1-1-2015

Impact Of Irrigation, Leaf Pubescence, and Week of Flowering on the Effect of Tarnished Plant Bug on Cotton Yields

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Impact of irrigation, leaf pubescence, and week of flowering on the effect of tarnished plant bug on cotton yields

By

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A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Master of Science
in Agricultural Life Science
in the Department of Biochemistry, Molecular Biology, Entomology and Plant Pathology

Mississippi State, Mississippi

May 2015

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Pages in Study: 59

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The tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), is the most important insect pest of cotton, *Gossypium hirsutum* (L.), in Mississippi. This research project was initiated to gain a better understanding of selected crop production factors that can improve tarnished plant bug integrated pest management. Results suggest that irrigation strategies and varietal pubescence can significantly influence tarnished plant bug management in cotton. Most notably, delaying irrigation for as long as possible and planting hairy varieties can minimize the impact of tarnished plant bug on cotton yields and reduce the number of insecticides needed to manage this pest. Additionally, these results show that tarnished plant bug management is most critical during the first four weeks of flowering. Results from these experiments will be used to improve the current integrated pest management program for tarnished plant bug in cotton and make cotton production more sustainable for Mississippi producers.

DEDICATION

I would first like to dedicate this research to my God and Savior. Without His grace and guidance, none of this would have happened. Next, I would like to dedicate this research to my parents Clint and Laura Wood, grandparents Alice Wood and C. E. Cotton, and the late W. Frank Wood and Carolyn Cotton. Their prayers, teaching and love throughout my life have molded me into who I am. I would also like to dedicate this research to Jimmy and Lisa Downs who have supported me and encouraged me greatly in the past few years. Most of all, I would like to dedicate this research to my wonderful wife Harrison. Your love, support, and encouragement has blessed me every day.

ACKNOWLEDGEMENTS

I would like to offer my deepest thanks and gratitude to all that have given so much time to make this research possible. Fist, my most sincere appreciation to my co-major advisors Dr. Jeff Gore and Dr. Angus Catchot. I am deeply grateful for their time, teaching and support given to me during the pursuit of this degree. They have taught and shaped me in ways that will help me throughout my career.

I would also like to thank all the members of my committee, Dr. Don Cook, Dr. Darrin Dodds, and Dr. Jason Krutz for their time and guidance. I am very grateful for the wisdom and support they have given to help me achieve my goal.

Lastly, I would like to thank all the summer workers and fellow graduate students Chris Dobbins and Bryan Olivi for all their help and support.

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CHAPTER I

INTRODUCTION

Cotton

Cotton (*Gossypium*) was introduced in Florida in 1556, and is a major economic crop in the Mississippi Delta (National Cotton Council 2012). The uses of cotton range from apparel, furniture, and household commodities to oil in animal and human food. In 2013, 4,131,980 hectares of cotton were planted in the United States and these hectares produced 12,275,000 bales (USDA NASS). There are four species of cotton cultivated; however, upland cotton, *Gossypium hirsutum* (L.), is the predominant species planted in Mississippi. Botanically, cotton is a perennial shrub that is grown as an annual row crop and has slow above ground development during the early growth stages.

Cotton undergoes five growth stages including: germination and emergence, seedling establishment, leaf area and canopy development, flowering and boll development, and maturation (Jenkins et al. 1990). A degree day model [((Maximum temp.+ Minimum temp.)/2) –15.55ºC or 60ºF] can be used to predict cotton growth stages based upon heat unit accumulation (Table 1.1) (Jenkins et al. 1990). Germination and radical appearance occurs three days after planting, and six days after planting seedling emergence occurs. Typically one day after emergence the cotyledons will unfold. Ten days after planting the roots will have grown to 15.2 to 30.5 centimeters in length. The first true leaf unfolds 14 days after planting after which time photosynthesis begins. Approximately 35 days after planting the first flower bud (square) will appear. The first white flower will emerge 55-65 days after planting and the beginning of pollination and sexual fertilization will occur. Full bloom, or peak flower, typically is reached 93 days after planting. It is during this time that boll and fiber development are at the highest level. At 110 days after planting the first boll should be opening.

Cotton has indeterminate growth, where vegetative growth will continue after the reproductive process has begun (Silvertooth et al. 1999). As such, cotton has a longer flowering period than most other crops and can flower in excess of eight weeks in Mississippi. The indeterminate growth habit also leaves the plant susceptible to pests for an extended period of time (Silvertooth et al. 1999). Once flowering has begun, cotton growth can be measured by counting nodes above white flower (NAWF). Nodes above white flower is determined by counting the number of main stem nodes above the highest first position white flower (Bourland et al. 1992). A first position flower can be defined as the uppermost fruiting branch that possesses a white flower at the first position from the main stem. Cotton is typically planted in Mississippi beginning in early April and will continue up into the end of May.

During the course of a season, numerous arthropod pests such as *Frankliniella occidentalis* (Pergande), *Tetranychus urticae* (Koch), *Acrosternum hilare* (Say), *Nezara viridula* (Linnaeus) and *Helicoverpa zea* (Boddie) infest cotton fields; however, the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), has become the most important insect pest in the Mid-South.

Tarnished Plant Bug

Biology and Ecology

Historically, tarnished plant bug control was achieved secondarily through broad spectrum insecticide applications targeting the boll weevil, *Anthonomus grandis grandis* (Boheman), and heliothine complex. However, now that 98.99% of cotton planted in Mississippi contains a dual gene Bt protein and the eradication of the boll weevil, the tarnished plant bug has become the most economically important pest of Mid-South cotton over the past decade (Musser et al. 2009, Williams 2012).

The tarnished plant bug is a true bug in the order Hemiptera, family Miridae. Females lay eggs inside the host plant's terminals or flower buds (Fleischer and Gaylor 1989). Ugine (2012) observed that females can lay 175 eggs in their lifetime at a rate of 10 eggs per day at 27°C. On average, it takes 7.62 days for a nymph to emerge from the egg (Ridgway and Gyrisco 1960). The tarnished plant bug is a paurometabulous insect and undergoes three life stages including: egg, nymph, and adult. The tarnished plant bug has five nymphal instars before molting into an adult. Nymphs take an average of 4.77 days, 3.08 days, 3.28 days, 3.33 days, and 5.22 days to complete the first, second, third, fourth, and fifth instars, respectively (Ridgway and Gyrisco 1960). At 30ºC, the generation time for a population was 21 days and the doubling time was 3.7 days (Ugine 2012). A tarnished plant bug takes 30 to 40 days to complete development and can have several generations per year in Mississippi.

Tarnished plant bugs have a broad host range, with over 385 documented host plants (Young 1986). Host plants range from wild plants and weeds to fruits, vegetables, and agronomic crops. Tarnished plant bug populations will typically pass one to two generations on early season wild hosts (Fleischer and Gaylor 1987) such as *Lolium* ssp., *Vicia* ssp., *Conyza sumatrensis* (Retz.) and *Amaranthus* ssp. As these hosts begin to senesce in late spring, tarnished plant bug populations move into agronomic crops (Layton 1995). This generally coincides with the flowering stages of corn and early planted soybeans and tarnished plant bugs will use these crops as reproductive hosts during the early summer (Snodgrass et al. 2009). When these agronomic hosts begin to senesce, which typically coincides with cotton beginning to bloom, large populations of tarnished plant bug will migrate into cotton fields. *Lygus lineolaris* comprises 94% of the collected bugs in flowering cotton within the Mid-South region (Musser et al. 2007). Tarnished plant bugs prefer to feed on the reproductive structures of plants. They will move from plant to plant depending on the phenological stage of the specific host (Snodgrass et al. 1984). The intensity and extent of populations moving into cotton will vary between years, but appears to be correlated with the amount of alternative hosts available and the presence of reproductive structures (Layton 1995).

Feeding and Damage

As previously stated, tarnished plant bug nymphs and adults feed on the reproductive structures of the plant, such as flower buds, flowers, or fruits. They feed by injecting digestive salivary enzymes into plant tissue that allows for ingestion of nutrients (Layton 1995). Damage occurs to the plant in two ways. Mechanical damage to plant cells occurs at the feeding site; however, the disruptive effects the enzymes have on plant tissues is likely more important (Layton 1995). Tarnished plant bugs prefer to feed on small squares, and this feeding typically results in the abscission of the square within a few days. Feeding on larger squares will occur; however, this usually does not cause the square to abscise. A single tarnished plant bug can cause 0.6 to 2.1 squares to abscise per a day due to feeding (Gutierrez et al. 1977, Mauney and Henneberry 1979, Wilson 1984). Tarnished plant bugs will feed in cotton during both the squaring period and the flowering period and can inflict significant yield loss during both growth stages. Severe early square loss due to tarnished plant bug populations can cause altered fruiting patterns and delayed maturity. Tarnished plant bug feeding symptoms can be seen as yellow staining on the square or in the bloom, brown or black anthers in the flower, and the presence of black necrotic spots on the outside of bolls. There is little to no effect on yield when less than 30% of anthers are damaged from tarnished plant bug feeding (Pack and Tugwell 1976); however, higher rates of damaged anthers can lead to malformed or aborted bolls (Layton 2000). Feeding on bolls can cause damage up to eight days after anthesis (Greene et al. 1999), yet lint yield is safe after the boll has accumulated 250-300 heat units after anthesis (Horn et al. 1999).

Sampling Methods

Numerous sampling methods are used to determine tarnished plant bug densities. During the squaring period, a 38 cm diameter sweep net is used to sweep back and forth across a row to dislodge insects which fall into the net. The recommended sweep net threshold is eight tarnished plant bugs per 100 sweeps (Catchot 2013). Once cotton is flowering, use of a 0.76m black drop cloth is placed between two adjacent rows and all cotton plants within the width are shaken vigorously over the cloth and the number of insects that have fallen onto the cloth are counted. Sweep nets are better for collecting adults, while drop cloths are better for determining number of nymphs. The recommended threshold for a drop cloth sample is three tarnished plant bugs per 1.83m or three tarnished plant bugs per one drop cloth sample (Catchot 2013). Determining square retention in a field is another method that can be utilized to determine damage sustained due to tarnished plant bug feeding. This method is performed by determining the percentage of first position squares retained on the plant in the top three nodes. Mississippi State University recommends that square retention not fall below 70% during the squaring period and early flowering period. Visually scouting for tarnished plant bugs can also be done and the recommended threshold for this method is ten tarnished plant bugs per 100 plants (Catchot 2013).

Management Practices

Previous research indicates that foliar applications to control tarnished plant bug can be significantly reduced by utilizing an early planting date and an early season variety (Adams et al. 2012). Also, applying a selective herbicide during the spring to control host plants, such as *Lamium amplexicaule* (L.) and *Capsella bursa-pastoris* (L.), has a significant economic impact later in the growing season by lowering the cost of control for the tarnished plant bug (Gore et al. 2010). Greater tarnished plant bug densities and subsequent crop injury is usually seen in field edges, especially when these edges are adjacent to corn. To aid in reducing this edge effect, cotton should be planted in large contiguous blocks and minimize planting to next other crops that tarnished plant bugs use extensively, such as corn (Gore et al. 2010). Also, there are several natural enemies that can aid in reducing tarnished plant bug populations. *Anaphes iole*, a small parasitic wasp that is widespread in North America, which pierces tarnished plant bug eggs and lays its own egg inside, thus killing the plant bug eggs. Several other beneficial insects, such as big eyed bugs, *Geocoris* spp., green lacewings, *Chrysoperla rufilabris*, and minute pirate bugs, *Orius insidiosus*, will prey on plant bugs.

Justification for Research

The cost of control and significant yield loss from the tarnished plant bug has driven many growers away from planting cotton in the Mid-South. Over the past few years, an average of $277 per hectare was spent on tarnished plant bug control. These costs can be attributed to insecticide resistance and high population numbers that require numerous insecticide applications to keep the pest suppressed. Nationally, *Lygus* was found in 37.85% of cotton hectares and caused 0.778% of cotton losses (Williams 2013). In 2013, 76,497 bales were lost in Mississippi due to damage from the tarnished plant bug (Williams 2014). This translates into $25,817,737 that was not put back into the economy of Mississippi. Given heavy yield losses and very high inputs cost associated with cotton new cultural practices and methods are needed to make cotton a profitable and appealing crop to plant.

Objective 1- Determine the critical time period of blooming cotton when yield loss is highest due to tarnished plant bug damage.

Objective 2- Determine if irrigation has an effect on the attractiveness and susceptibility of cotton to the tarnished plant bug.

Objective 3- Determine the impact of smooth leaf, semi-smooth leaf, and hairy leaf varieties on tarnished plant bug population development, damage, and yield loss in cotton.

Table 1.1 Cotton growth and heat unit accumulation requirements based upon growth stage.

Growth Period	**Heat Units Needed**
Planting to Emergence	50-60
Each Successive Node up Main Stem	45-60
Emergence to First Square	425-475
Square to White Flower	300-350
Planting to First Flower	775-850
White Flower to Open Boll	850
Planting to Harvest	2,600

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CHAPTER II

IMPACT OF IRRIGATION TIMING ON TARNISHED PLANT BUG POPULATIONS AND YIELD OF COTTON

Introduction

The tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), is the most important insect pest of cotton in Mississippi and surrounding states (Musser et al. 2007, Gore et al. 2012). Insecticide resistance has become prevalent in tarnished plant bug populations in the Mid-South (Snodgrass et al. 2009, Snodgrass 1996), and 5-7 applications are generally needed to prevent economic losses (Williams 2014). In general, the risk of yield losses from tarnished plant bug are lower during the pre-bloom period compared to 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.

Several agronomic practices have been shown to reduce tarnished plant bug populations in cotton or reduce 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. Planting cotton prior to 15-May can eliminate one to two insecticide applications compared to later planting dates (Adams et al. 2013). Yield losses from tarnished plant bug averaged 26.0% for an early maturing variety compared to 44.8% for a late maturing variety. Fertilization also can impact tarnished plant bug management in cotton. Fewer insecticide applications were needed where 89.82 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 75% of the 162,000 hectares of cotton planted in Mississippi are 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. If cotton becomes severely drought stressed a reduction in photosynthesis may occur as well as fruit abscission and yield loss. Drought stress and insect pests such as the tarnished plant bug, can result in significant yield loss; however, the interaction between these factors has not been studied. Demands for water are greatest during the reproductive and early boll maturation periods (Janat 2008) (Table 2.1), which is when tarnished plant bugs tend to be most prevalent.

In addition to the interaction between drought stress and injury from tarnished plant bug, little is known about the attractiveness of cotton to tarnished plant bug under different irrigation scenarios. It is hypothesized that tarnished plant bugs will not be as attracted to drought stressed cotton during the squaring period which can result in reduced 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 in order to develop more cost efficient production practices. Therefore, the purpose 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 09-May 2014 at 113, 668 seeds/ha. 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 in which 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 row. Plots were arranged across the field to allow furrow irrigation to easily be controlled. 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 and these sensors measure soil water tension by reading the amount of water absorbed through a granular matrix. When soil moisture readings from the three sensors averaged over 100 centibars, indicating a depravation in adequate soil moisture, an irrigation was initiated. The sensors were set in the fourth row of the middle tier of each replication and were monitored weekly. Irrigation events were completed when the soil was adequately saturated based on soil moisture sensors. The sub-plot factor was tarnished plant bug management for each irrigation timing. Tarnished plant bug management included sprayed weekly, sprayed at threshold, and a non-treated control.

Rows 4-7 of all plots were sampled twice per week to determine tarnished plant bug adult and nymph densities. During the pre-flowering stages, 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). Threshold during the squaring period were 8 tarnished plant bugs per 100 row sweeps and then 3 tarnished plant bugs per 1.52-m of row was utilized as the threshold once flowering began. Insecticide mixtures that provide maximum control of tarnished plant bug were used for all spray treatments. Insecticides utilized were Orthene 90S (Valent Corporation, Walnut Creek, CA), Transform WG (DOW AgroSciences, Indianapolis, IN), Centric 40 WG (Syngenta Crop Protection, Greensboro, NC), and Orthene 90S tank mixed with Bifenthrin. 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 these treatments until irrigations were initiated. Final plant heights and nodes above white flower counts were taken at week six of the flowering period. All sampling methods were terminated at the 6th week of flowering due to cotton reaching physiological maturity. At the end of the season, rows 2-3 of every plot were harvested mechanically with a picker modified for small plot harvest and seedcotton weights were recorded. All data were analyzed with Analysis of Variance, PROC MIXED (Littell et al. 1996). With regard to 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 $\alpha=0.05$.

Results

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 per 3.04-m. The non-treated control had more tarnished plant bugs than all other treatments except at squaring (Fig. 2.1). The weekly spray treatment had the fewest number of tarnished plant bugs at first flower and at peak flower. At 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. 2.1).

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 non-treated control spray treatment for both irrigation timings had significantly more nymphs than the weekly and threshold spray treatments (Fig. 2.2). 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. 2.2).

Within the threshold spray treatment, irrigation had a significant effect on the number of times tarnished plant bug populations exceeded threshold ($F=7.63$; $df=3, 21$; $P<0.01$). When irrigations were initiated at squaring, tarnished plant bug populations exceeded threshold significantly more often than all other irrigation treatments (Table 2.3).

For tarnished plant bug numbers with all irrigation treatments included, there was a significant interaction between irrigation timings and spray treatment ($F=2.96$; $df=6, 178$; $P<0.01$). In general, the non-treated control had more tarnished plant bug nymphs than the threshold spray treatment and the weekly spray treatment for all irrigation timings (Table 2.4). No differences were observed among the irrigation timings within the non-treated control or weekly spray treatments. Within the threshold spray treatment, irrigations initiated at squaring had significantly more tarnished plant bugs than where irrigations were initiated at first flower, peak flower and the non-irrigated control (Table 2.4).

There was no significant interaction between irrigation timing and spray treatment for final cotton heights (F=0.51; df=6, 56; P=0.79). Spray treatment did not have a significant effect on cotton height (F=1.45; df=2, 56; P=0.24), but irrigation timings did have a significant effect on plant height (F=3.70; df=3, 21; P=0.02). The squaring irrigation timing was significantly taller than the non-irrigated treatment (Fig. 2.3). Both the peak flower irrigation timing (117.72±5.08 cm) and the first flower irrigation timing (115.69±5.08 cm) were not significantly different from either of the other treatments.

There was no significant interaction between irrigation timing and spray treatment on nodes above white flower (F=1.11; df=6, 40; P=0.37). Spray treatment did have a significant effect on 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 (2.93±0.32) (Fig. 2.4). Cotton in the threshold treatment had significantly more nodes above white flower than the weekly spray treatment (2.59±0.32) (Fig. 2.4). Irrigation timing also had a significant effect on 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 similar nodes above white flower counts to cotton in which irrigation was initiated at all other timings (Fig. 2.5).

There was a significant year by spray treatment interaction (F=3.88; df=2, 48; P=0.02) and a significant year by irrigation timing interaction (F=4.31; df=3, 18; P<0.01) for lint yield. Therefore yields were analyzed by year. Rainfall events were more frequent in 2014 compared to 2013 (Table 2.2). A total of 31 cm of rain occurred from June to mid-August in 2014 compared to only 15 cm during that same time frame in 2013 (http://www.deltaweather.msstate.edu/).

There was no significant 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 2.4). 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 significantly greater yields than cotton that was non-irrigated (1,085±41 kg/ha) in 2013. Spray treatment also had a significant effect on lint yield (F=81.86; df=2, 24; P<0.01) (Table 2.5). 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 a significant 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 2.5). Cotton yields were significantly greater when sprayed weekly compared to when sprays were based on threshold as well as non-treated control. Yields were significantly greater when sprayed based on threshold compared to the non-treated control.

Discussion

Differences in rainfall between 2013 and 2014 impacted the results of this experiment. The summer of 2013 was characterized by hot, dry conditions throughout the summer. Yet, the summer of 2014 saw significant amounts of rainfall and cooler temperatures throughout June, July, and early August. Fewer irrigations were needed during the summer of 2014 compared to the summer of 2013. The effect of environmental conditions between the two years can be observed in lint yields between the irrigation treatments. 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; however in 2014, the squaring treatment received two irrigation events, first flower treatment received one, and the peak flower received no irrigation events.

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, to be conducted (Perry et al. 2012). Also, growers believe water stress early in the growing season will boost root development (Perry et al. 2012). Water needs are low during the early growing season but demand increases drastically during the reproductive stages (Table 2.1). The majority of growers in the Mid-South initiate irrigations when squaring begins. However, initiating irrigation during the squaring period caused tarnished plant bugs to exceed the threshold significantly more times than if irrigations had been postponed until later in the growing season. Irrigation initiated at squaring also resulted in significantly taller cotton compared to when irrigation was initiated later in the growing season. This potentially could have affected sampling efficiency or the level of control that was achieved with insecticide applications. There does seem 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. Several studies demonstrated damage and yield loss from tarnished plant bug population in squaring cotton (Layton 1995, Tugwell et al. 1976). Therefore, making cotton more attractive during this time can compound damage observed from tarnished plant bug.

Nodes above white flower data indicate that greater tarnished plant bug control minimized delays in maturity and that when irrigations were postponed no delay in maturity occurred. Also, when irrigations were postponed until the point of peak flower, no significant decrease in yield was observed. Based on these data, a grower could make fewer insecticide applications without a penalty in yield by postponing irrigations until peak flower. 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. However, lush, freshly irrigated plants were nearby to dry non-irrigated plants, which 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 initiating irrigation at this time resulted in similar yields compared to when irrigation was initiated at squaring. A grower may save money by not only reducing the number of irrigations, but also by reducing the number of insecticide applications. Given the current price to pump 2.54 centimeters per hectare of water is $8.23, and a single insecticide application averages $30 a hectare, skipping one irrigation and one insecticide application on 250 hectares of cotton could save $12,500, all while not suffering significant yield losses. The longevity of the growing season in the Mid-South 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. However, using simple cultural control methods, such as the manipulation of irrigation, can reduce the input costs associated with cotton production in Mississippi.

Table 2.1 Water use during cotton growth stages and the percentage lifespan cotton plants remain in the specific growth stage.

Growth Stage	Percent of Life Cycle	Percent Water Used
Planting-Fourth Leaf	34%	22%
Fourth Leaf-First Square	20%	26%
First Square-Peak Flower	35%	53%

Table 2.2 Rainfall and heat unit accumulation by month and year for 2013 and 2014 at Stoveville, MS

Month and Year	**Precipitation (cm)**	**Heat Units**
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**

(http://www.deltaweather.msstate.edu/).

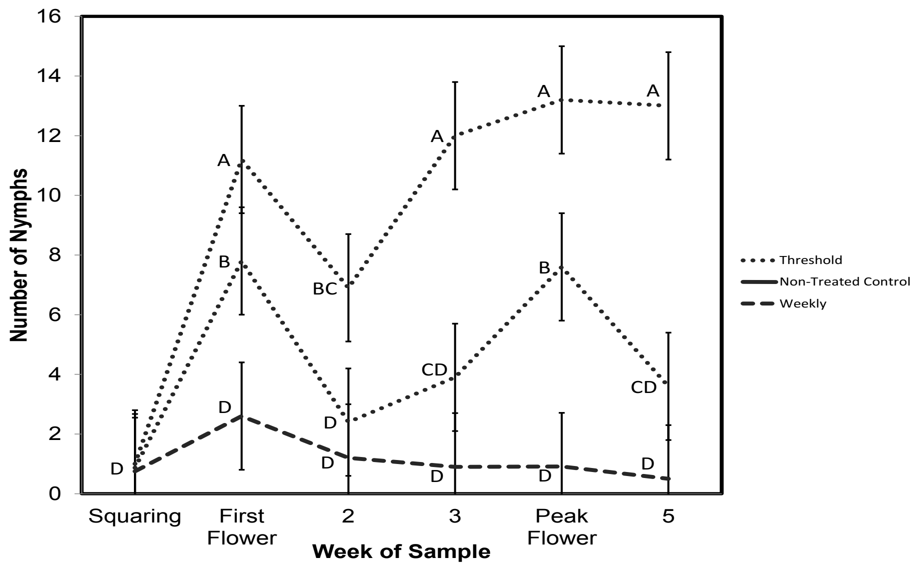

Figure 2.1 Effect of spray treatment regime and week of sampling on mean (SEM) number of tarnished plant bugs per 3.04-m of row by week across 2013 and 2014 in Stoneville, MS.

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

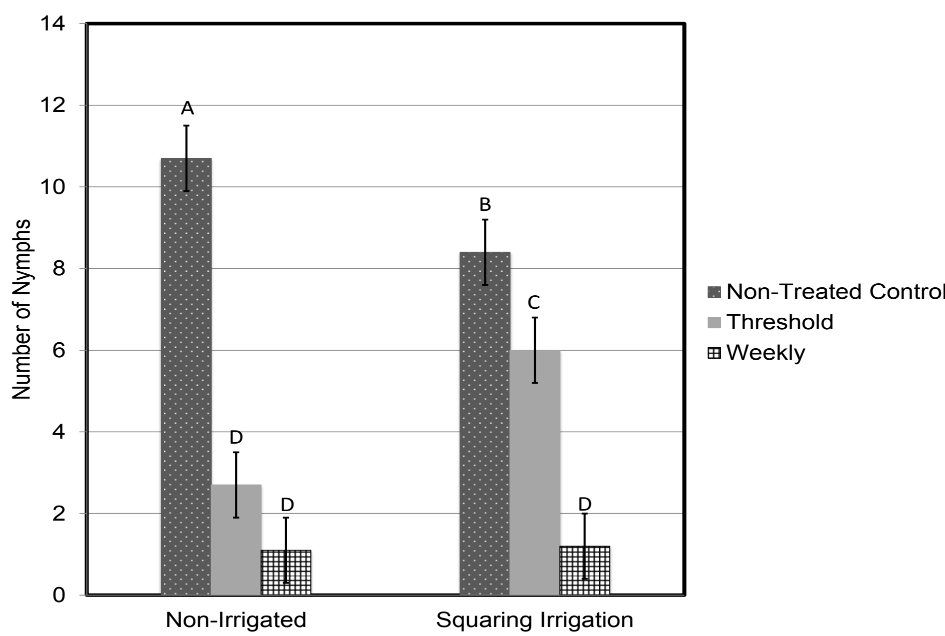

Figure 2.2 Impact of irrigation treatment and spray treatment regime on mean number of tarnished plant bugs per 3.04-m of row across 2013 and 2014 in Stoneville, MS.

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

Table 2.3 Mean ±SEM number of times that irrigation timing plots exceeded the recommended threshold in the threshold spray treatment averaged for 2013 and 2014.

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

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

Table 2.4 Mean±SEM number of tarnished plant bugs per 3.04-m of row by irrigation timing and spray treatment averaged across weeks 5 and 6 of the flowering period for 2013 and 2014 in Stoneville, MS.

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

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

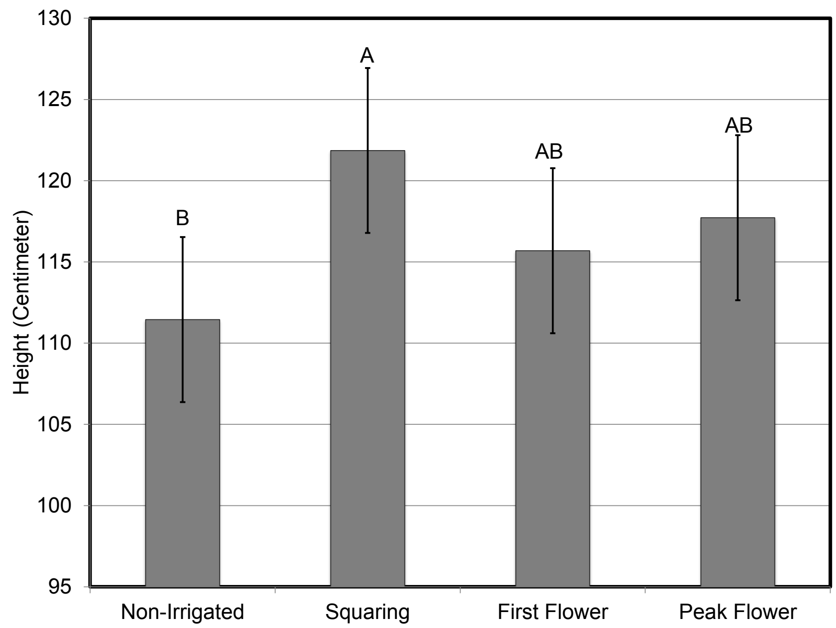

Figure 2.3 Impact of irrigation initiation timings on final mean (±SEM) plant heights averaged across 2013 and 2014 in Stoneville, MS.

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

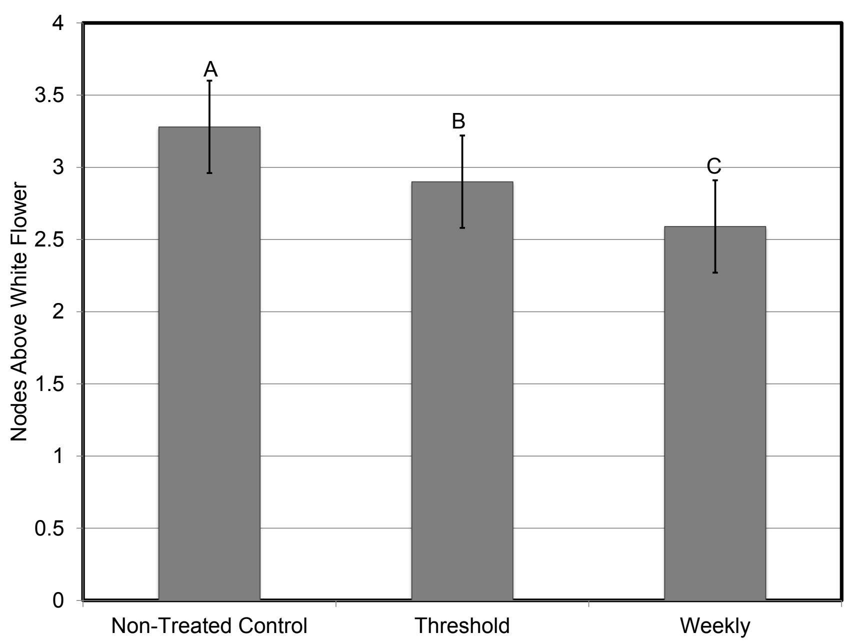

Figure 2.4 Impact of tarnished plant bug spray regime on mean (SEM) nodes above white flower counts averaged across 2013 and 2014 in Stoneville, MS.

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

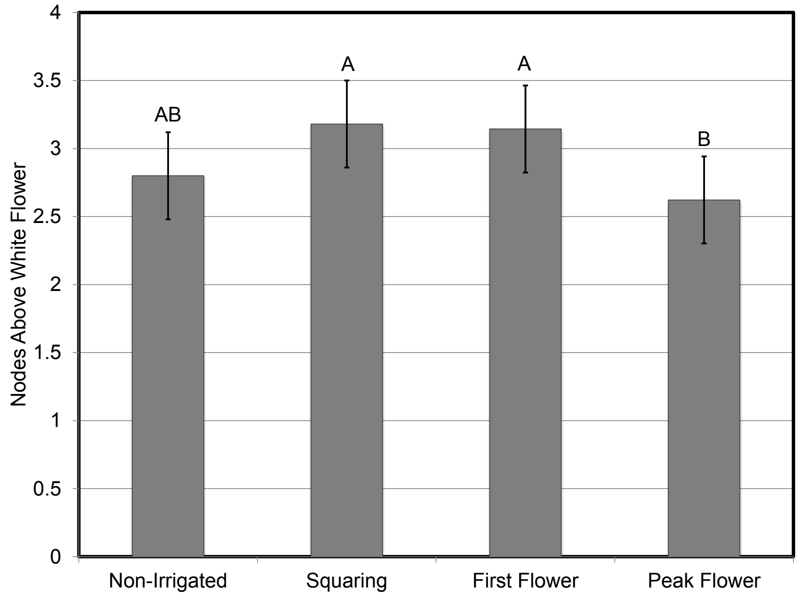

Figure 2.5 Impact of irrigation timing on mean (SEM) nodes above white flower counts averaged across 2013 and 2014 in Stoneville, MS.

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

Table 2.5 Impact of irrigation timing and insecticide spray strategy on mean±SEM lint yields in kg/ha for 2013 and 2014 in Stoneville, MS.

		2013		
Irrigation	**Non-Treated**	**Weekly**	**Threshold**	**Mean**
Non-Irrigated	859±89	1,250±72	1,150±45	**1,085b±63**
Squaring	1,186±193	1,837±94	1,675±94	**1,568a±111**
First Flower	1,050±73	1,719±91	1,722±19	**1,497a±101**
Peak Flower	1,089±125	1,723±177	1,621±174	**1,472a±118**
Mean	**1,047b±65**	**1,634a±79**	**1,537a±74**	
		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	**1,586c±43**	**2,112a±46**	**1,889b±44**	

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

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CHAPTER III

EFFECT OF LEAF PUBESCENCE ON TARNISHED PLANT BUG ABILITY TO CAUSE DAMAGE AND YIELD LOSS IN MID-SOUTH COTTON

Introduction

Pubescence acts as an important non-preference trait in cotton, *Gossypium hirsutum* L., against piercing-sucking insects. Phenotypes of cotton can be described as smooth (glabrous), hirsute (moderate pubescence), or pilose (dense pubescence). An extreme state of pubescence is typically referred to as velvet hairiness. Pubescence refers to the presence of trichomes, which are unicellular outgrowths from the epidermis of leaves (Nawab et al. 2011). The degree of pubescence or trichome density on the leaves of cotton is related to varying degrees of resistance/susceptibility to various insect pests (Meagher et al. 1997).

With multiple cultivars on the market, it would be economically feasible for a grower to select a cultivar if there is added benefit of protection due to level of pubescence that is expressed. Varieties have previously been selected for nectariless traits, which provide some resistance against tarnished plant bugs (Platt et al. 1999). If leaf pubescence can provide some resistance to tarnished plant bug damage, then that could be potentially employed as a cultural control tactic. Research has shown that infestation by aphid species can be negatively impacted by trichome density on leaves in other crops (Dixon 1998). This may be due to effects on mobility and the ability to feed.

However, some pests, such as the cotton aphid, *Aphis gossypii* (Glover), and whiteflies, *Bemisia tabaci* (Gennadius), prefer densely pubescent leaves (Zarpas et al. 2006, Butler et al. 1986). There is a direct relationship between performance of the cotton aphid and trichome density of the abaxial surface of cotton leaves (Zarpas 2006). Research has also shown that some mirid pests of cotton tend to prefer densely pubescent leaves with respect to oviposition (Benedict et al. 1983). Dense pubescence can confer some level of tarnished plant bug resistance; however, some glabrous varieties possessed similar levels of resistance (Bourland et al. 2014). Results suggest different mechanisms of resistance and as a result, little is still known about the impact leaf pubescence has on tarnished plant bug. Variety selection would be an inexpensive tool for a grower if it meant reducing the amount of damage sustained from tarnished plant bugs or decreasing the number of insecticide applications made targeting this pest. The purpose of this study was to determine if leaf pubescence has an effect on tarnished plant bug populations in cotton.

Materials and Methods

An experiment was conducted at the Delta Research and Extension Center in Stoneville, MS in 2013 and 2014 to determine the impact of leaf pubescence on tarnished plant bug populations. Treatments were arranged in a randomized complete block design with six replications. Treatments consisted of a smooth leaf variety (DP 1050 B2RF), semi-smooth leaf variety (PHY 499 WRF), and a hairy leaf variety (ST 5288 B2F). To determine which varieties to use, a total of eight varieties were planted in a greenhouse on 29-January 2013. Two leaves from the upper three nodes on five plants were collected from each variety. A threadcounter lens with 10X magnification was used to count the total number of trichomes per 6.45 cm^2 area of leaf surface. From these trichome counts, the three varieties were chosen to represent a range in trichome densities. All cotton varieties were planted on 21-May 2013 and 21-May 2014 at 113,668 seeds/ha. Plots consisted of four 1.01 m wide rows that were 15.2 m long. Once flowering began, tarnished plant bug densities were determined by taking two drop cloth samples per plot with a 0.76 m black drop cloth in the center two rows of each plot on a weekly basis. Square retention and nodes above white flower counts were also collected once a week using the center two rows of each plot. Square retention was monitored by determining the number of abscised first position squares in the upper three nodes on 16 plants per plot. 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 plots were irrigated on a regular schedule. No insecticide applications were made to the trial at any point during the growing season. At the end of the season, the center two rows of each plot were harvested using a cotton picker modified for small plot research and seedcotton weight was recorded. All sampling and yield data were subjected to analysis of variance (PROC MIXED Littell et al. 1996). Tarnished plant bug densities and square retention were both separately analyzed by year due to differing numbers of samples between years. For tarnished plant bug densities, treatment (variety) was considered a fixed effect in the model and sampling date was used as a repeated measure. Replication nested within year was considered random and served as the error term and residual error for treatment. For square retention, treatment and sample date were considered as fixed effects in the model. The replication by sample date interaction was considered random and served as the error term and residual error for treatment. Degrees of freedom were estimated using the Kenward-Roger method. Means were separated using the LSMEANS statement. Differences were considered significant for $\alpha=0.05$.

Results

There were significant differences in trichome densities among the three varieties ($F=457.14$; $df=3, 357$; $P<0.01$) (Fig. 3.1). The hairy variety (307±6) had the greatest density of trichomes, followed by the semi-smooth variety (140±6) which had significantly fewer trichomes per square inch than the hairy variety. The smooth leaf variety (56±6) had significantly fewer trichomes than either of the other varieties.

Mean number of nymphs per 3.04-m were analyzed by year because more samples were taken in 2014 than 2013. In 2013, variety had a significant effect on tarnished plant bug numbers ($F=4.55$; $df=2, 51$; $P<0.01$). The hairy variety (17.1±1.6) had significantly greater infestation of nymphs than the smooth variety (9.6±1.6) in 2013 (Table 3.1). The semi-smooth variety (13.9±1.6) had a similar infestation of tarnished plant bug nymphs as both the hairy and smooth varieties. In 2014, there was no significant effect of treatment on number of tarnished plant bugs per 3.04-m of row ($F=1.01$; $df=2, 69$; $P=0.36$).

Square retention was analyzed by year due to more samples being taken in 2013 than 2014. In 2013, there was a significant interaction between treatment and sample date ($F=4.52$; $df=10, 88.6$; $P<0.01$) for mean square retention (Table 3.2). In general, square retention remained relatively high in the hairy variety. In contrast, square retention in the smooth variety started off high early in the year and declined significantly as the season progressed. Similarly, square retention was high in the semi-smooth variety early in the year, but significantly declined during weeks two and three of flowering. However, the reduction in square retention in the semi-smooth variety was not as great as that in the smooth variety late in the flowering period.

In 2014, there was no significant interaction between variety and sample date (F=0.37; df=6, 54; P=0.89). Variety had a significant effect (F=18.01; df=2, 54; P<0.01) on square retention (Table 3.2). The hairy variety (79.6±2.5) and the semi-smooth variety (76.1±2.5) had significantly greater square retention than the smooth variety (59.9±2.5). There also was a significant effect of sample date (F=10.06; df=3, 54; P<0.01) on square retention. Significantly greater square retention was present at the first week of flowering (83.1±2.7) compared to the second (67.9±2.7) and fourth weeks of flowering (63.1±2.7). Square retention at the third week flowering (73.3±2.7) was not significantly different than square retention at any week of sampling.

Variety did not have a significant effect on average node above white flower counts in 2013 (F=0.19; df=2, 45; P=0.82) or 2014 (F=1.61; df=2, 42; P=0.21). These results show that variety did not impact node above white flower counts (Data not shown).

There was a significant effect of variety on mean lint yield (F=96.97; df=2, 22; P<0.01). The hairy variety (1708.97±23.8 kg/ha) yielded significantly greater than all other varieties. The semi-smooth variety (1330.42±23.8 kg/ha) yielded significantly less than the hairy variety but significantly more than the smooth variety (918.24±23.8 kg/ha).

Discussion

In 2013, drop cloth samples were not taken prior to flowering; however, square retention counts were collected. By the time drop cloth samples were initiated, plant bugs had already caused damage which is evidenced by square retention during weeks three and four (coincides with when drop cloth samples began). In 2014, drop cloth samples were collected earlier in the season when tarnished plant bug numbers were still low. The differences between sample timing could explain the significant differences with regards to tarnished plant bugs within each year. The hairy variety had significantly more tarnished plant bug nymphs per 3.04-m of row in 2013; however, it retained a significantly higher percentage of squares and yielded significantly more than the other two varieties. In 2014, there were no differences in tarnished plant bug densities among varieties; however, square retention followed a similar trend as it did in 2013. In 2014, variety had no significant effect on tarnished plant bug numbers, which may suggest there is preference of selection in terms of pubescence. Significant differences appeared for variety in 2013 when tarnished plant bug populations shifted out of smooth leaf variety plots into the other two varieties. The smooth variety had been heavily damaged and had little fruit left for tarnished plant bugs to feed on. It seems that there is a correlation between leaf pubescence and tarnished plant bug feeding. The hairy variety had over three times the recommended threshold of tarnished plant bugs, yet still yielded significantly greater than the other two varieties. It is hypothesized that the trichomes interfere with tarnished plant bug feeding and they do not cause as much injury in the hairy leaf variety as they do in the smooth variety. Research has shown that pests, such as *Amrasca devastans* (Distant), are negatively affected by leaf pubescence (Murugesan et al. 2010). Murugesan et al. (2010) showed that oviposition and feeding damage were lower in varieties possessing densely pubescent leaves. However, more research is still needed to determine the full extent of what is causing the ability of the hairy leaf variety to possess high populations of tarnished plant bugs, yet still retain significantly more squares and yield significantly greater than the other varieties. Although the hairy variety yielded the greatest and retained more squares, there could be a trade off at time of harvest due to leaf trash. Negative impact from hairy leaf varieties in terms of deducts due to leaf trash commonly occur. Also, research has shown that lepidopteran pests, such as *Helicoverpa zea* (Boddie), prefer to oviposit onto densely pubescent leaves (Chatzigeorgiou et al. 2010, Javed et al. 2009). The potential for an insecticide application targeting lepidopteran pests could occur when planting a hairy leaf variety. However, it could be beneficial for a grower to plant a semi-smooth leaf variety which still has an impact on tarnished plant bug populations but could have less negative effects at the gin or when dealing with lepidopteran pests. More research needs to be conducted to determine if this is the best option available. Additionally, more research is needed to gain a better understanding about how leaf pubescence impacts tarnished plant bug injury in cotton.

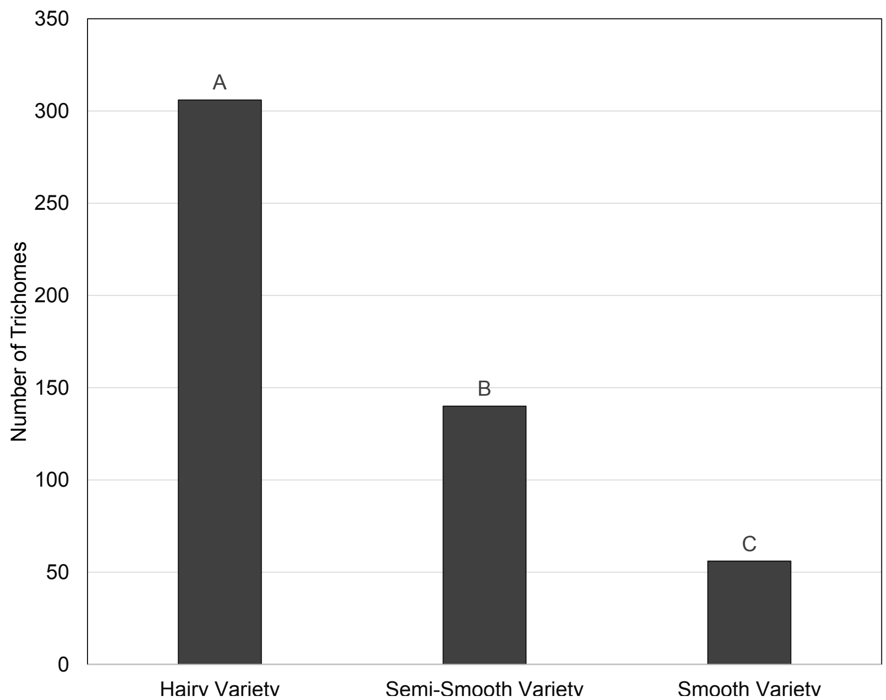

Figure 3.1 Mean number of trichomes per 6.45cm² by variety averaged for 2013 and 2014.

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

Table 3.1 Mean ± SEM number of tarnished plant bugs per 3.04-m of row for 2013 and 2014 by variety and week in Stoneville, MS.

2013	First Flower	2 WOF[a]	3WOF	Mean
Hairy	12.3±1.4	18.6±3.4	20.3±3.9	**17.1A±1.9**
Smooth	5.8±0.9	13±3.1	10±2.6	**9.6B±1.5**
Semi-Smooth	7.3±0.9	19.3±3.9	15±2.4	**13.8AB±1.9**
Mean	**8.5±1.4**	**17±3.4**	**15.1±3.7**	

2014	Squaring	First Flower	2 WOF	3WOF	Mean
Hairy	0.6±0.5	7.6±2.6	16.5±3.6	8.3±1.6	**8.2±1.6**
Smooth	0.8±0.5	6.1±1.3	13.5±3.2	5.5±1.2	**6.5±1.3**
Semi-Smooth	1±0.4	8.3±1.9	20.6±4.4	9±1.8	**9.7±1.9**
Mean	**0.7±0.5**	**7.6±2.6**	**16.5±3.6**	**7.6±1.6**	

Means in a column followed by a common uppercase letter are not significantly different at α=0.05.
[a]WOF=Week of Flowering

Table 3.2 Mean (SEM) square retention for 2013 and 2014 by variety and week sample was conducted in Stoneville, MS.

2013	Squaring	First Flower	2WOF[a]	3WOF	4WOF	5WOF	Mean
Hairy	97.3a±1.6	87.3a-d±1.8	78.6a-e±4.4	91.3abc±2.3	88a-d±0.7	90.6abc±1.1	**88.8±1.3**
Smooth	96ab±1.2	77.6b-e±3.5	60.6efg±4.6	56.6fg±3.7	51g±8.4	56fg±6.3	**66.3±3.3**
Semi-Smooth	96.6a±1.8	85.6a-d±4.1	70def±3.5	76.6cde±3.7	79.3a-e±2.9	81.3a-d±1.7	**81.6±1.8**
Mean	**96.6±1.6**	**83.5±1.8**	**69.7±4.4**	**74.8±2.3**	**72.7±0.7**	**76±0.7**	

2014	First Flower	2WOF	3WOF	4WOF	Mean
Hairy	91±2.4	72.6±3.6	83.5±2.1	72.3±2.5	**79.6A±3.7**
Smooth	72.6±6.9	59.3±5.9	58.5±12.1	49±3.9	**59.8B±3.7**
Semi-Smooth	85.6±3.9	71.6±4.2	78±5.3	68±2.8	**76.1A±2.4**
Mean	**83.1a±2.4**	**67.8b±3.6**	**73.3ab±2.1**	**63.1b±2.5**	

Means within a column separated by common uppercase letter or within a row followed by a common lowercase letter are not significantly different at α=0.05
[a]WOF=Week of Flowering

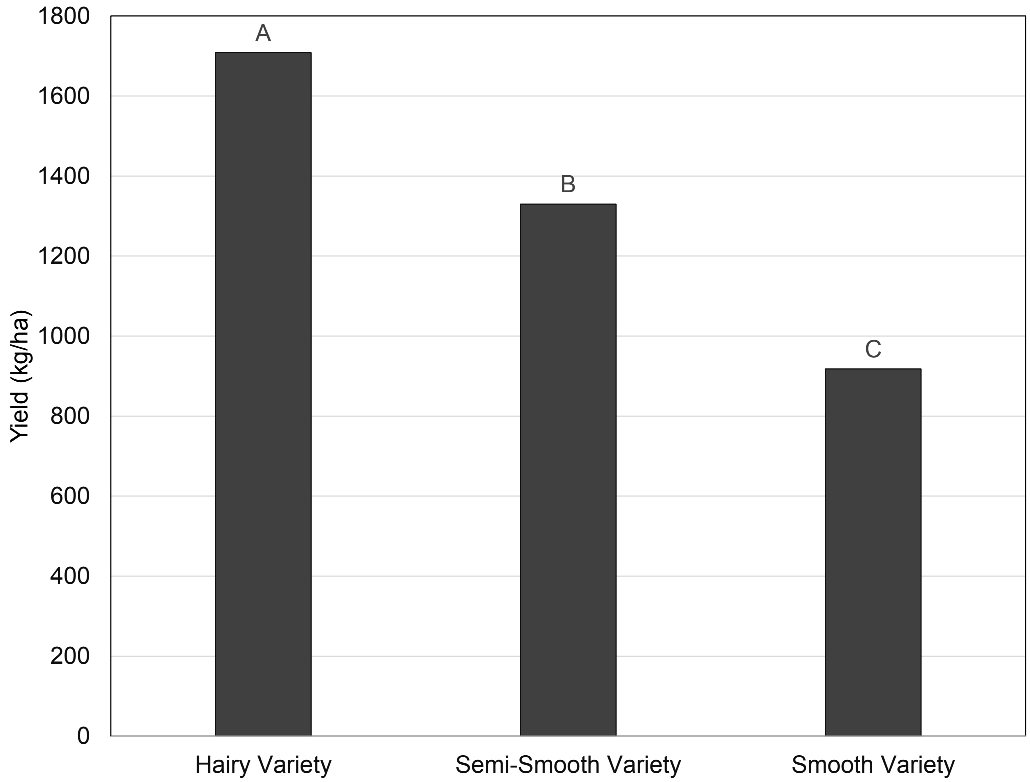

Figure 3.2 Mean (SEM) lint yield averaged for hairy, semi-smooth and smooth cotton varieties during 2013 and 2014 in Stoneville, MS.

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

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CHAPTER IV

CRITICAL WEEKS WITHIN FLOWERING PERIOD OF COTTON BETWEEN TWO PLANTING DATES THAT ARE MOST SUSCEPTIBLE TO DAMAGE AND YIELD LOSS DUE TO TARNISHED PLANT BUG

Introduction

The costs of control and the significant yield losses that tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), populations can cause has driven many growers away from planting cotton in the Mid-South. An average of 6 insecticide applications were made to target 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* was found in 37.85% of cotton hectares and caused 0.778% of cotton losses (Williams 2014). Over the past few years, an average of $277 per hectare was spent on insect control in Mississippi and this is unsustainable for cotton growers. These costs account for several pests, such as spider mites, *Tetranychus urticae* (Koch), thrips, *Frankliniella occidentalis*, and bollworm, *Helicoverpa zea* (Boddie). However, $197 per hectare can be attributed to tarnished plant bug control (Williams 2013). This inflated cost of control for one pest can be attributed to high levels of insecticide resistance that results in numerous insecticide applications and large populations that move into cotton during the reproductive stages (Snodgrass et al. 1996, Snodgrass et al. 2000, Snodgrass et al. 2009). Several cultural control methods, such as intercropping, destruction of host plants, and nectariless cotton (Stewart et al. 2000), serve as inexpensive ways to reduce input costs. Also, recent research showed that foliar applications to control tarnished plant bug can be significantly reduced by utilizing an early planting date and an early season variety (Adams et al. 2013). These data showed the benefits of "earliness" with early planting dates and early maturing varieties. Yet, with high input costs and low cotton prices more management practices are needed to safeguard yield from tarnished plant bug populations and make cotton a profitable and appealing crop to grow.

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 (Layton 1995, Black 1973, Zink et al. 2005, Tugwell et al. 1976). However, little is known about the impact of tarnished plant bug infestations within the separate weeks of the flowering period. Another question is if the effects of tarnished plant bug infesting cotton during the weeks of flowering would be different with respect to planting date. Reducing the number of insecticide applications during the flowering period could prove highly beneficial to growers. Lastly, it is not known exactly when cotton yield is safe and when insecticide applications targeting the tarnished plant bug 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 NAWF 5+300 HU (Catchot et al. 2013). Determining the effect of tarnished plant bugs in flowering cotton on yield within separate planting dates and when to properly terminate insecticide applications for the tarnished plant bug could prove economically valuable to growers.

Materials and Methods

An experiment was conducted at the Delta Research and Extension Center in Stoneville, MS to determine the effect of tarnished plant bug in flowering cotton within separate planting dates. A full season smooth leaf Bollgard II cotton variety (Deltapine 1050 B2RF) was planted at 113,668 seeds/ha for both planting dates. Plots consisted of eight 1.01-m rows wide by 21.33-m long. Treatments were in a split-plot arrangement in a randomized complete block design with four replications. The main-plot factor was planting date. Two separate planting dates within a growing season were used that included 26-April 2013, 28-May 2013, and 2-May 2014, 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 that 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. 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 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. Treated plots were sprayed using insecticide mixtures at their highest labeled rates designed to maximize the control of tarnished plant bug. Insecticides utilized were Orthene 90S (Valent Corporation, Walnut Creek, CA), Transform WG (DOW AgroSciences, Indianapolis, IN), Centric 40 WG (Syngenta Crop Protection, Greensboro, NC), and Orthene 90S tank mixed with Bifenthrin. Rows two and three were harvested and rows four-six were used for sampling. Plots were sampled twice a week for tarnished plant bug densities. Tarnished plant bug densities were determined by taking two drop cloth samples in each plot with a 0.76-m black drop cloth. Square retention and nodes above white flower counts were also conducted once a week in all plots. Seasonal averages were obtained for tarnished plant bug densities and square retention for all treatments by planting date and year. Averages were subjected to Analysis of Variance, PROC MIXED (Littell et al. 1996). Replication by planting date by treatment nested within year were served as the error term. At the end of the season, sequential harvesting was conducted in a 3-m subsection of each plot to quantify crop maturity. To accomplish this, all open bolls in a 3-m section of each plot were harvested by hand each week. This sampling was conducted weekly until all mature bolls were harvested from the 3-m area. Chemical defoliants and desiccants were applied to the entire test area when 80% of the bolls were open and harvested across all 3-m sections. The seedcotton weight and number of bolls were recorded for each plot every week within the specific planting date. Lint yield was determined by taking 38% of the seedcotton weights. It was then determined at what week 80% of bolls were open within a treatment for both planting dates. The results were analyzed with Analysis of Variance, PROC MIXED (Littell et al. 1996). Replication nested within year was considered random and served as the error term for treatment. To determine which treatments show a delay in maturity, all treatments were compared to the season long control. All treatments that are significantly greater than the season long control will denote a delay in cotton maturity. At the end of the season rows two and three of each plot were harvested mechanically and seedcotton weights were recorded. 38% of seedcotton weights was used to determine lint yield. All sampling and yield data were analyzed with Analysis of Variance, PROC MIXED (Littell et al. 1996). The replication by planting date nested within year was considered random and served as the error term for planting date. Replication by planting date by treatment nested within year served as the error term for treatment and residual error. Planting date and treatment were considered fixed effects in the model. Degrees of freedom were estimated using the Kenward-Roger method. Means were separated based on the LSMEANS and separated according to Tukey's studentized range test. Differences were considered significant for $\alpha=0.05$.

Results

Tarnished plant bug populations were high to average during the 2013 and 2014 growing seasons, respectively. Tarnished plant bug densities in the untreated control treatment remained over the recommended threshold for the majority of the growing season during both years (Figure 4.1). The season long control treatment remained below the threshold during both years.

There was no significant interaction between planting date and treatment for mean number of nymphs per 3.04-m of row (F=1.82; df=9, 126; *P*=0.07). Planting date (F=0.75; df=1, 14; *P*=0.40) did not have a significant effect on tarnished plant bug densities. Treatment (F=42.01; df=9, 126; *P*<0.01) had a significant effect on mean number of tarnished plant bug nymphs (Table 4.1). When tarnished plant bug spray treatments were delayed for four or more weeks, or terminated during the second week of flowering more nymphs were observed compared to all other treatments except the untreated control. Although no interactions were observed, population trends within each planting date and year are needed to better explain yield results (Figs. 4.2 and 4.3). Treatments that were initiated during the second week of flowering were effective at reducing tarnished plant bug densities below the economic threshold for both planting dates and years. In contrast, treatments that were initiated during the fourth week of flowering were only effective at reducing tarnished plant bug populations for the first planting date. Plots where sprays were not initiated during weeks six and eight had little fruit left and tarnished plant bug populations had generally migrated out of those plots before treatments were initiated, especially in 2013. Where treatments were terminated during the second week of flowering, tarnished plant bug populations increased to levels well above threshold by the fourth week of flowering. When insecticide applications were terminated during the fourth through eighth weeks of flowering, populations never increased above threshold.

There was no significant interaction between planting date and treatment for mean square retention (F=1.62; df=9, 126; P=0.11). Treatment had a significant effect on mean square retention (F=32.13; df=9, 126; P<0.01). Square retention in treatments that had insecticide applications terminated in the later portion of the flowering period was significantly greater than in treatments when insecticide applications were delayed during the early flowering period (Table 4.2).

Treatment had no significant effect on average nodes above white flower counts in any week ($F<1.38$; df=9, 124; $P>0.05$, data not shown). This shows no delay in maturity from treatments during the flowering period.

In the early planting date, there was no significant interaction between treatment and year for a delay in cotton maturity ($F=1.38$; df=9, 54; $P=0.21$) based on sequential harvest. Year did not affect maturity ($F=3.05$; df=1, 6; $P=0.13$); however, treatment did significantly affect cotton maturity ($F=5.82$; df=9, 54; $P<0.01$). In general, plots that were managed for tarnished plant bug control during the early flowering period were not significantly different than the season long control. Cotton in treatments that had insecticide applications delayed or terminated during the early flowering period achieved 80% open boll quicker than the season long control (Table 4.3).

In the later planting date there was no significant interaction between treatment and year on cotton maturity ($F=0.37$; df=9, 54; $P=0.94$). Neither treatment ($F=1.19$; df=9, 54; $P=0.32$) or year ($F=0.88$; df=1, 6; $P=0.38$) had a significant effect on cotton maturity.

There was no significant interaction between planting date and treatment for yield ($F=1.56$; df=9, 136; $P=0.13$). Planting date ($F=51.80$; df=1, 25.5; $P<0.01$) had a significant effect on yield. The first planting date (1,106±22 kg/ha) yielded significantly more than the second planting date (531±22 kg/ha). Treatment ($F=42.24$; df=9, 136; $P<0.01$) also had a significant effect on yield. Termination after the sixth week (1,159±81 kg/ha), and eighth week (1,109±82 kg/ha) of flowering and the season long control treatment (1,075±90 kg/ha) yielded significantly more than the termination after the second week of flowering (860±74 kg/ha). Termination after the fourth week of flowering (1,052±71 kg/ha) and initiation during the second week of flowering

(1,018±119 kg/ha) did not yield significantly different than the termination after the sixth or the second week of flowering. Initiation during the fourth (602±95 kg/ha), sixth (446±58 kg/ha), and the eighth week of flowering (431±76 kg/ha), and the untreated control (436±63 kg/ha) yielded significantly lower than all other treatments (Fig. 4.6).

Discussion

While past research has shown that damage received during the squaring period will cause a delay in 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 injury and this results in a delay in maturity. In the current experiment, cotton did not have sufficient time to compensate for injury during the flowering period and significant yield losses were observed rather than a delay in maturity.

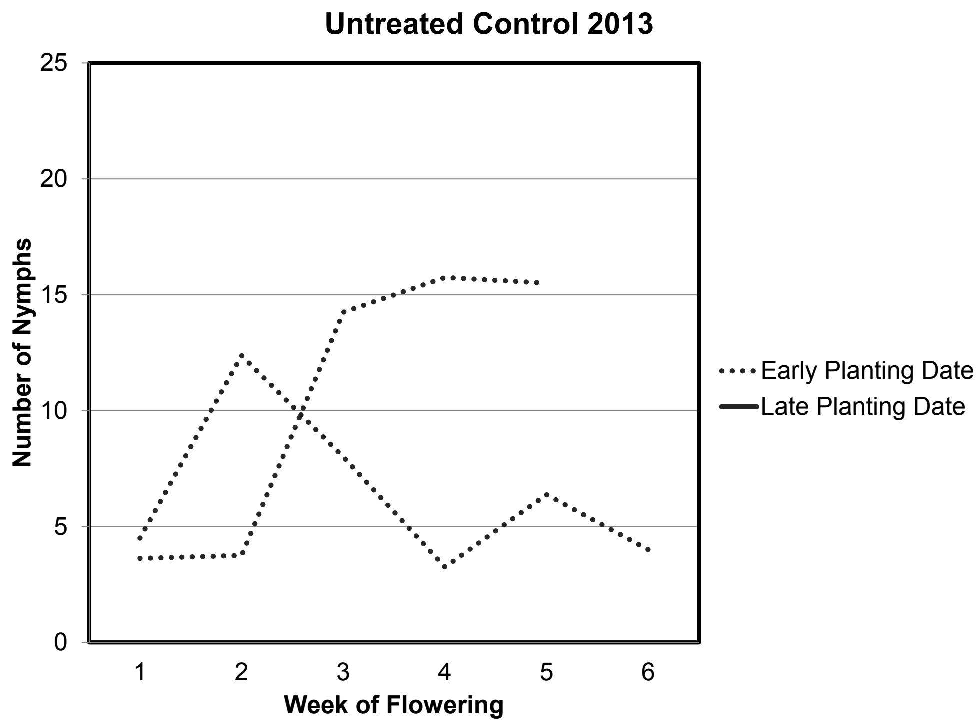
Tarnished plant bug populations migrate from other hosts, such as corn senescing, and move into cotton as the crop is beginning to flower (Snodgrass et al. 2009). When insecticide applications targeting tarnished plant bugs were delayed until the fourth week of flowering or later, populations grew to an average two times the recommended threshold. In treatments that had insecticide applications delayed during the early to mid-flowering period, tarnished plant bug populations exceeded that of the treatments that terminated insecticide applications at the similar weeks within the flowering period. Failing to control tarnished plant bugs during the first 4 weeks of flowering or delaying insecticide applications at this time can lead to populations that rapidly increase within several days.

Planting date and insecticide application timings during the flowering period significantly affected yield. Yield losses suffered in the treatments that were vulnerable to tarnished plant bug damage during the early flowering period suggest 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 when thresholds should strictly be followed to minimize yield losses, because the plants were not able to compensate for the damage they received at this time. Because there was no significant interaction between planting dates, it can also be assumed that these weeks would be the same for an early or late planting date or in environments with different yield potentials. However, an early planting date will likely have greater yield potential due to less insect pressure during the reproductive period of the crop, which can result in fewer insecticide applications that would need to be made (Adams et al. 2013).

Nodes above white flower 5+300 HU is the current recommendation to terminate insecticides targeting tarnished plant bugs 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. The 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 would be observed. However, it needs to be stated that tarnished plant bugs did not rebound to above threshold densities and this may have impacted these results. In the plots that had insecticide applications terminated at the fourth week of flowering, which on average was one week prior to the current recommendation of NAWF 5+300 HU, there was no significant yield loss observed. So 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 still needed in large plot trials conducted across a range of environments. However, our current insecticide termination recommendation is adequate in safeguarding yield from tarnished plant bug damage.

In a recent study conducted by Musser et al. (2009), it was observed that yield loss was strongly linked to tarnished plant bug densities during the late flowering period rather than the early flowering period (Musser et al. 2009). This does not coincide with the results from this trial that showed the early to middle flowering period being the most critical time when yield losses can occur in our current management system as seen by the significant yield loss suffered when insecticide application was delayed until the fourth week of flowering compared to when insecticide applications were terminated after the second week of flowering. These results further solidify the need to manage tarnished plant bugs efficiently during the early flowering period.

The results of this study show that our current termination recommendation is adequate in protecting yield from late season tarnished plant bugs and that late season insecticide applications targeting tarnished plant bugs are not needed because no yield loss can occur at that time due to damage. Results also show the strong need to strictly adhere to thresholds during the first 4 weeks of the flowering period because significant yield loss can occur due to tarnished plant bug infestations. With $177 per hectare that is spent solely to control tarnished plant bugs (Williams 2012), every management practice that could reduce input cost or safeguard yield is needed to make cotton an appealing crop to plant once again in the Mid-South.



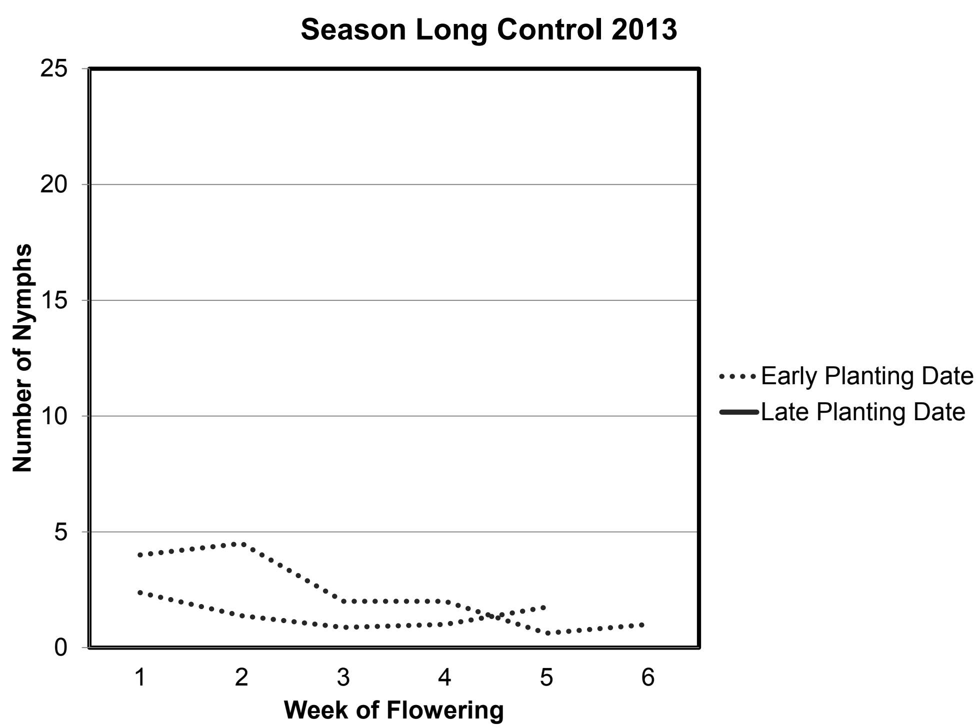
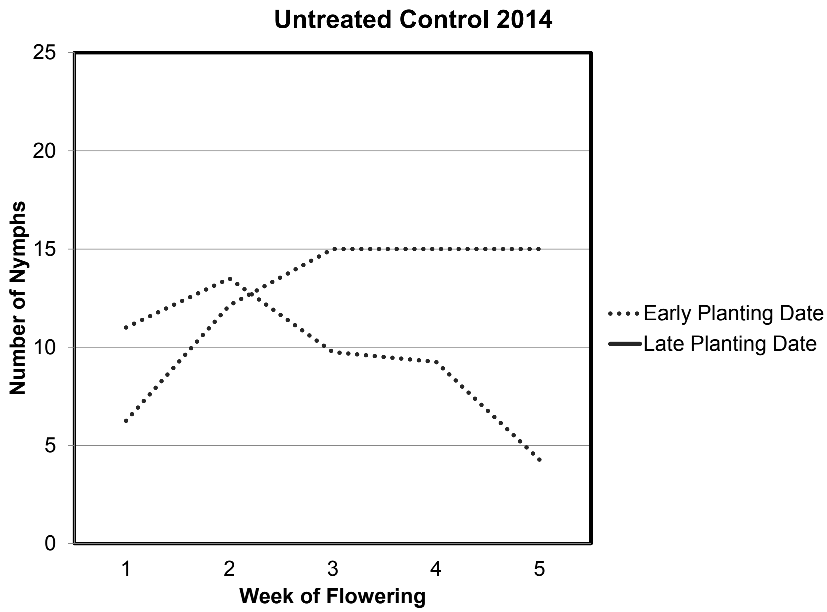


Figure 4.1 Mean number of tarnished plant bug nymphs per two drop cloth samples for season long control spray treatment and untreated control spray treatment by sample date within the flowering period in 2013 and 2014 in Stoneville, MS.



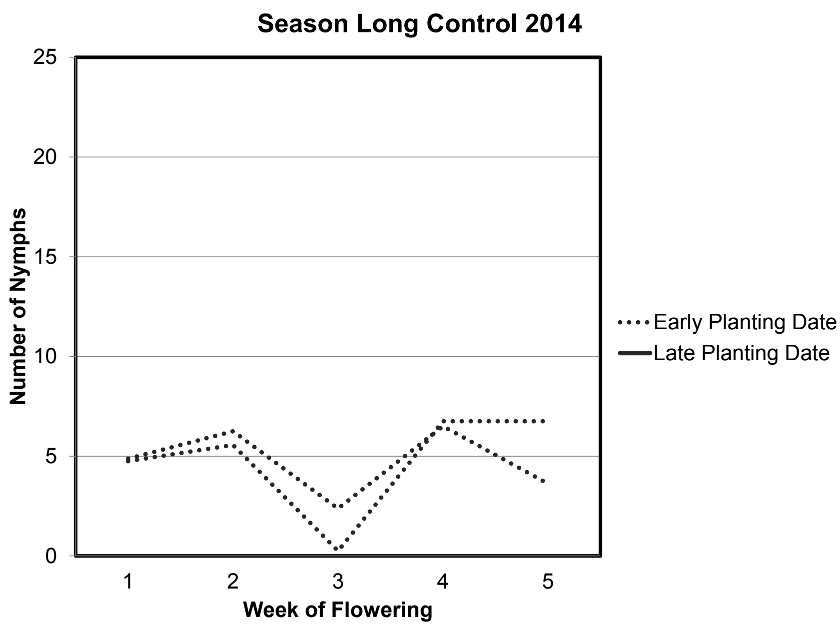


Figure 4.1 (continued)

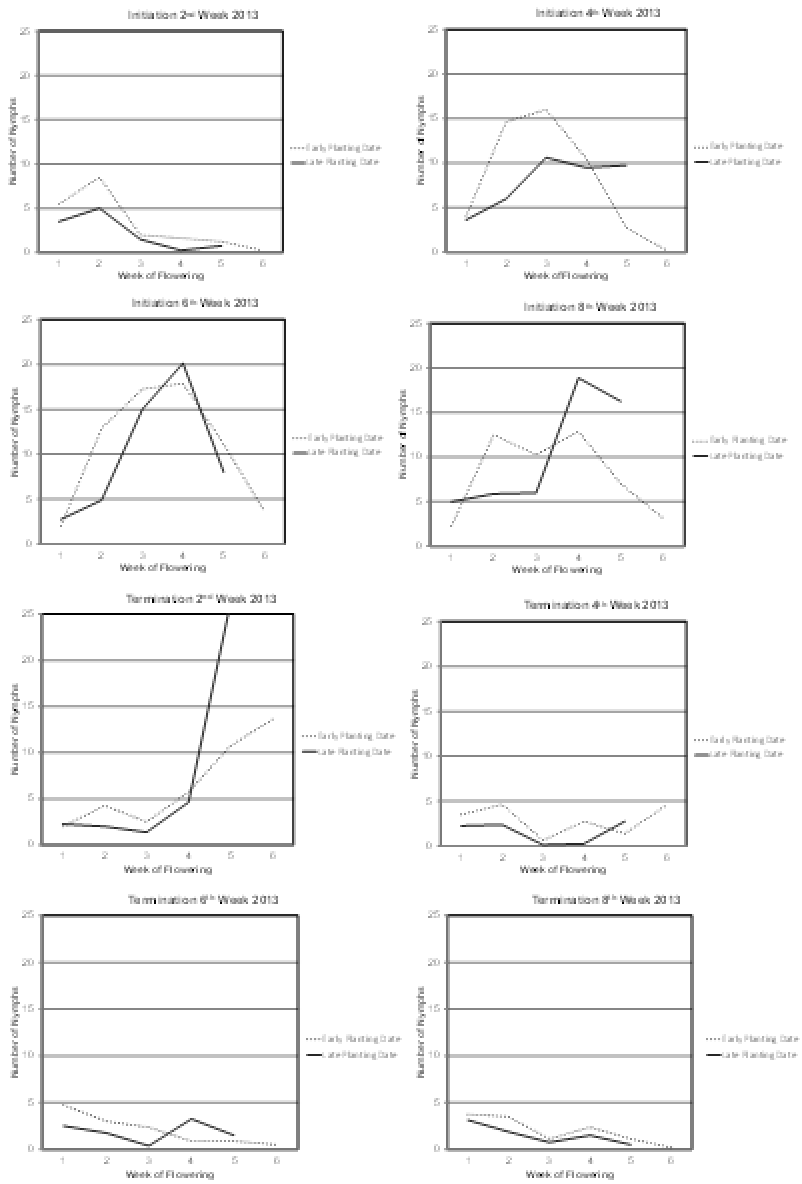


Figure 4.2 Mean number of tarnished plant bug nymphs per two drop cloth samples for insecticide application initiation and termination treatments for each planting date by week of flowering period for 2013 in Stoneville, MS.

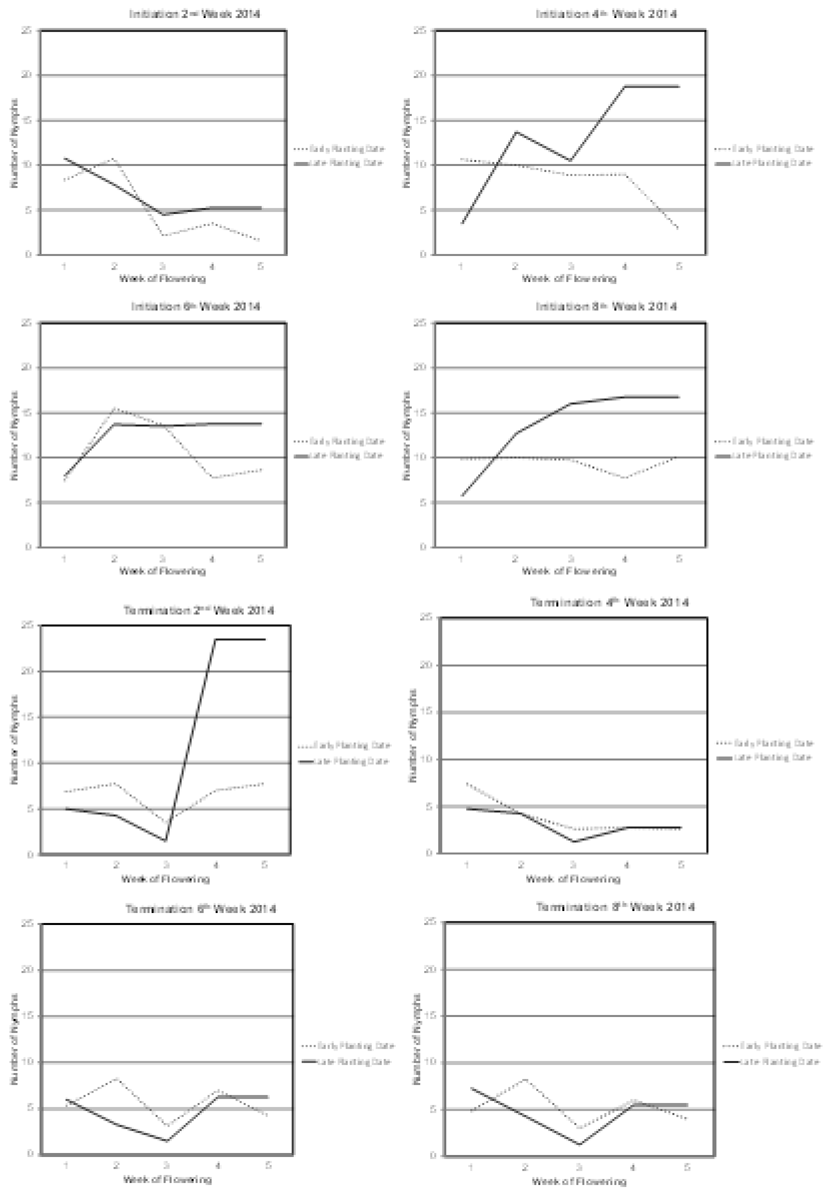


Figure 4.3 Mean number of tarnished plant bug nymphs per two drop cloth samples for insecticide application initiation and termination treatments for each planting date by week of flowering period for 2014 in Stoneville, MS.

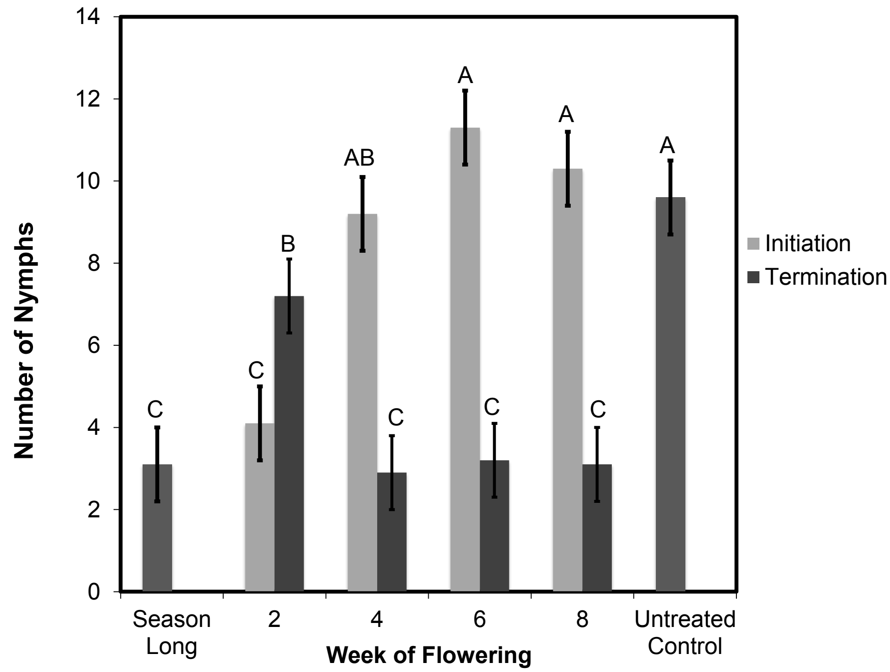


Figure 4.4 Mean±SEM number of tarnished plant bug nymphs per two drop cloth samples by treatment averaged across years and planting dates.

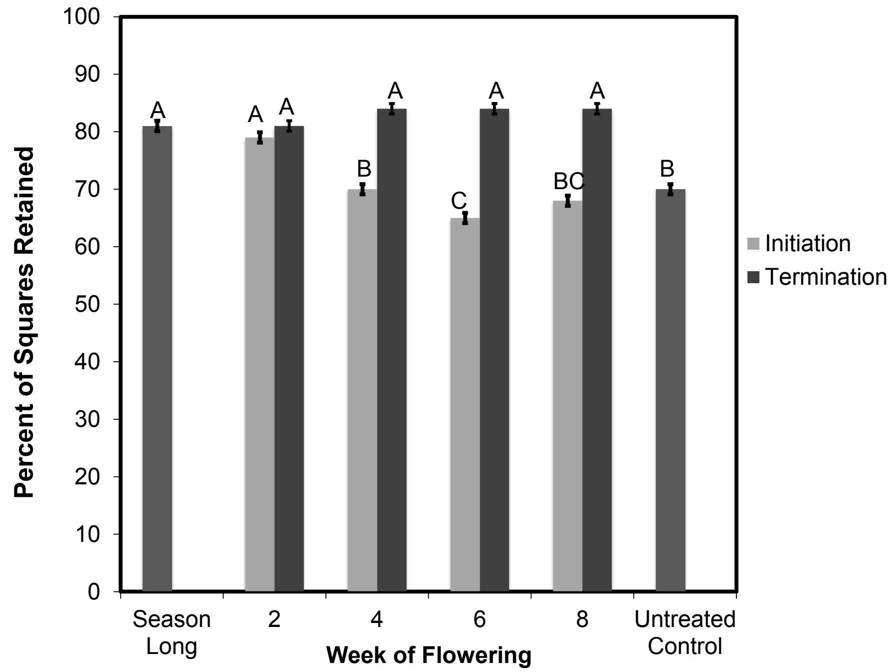


Figure 4.5 Mean±SEM square retention shown as a percentage by treatment averaged across years and planting dates.

Table 4.1 Amount of weeks after open boll until 80% open boll is achieved in early planting date between years 2013 and 2014 in Stoneville, MS.

Treatment	**Weeks After Open Boll**
Season Long	**4.4ab**±0.3
Initiation 2nd Week	4.9a±0.1
Termination 4th Week	4.9 a±0.1
Initiation 4th Week	4.5ab±0.3
Termination 8th Week	4.5ab±0.2
Termination 6th Week	4ab±0.2
Initiation 8th Week	3.9b±0.1
Termination 2nd Week	3.9b±0.4
Untreated Control	3.6b±0.2
Initiation 6th Week	3.6b±0.2

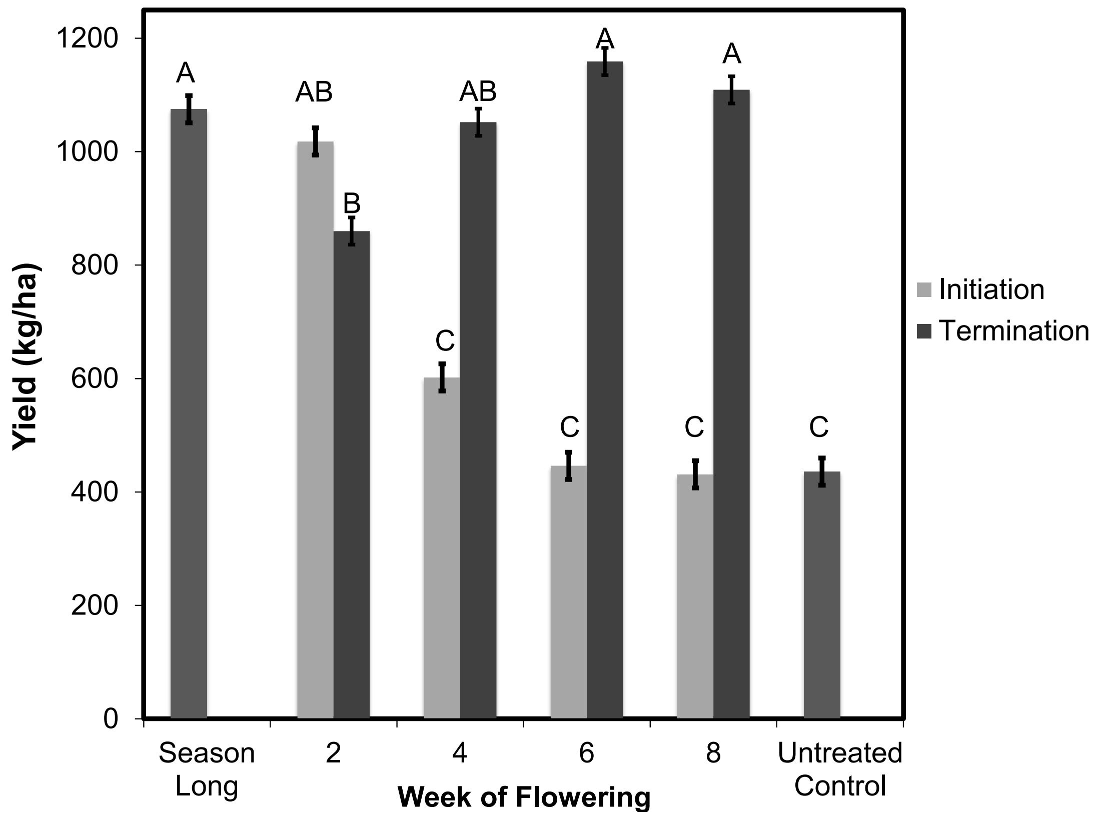


Figure 4.6 Impact of insecticide sprays initiated and terminated during the flowering period on mean±SEM lint yield averaged across years and planting dates in Stoneville, MS.

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