Arkansas, Fayetteville, AR.

USDA/NASS. 2012. Agricultural Census. https://quickstats.nass.usda.gov (accessed 21 March 2014).

Willers, J. L., M. R. Seal, and R. G. Luttrell. 1999. Remote sensing, line-intercept sampling for tarnished plant bugs (Heteroptera: Miridae) in mid-south cotton. J. Cotton Sci. 3: 160-170.

Willers, J. L., and D. C. Akins. 2000. Sampling for tarnished plant bug in cotton. Southwest. Entomol. Suppl. No. 23: 39-57.

Williams, M. R. 2014. Cotton insect losses. Proc Beltwide Cotton Conference, New Orleans, LA. 798-812.