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The Biology and Management of Tarnished Plant Bug Lygus Lineolaris (Palisot De Beauvois), in Cotton, Gossypium Hirsutum (L.), in the Mississippi Delta

Brian Patrick Adams

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By

Brian Patrick Adams

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THE BIOLOGY AND MANAGEMENT OF TARNISHED PLANT BUG

LYGUS LINEOLARIS (PALISOT DE BEAUVOIS), IN

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In field experiments, managing for earliness through planting date and varietal maturity reduced tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), densities, insecticide applications, and yield loss. A second experiment highlighted the importance of timely insecticide applications for managing tarnished plant bugs. Differences in fitness parameters were observed between tarnished plant bug populations collected from the Hills and Delta regions of Mississippi. Populations from the Delta region laid more eggs and produced more viable offspring than populations from the Hills. Populations from the Delta reared on cotton developed significantly faster to each life stage than those reared on diet or populations from the Hills region. Overall, tarnished plant bugs survived significantly better on diet than on cotton. Results from these experiments will be important for improving IPM practices for tarnished plant bugs in Mississippi cotton.

DEDICATION

This research is dedicated to Jeff, Jerry, and Timmy White of White Farms in Huntingdon, TN. It was these three men who first introduced me to and employed me in agriculture, and were first to help foster my love for the agriculture industry. It was under their direction that I learned just how valuable agriculture is to our country. Words could never express how thankful I am to these three men for the wisdom and direction they provided to me over the years. Without them, my life's path would not have lead me to the choice of a career field that allows me to serve and help to the best of my ability, the American farmer who breaks his back day in and day out in one of the most important, yet most thankless jobs. My sincere appreciation goes out to these three men, for all that they have done for me throughout my life.

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CHAPTER I

INTRODUCTION

Cotton

Cotton (*Gossypium hirsutum* [L.]), is an important crop for the local economy in Mississippi. The fiber and seed of cotton are both marketable commodities. Cotton fiber is used in many items including linens, paper, and money. Oil from cotton seed, like the fiber, has many uses that include vegetable oil and livestock feeds (National Cottonseed Products Association 2002). In the U.S., cotton was first planted in Florida in 1556 (National Cotton Council). Today there are millions of hectares of cotton grown throughout the world. In 2011, the United States produced 15.6 million bales of cotton which equates to roughly twelve percent of all world production for the year (NASS 2012).

Although there are four species of cultivated cotton in the world, *G. hirsutum* makes up over 90% of the cultivated area. Cotton is a perennial shrub that is grown as an annual crop. Because of this, cotton has a different growth habit than most other cultivated crops. Cotton is characterized by slow above ground development during early growth stages. It does; however, possess a very predictable growth rate based on heat unit accumulation. The degree day formula used to calculate heat unit accumulation is the sum of the daily high and low temperatures divided by two minus sixty (National Cotton Council 2007). Sixty degrees Fahrenheit is the minimum temperature for physiological development. From planting to harvest, cotton requires approximately

2600 heat units to reach full maturation. According to Jenkins (1990), cotton growth stages can be predicted based on heat unit accumulation (Table 1.1).

Table 1.1 Cotton growth and heat unit accumulation

Growth Event	**Heat Units Required**
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 Total	2600

Jenkins (1990) describes the five main growth stages of cotton as germination and emergence, seedling establishment, leaf area and canopy development, flowering and boll development, and maturation. Cotton growth and development is often characterized by the number of mainstem nodes prior to flowering. Once flowering begins, growth is measured by the number of mainstem nodes above the upper-most first position white flower (Bourland et. al 1992). Jenkins (1990) noted that germination and radical appearance occur on average around the third day after planting through the occurrence of imbibition, which is the uptake of water through the chalazal aperture, and respiration. At six days after planting, seedling emergence takes place as the hypocotyl arch extends above the ground. The cotyledons unfold typically on the seventh day after planting.

The roots reach six to twelve inches in length on the tenth day after planting. On the 14th day after planting, the first true leaf unfolds and true photosynthesis will begin. Early reproductive growth begins around the thirty-fifth day after planting with the occurrence of the first flower bud. The first white flower occurs at 65 days after planting signaling the beginning of pollination and sexual fertilization of the plant. At 93 days, the plant should be in full bloom which is also known as peak flower. During this time, fiber and boll development is at its highest level. Finally, the first boll should begin opening at 110 days after planting, which signals that the plant is approaching physiological maturity.

Due to the heat unit requirements of cotton, it is only grown in warmer climates such as the Southeastern and Southwestern U.S. It has an indeterminate growth habit meaning that vegetative growth continues even after reproductive growth begins (Silvertooth et al. 1999). This feature of cotton is not present in most other cultivated crops. The indeterminate growth habit results in a long flowering period compared to other crops. Cotton will flower for approximately six to eight weeks in Mississippi. Because of this, cotton is more susceptible to economic injury from some insect pests over a longer period of time compared to other crops (Silvertooth et al. 1999). Cotton planting in Mississippi begins in mid-April and usually concludes around the end of May. Cotton is grown in many different row spacings. Some of the more common in Mississippi are 91 cm (36"), 96.5 cm (38"), and 102 cm (40") rows. Cotton is typically planted between 1.25 cm (0.5") and 3.8 cm (1.5") deep (Collins and Whitaker 2011). Cotton typically yields the best when planted at populations of 98,842 to 123,553 seeds per hectare (40,000-50,000 seed per acre). Cotton yield is most often measured in bales per hectare or kilograms of lint per hectare. One bale of harvested seedcotton weighs 217.72 kg. In 2011, Mississippi's cotton crop yielded 1,085 kg/ha of lint (NASS 2012).

Tarnished Plant Bug

Biology and Ecology

The tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), is the most important pest of cotton in Mississippi (Williams 2012). Tarnished plant bugs are true bugs of the Miridae family in the order Hemiptera (Triplehorn and Johnson 2005). All mirids have piercing-sucking mouthparts (Triplehorn and Johnson 2005). Digestive salivary enzymes are injected into the plant during feeding by tarnished plant bugs, and the disruptive effects of those enzymes on the plant causes the most damage as opposed to the amount of tissue consumed by plant bugs (Layton 1995). Tarnished plant bugs are phytophagous insects that feed preferentially on the squares (flower buds) of cotton. The tarnished plant bug is one of several plant bug species that attacks cotton in the U.S. but it has the broadest range of any of the other species and is the main species infesting Mid-South cotton (Young 1986). The majority of tarnished plant bug eggs are laid inside the host plant (Fleischer and Gaylor 1988). In the case of cotton, these sites are most often the terminals and squares. Tarnished plant bugs are a paurometabolous insect meaning they undergo gradual metamorphosis. The three life stages of the tarnished plant bug are egg, nymph, and adult. The life cycle of a tarnished plant bug typically lasts 30-40 days (Fleischer and Gaylor 1988). Ridgway and Gyrisco (1960) observed that the time required for incubation of tarnished plant bug eggs was 7.62 days at 25˚C. The authors also noted that the first instar required an average of 4.77 days, second instar required 3.08 days, third instar needed 3.28 days, fourth instar needed 3.33 days, and fifth instar required 5.22 days to complete development. Upon completion of the fifth instar, tarnished plant bug nymphs molt for the final time and reach maturity in the adult stage. Tarnished plant bugs will complete several generations per year in Mississippi. The first

1-2 typically occur on wild early season hosts (Fleischer and Gaylor 1987). Once these early season hosts reach a stage where they are no longer attractive, tarnished plant bugs move into agronomic crops such as cotton, and may cause significant economic damage (Layton 1995).

The tarnished plant bug is a polyphagous insect. Young (1986) observed a total of 385 host plants for tarnished plant bugs and suggested that it could have the widest host range of any insect. These host plants ranged from agronomic hosts to wild hosts to fruits and vegetables. Tarnished plant bugs prefer to feed on plants near bloom and will move from location to location based on temporal changes in the phenological stages of plant hosts (Snodgrass et al. 1984). Layton (1995) noted that the duration and intensity of movement into cotton varied with the year, but noted that movement appeared to correlate with the amount of alternate hosts available and the flower buds on those hosts.

Feeding and Damage to Cotton

Damage in cotton from tarnished plant bugs can begin as early as emergence and persist until early lint development of the last harvestable bolls (Black 1973). Economic damage more often is found however, from first square through the early bloom stages of cotton (Black 1973). Feeding on cotton by tarnished plant bugs can cause swollen nodes, shortened internodes, aborted terminals, deformed leaves, excessive branching along the main stem, and delayed fruiting, all of which can lead to reduced yields (Hanny et al. 1977). Layton (1995) noted that damage from tarnished plant bugs remains localized to the area of feeding, and does not appear systemically anywhere else on the plant. In presquaring cotton, tarnished plant bugs feed on terminal tissues causing a loss of apical dominance. This feeding can result in the formation of multiple secondary terminals, often called “crazy cotton” (Scales and Furr 1968). Tarnished plant bugs prefer to feed on squares less than 1/8 inch in diameter in cotton as opposed to bolls and larger squares (Tugwell et al. 1976). This feeding results in abscission of those squares (Layton 1995). Delayed crop maturity and altered fruiting patterns may result from excessive early square loss due to high plant bug populations. Larger squares may abscise, but are more likely to remain on the plant and form a bloom depending on the intensity of damage. On larger squares, tarnished plant bugs damage developing anthers. Damage sustained during the square stage may be observed on the open bloom as dark brown anthers. Flowers with discolored anthers are often referred to as “dirty blooms.” Pack and Tugwell (1976) noted that there is a correlation between dirty anthers and boll damage. There is little to no yield loss when less than 30% of anthers are damaged. When the level of anther damage increased beyond 30%, the level of malformed bolls and percent of boll shed increased. This was most likely the result of inadequate pollination. Tarnished plant bugs also feed on small bolls (Pack and Tugwell 1976). Feeding on bolls results in sunken lesions on the outside of the boll wall that turn black and necrotic (Pack and Tugwell 1976). On larger bolls that are more developed, damage to the entire boll is not common, but individual seeds are damaged, resulting in discolored lint, and a reduction in overall boll weight (Pack and Tugwell 1976).

Damage in flowering cotton from tarnished plant bugs was relatively minor before 1996 due to control gained by insecticide applications targeting other pests (Musser et al. 2007). This is no longer the case due to successful eradication of the boll weevil, *Anthonomus grandis grandis* (Boheman), and the wide scale adoption of Bt (*Bacillus thuringiensis*) transgenic cotton varieties. The result has been an overall decline in the frequency of foliar insecticide applications for other pests. In 2010, growers in the Delta Region of Mississippi averaged 6 foliar insecticide applications for tarnished plant bugs with an average cost of $27.84 per hectare (Williams 2012). This results in approximately $167 per hectare to control one pest alone.

Thresholds and Sampling

States where cotton is grown have specific recommendations for sampling and management of tarnished plant bugs once they have reached economically damaging levels. Thresholds tend to be lower during the earlier stages of cotton development and will increase as the crop matures (Craig 1998). The current threshold for the tarnished plant bug between emergence and first square is one plant-bug-flagged plant and one or more plant bugs per ten row feet (Catchot 2010). Current thresholds for tarnished plant bugs in Mississippi during the first two weeks of squaring are one plant bug per 1.83 row meters with a drop cloth, five plant bugs per one hundred terminals using a visual inspection method, or eight plant bugs per one hundred sweeps when using a sweep net (Catchot 2010). Thresholds for tarnished plant bugs from the third week of squaring through bloom is three bugs per 1.83 row meters with a drop cloth, ten bugs per one hundred plants when visually inspecting plants, fifteen bugs per one hundred sweeps when using a sweep net, or ten percent dirty squares (Catchot 2010). A dirty square is characterized as a medium sized square with exposed buds that have been discolored yellow due to feeding from plant bugs.

Management Practices

Control of the tarnished plant bug in the Mid-South is primarily obtained through the use of insecticides. Current recommended insecticide treatments for tarnished plant bugs according to Catchot (2010) include a variety of insecticide classes.

Organophosphates such as acephate (Orthene 90S, Amvac Chemical Company., Walnut Creek, CA), dicrotophos (Bidrin 8E, Amvac Chemical Company, Walnut Creek, CA), and malathion (Fyfanon ULV 9.9C, Cheminova, Durham, NC) are recommended. Acephate and other organophosphates are not recommended for control of tarnished plant bugs before first bloom. The highest labeled rates of these insecticides are recommended for adequate control (Catchot 2010). Dicrotophos is also limited in that it may only be used before first square and after first bloom with a minimum of two weeks between applications (Catchot 2010). Chloro-nicotinyl insecticides such as acetamiprid (Intruder 70 WP, Gowan Company, Yuma, AZ), imidacloprid (Admire Pro 4.6 SC, Bayer CropScience, Research Triangle Park, NC), and thiamethoxam (Centric 40WG, Syngenta Crop Protection, Greensboro, NC) are also recommended (Catchot 2010). Currently, novaluron (Diamond 0.83 EC, Chemtura USA Corporation, Middlebury, CT) is the only insect growth regulator with activity on plant bugs. It only has activity on nymphs and is generally tank mixed with another class of insecticide for adult control (Catchot 2010). Other insecticides recommended for tarnished plant bug control include the carbamate, oxamyl (Vydate C-LV 3.77, DuPont Crop Protection, Wilmington, DE) and the pyridine carboxamide, flonicamid (Carbine 50WG, FMC Corporation, Princeton, NJ). Fifth instar nymphs are nearly four fold more tolerant to several insecticides than adults (Hollingsworth et al. 1997). Pyrethroid resistance in tarnished plant bugs was first documented in the Mississippi Delta in 1992 (Snodgrass 1994). Resistance to organophosphates has also been documented in tarnished plant bugs (Snodgrass et al. 2009). Because of these factors, use rates for some chemicals such as acephate have tripled over time, while control levels have diminished to around 60%. This resistance has also limited the class of chemistry options available for tarnished plant bug control.

Improved Management Practices Justification

Because tarnished plant bugs are difficult to control in the Midsouth due to insecticide resistance issues, there is a need for better management practices that integrate multiple strategies to minimize economic losses from this pest. Use of early season insecticide applications often eliminate beneficial arthropods, an effect that is sometimes felt throughout the entire growing season. If sufficient control of tarnished plant bugs could be gained with lower input costs, then it is possible that cotton acreage would begin to increase again. Currently, improved strategies with insecticide use and cultural control methods appear to be the most likely alternatives to achieve the goal of lowering input costs and reducing insecticide applications. To address the current problem with tarnished plant bugs in Mid-South cotton, particularly the Mississippi Delta region, the following objectives were proposed:

Objective 1: Develop insecticide use strategies to optimize tarnished plant bug management

Objective 2: Determine the impact of planting date and variety selection on tarnished plant bug damage and insecticide application frequency

Objective 3: Compare development of tarnished plant bugs from the Delta and Hills regions of Mississippi on cotton

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CHAPTER II

INSECTICIDE USE STRATEGIES TO OPTIMIZE TARNISHED PLANT BUG MANAGEMENT IN COTTON

Abstract

An experiment was conducted in Stoneville, MS in 2010 and 2011 to determine the optimum insecticide use strategy for controlling tarnished plant bugs in cotton. Treatments included an untreated control, application at threshold, application at threshold plus an additional application five days after the threshold treatment, application at threshold plus an additional application ten days after the threshold treatment, and application once populations reached threshold that was delayed to the next sample date to illustrate the effects of delayed application timing. Data were pooled across years and analyzed with analysis of variance. Numbers of applications initiated by tarnished plant bug densities reaching or exceeding threshold varied from one to two in 2010, and two to four in 2011. All treatments significantly reduced tarnished plant bug populations below the untreated control although no differences were observed among sprayed treatments. Similarly, all treatments yielded significantly more lint than the untreated control but, no differences were observed among the different spray regimes.

Introduction

Historically, cotton production has been important for the economy of Mississippi. Cotton acreage has declined recently in the Midsouth (NASS 2012) due to higher input costs and increased demand for other commodities. Increasing input costs associated with planting and pest control in cotton have made corn and soybean more profitable for growers. The increased demand for grain crops resulted in a dramatic increase in the prices received for soybeans and corn. Additionally, input costs are relatively low for these crops compared to cotton.

Input costs associated with planting have increased for all major agronomic crops. Some of these costs are technology fees that are incurred when buying transgenic seed varieties, seed treatments, weed control costs associated with resistant species of weeds, higher fuel and fertilizer costs associated with rising energy costs, and control costs for other insect pests (Riley et al. 2010). The main difference in input costs between the grain crops and cotton is in-season insect control. In 2011 the cost of in-season foliar insecticide applications to cotton in the Delta averaged nearly $366 per hectare (Williams 2012). In 2011, growers in the Delta region of Mississippi averaged approximately two applications for the *Heliothis* complex at an average cost of $47.25 per hectare (Williams 2012). During the same time in the Delta, there was an average of 0.8 applications for spider mites, 1.3 applications for thrips, and 0.5 applications for aphids with an average cost per hectare of $23.66, $24.65, and $17.98, respectively. One tarnished plant bug application in the Delta averaged $34.23 per hectare with an average of seven applications. The total cost for tarnished plant bug control totaled approximately $240 per hectare (Williams 2012). This equates to over two times more input costs for tarnished plant bug compared to the other four most common arthropod pests in cotton combined. If in-season costs associated with insect pest management were lowered, cotton production may become more profitable for growers and result in an increase in cotton acres. As recently as 2006, there were over 485,600 hectares of cotton planted in Mississippi, but that number had fallen to fewer than 121,500 hectares by 2009 (NASS

2009). The recent increase in control costs for tarnished plant bugs has contributed to this decline. Snodgrass (1994) documented resistance to the pyrethroids among tarnished plant bugs in Mississippi. Resistance to organophosphates has also been documented (Snodgrass et al. 2009). Resistant populations of insects are typically found later in the year after being selected for through multiple insecticide applications. Due to the incomplete control provided by insecticides, a more effective insecticide application strategy is needed for tarnished plant bug control in Mississippi.

Materials and Methods

To determine the optimum insecticide use strategy for tarnished plant bug control on cotton in Mississippi, an experiment was conducted at the Delta Research and Extension Center in Stoneville, MS in 2010 and 2011. The experiment was a randomized complete block design with four replications. The treatments included five insecticide application regimes during the flowering stages of cotton development. During pre-flowering stages, tarnished plant bug densities were determined by taking 25 sweeps with a standard 38 cm diameter sweep net in each plot. Prior to flowering, the entire experimental area was treated uniformly with insecticide as needed for tarnished plant bugs based on sweep net samples and square retention. Treatments during the flowering stages included:

1. Untreated control
2. Treat at threshold
3. Treat at threshold and again automatically at 5 days after initial application
4. Treat at threshold and again automatically at 10 days after initial application
5. Treat at threshold but delay application until the next sample date

During the flowering stages, all plots were sampled twice per week with a black drop cloth. Two drop cloth samples were collected per plot. Numbers of tarnished plant bug adults and nymphs were recorded. For all of the threshold treatments, applications were made when the overall average number of tarnished plant bugs from all replications reached three tarnished plant bugs per 1.5 row m (Catchot 2011). The untreated control was not sprayed for tarnished plant bug after first flower. The threshold treatment was sprayed the same day as sampling. Similarly, initial applications for the threshold plus five days and threshold plus ten days treatments were treated on the day of sampling. For those treatments, a second application was made five or ten days, respectively, after the threshold application regardless of tarnished plant bug densities after the first application. After the second application at five or ten days, those plots were not sprayed again until the average numbers of tarnished plant bugs reached threshold. Whenever those plots reached threshold again, the same procedure was used. The delayed application (Treatment 5) was sprayed on the sampling date that immediately followed the initial sampling date where threshold was reached (3-4 days after threshold was reached). This treatment was used to display the effects of tardiness of application. All insecticides were used at maximum labeled rates. The insecticides used for control were rotated for resistance management (Table 2.1).

Table 2.1 Insecticide rotation used in this experiment.

Growth Stage	**Insecticide**
Pre-flowering stage	Thiamethoxam
First two weeks of flowering	Acephate
Second two weeks of flowering	Acephate tank mixed with Bifenthrin
Third two weeks of flowering	Thiamethoxam
Fourth two weeks of flowering	Dicrotophos tank mixed with Bifenthrin

Plot size was sixteen rows by 22.8 m. Stoneville 5458 B2F was planted to minimize the impact of lepidopteran insect pests. Cotton was planted at 118,560 seed per hectare into raised conventional tilled beds with 1.02 m row spacing. Seed were treated with a neonicotinoid (Avicta Complete Pak®, Syngenta Crop Protection, Greensboro, NC) to minimize the impacts of thrips. A preemergence application of herbicide was made over the entire plot area for control of summer annual weeds. Estimates of crop maturity were determined weekly by counting nodes above white flower in each plot. Briefly, nodes above white flower (NAWF) were determined by counting the number of main stem nodes above the uppermost first position white flower (Bourland et al. 1992). This was done to determine when individual treatments reached nodes above white flower 5 to identify the last economically harvestable bolls across the plot area (Bourland et al. 1992). Russell et al. (1999) found that bolls that have accumulated at least 300 heat units were not damaged by tarnished plant bugs. Therefore, it can be assumed that the last harvestable bolls were safe from tarnished plant bug damage when plants averaged nodes above white flower 5 plus 300 heat units and insecticide applications were terminated at that point in this experiment. The center two rows of each plot were harvested at the end of the season in 2010 and seedcotton weights were recorded. Rows five and six along with rows nine and ten were harvested in 2011 and seedcotton weights were recorded. Lint yield was determined by taking the weight of the harvest sample and multiplying by 38%. All data were analyzed using analysis of variance (Littell et al. 1996). In the model, treatment was designated as a fixed effect, and replication and year were designated as random effects. Degrees of freedom were calculated using the Kenwood-Rogers method. Differences were considered significant for $\alpha=0.05$.

Results and Discussion

The number of applications triggered by populations reaching threshold in 2010 ranged from 1 to 2 (Table 2.2). In terms of total insecticide applications, all of the treatments were sprayed two times during the flowering period. In 2011, the number of applications triggered by populations reaching threshold ranged from 2 to 4 (Table 2.3). The threshold and threshold plus 10 day automatic treatment were sprayed 4 times. The threshold plus 5 day automatic treatment was sprayed 6 times, and the threshold delayed treatment was sprayed 3 times.

Tarnished plant bug populations for all treatments remained above threshold several weeks during the flowering period in 2010 (Figure 2.1). Once the untreated control reached a level above threshold early during the flowering period, it never returned to levels below threshold throughout the flowering period. The remaining four treatments followed a similar trend to each other in population densities throughout the season. They reached levels above threshold early in the flowering period, but fell back below threshold levels near the end of July and remained below threshold through physiological maturity. The threshold delayed treatment reached its peak population slightly later than the other three threshold treatments, and also sustained populations of tarnished plant bugs above threshold for a slightly longer period of time.

Populations of tarnished plant bug had a tendency to fluctuate more in 2011 than 2010. Populations for all treatments spent varying amounts of time above threshold at various times during the sampling period (Figure 2.2). Similar to 2010, once the untreated control reached a level above threshold, it rarely returned to levels at or below threshold. Also similar to 2010, the threshold delayed treatment again had a slightly later peak in populations of tarnished plant bugs, and also had slightly longer periods of sustained tarnished plant bug levels above threshold.

Treatment had a significant effect on the mean number of tarnished plant bugs per 3 m of row across all sample dates (F=28.16; df= 4, 395; $P<0.01$) (Table 2.4). All treatments provided significantly better control of tarnished plant bugs than the untreated control. However, none of the sprayed treatments were significantly different from each other (Table 2.4).

Treatment had a significant impact on lint yields of cotton (F=20.04; df= 4, 28; $P<0.01$). All treatments yielded significantly more lint than the untreated control, but none of the sprayed treatments were significantly different from each other (Table 2.5).

These data suggest that by being timely with applications, populations are reduced faster than being late with applications or not treating for tarnished plant bugs once they reach levels above threshold. Delayed applications allowed tarnished plant bug populations to remain above threshold for longer periods of time. Making applications in a timely fashion could potentially reduce the risk of unnecessary yield losses. These data also suggest that automatic or prophylactic treatments do not significantly improve yields or significantly reduce overall tarnished plant bug populations. Growers could protect yield and keep tarnished plant bug populations at acceptable levels by following good IPM practices, scouting thoroughly and often, and being timely with applications of insecticides when tarnished plant bug populations reach or exceed threshold.

Table 2.2 Number of threshold and automatic applications made for each treatment in 2010.

Treatment	Num. Applications Threshold (Auto)
Check	N/A
Threshold Only	2
Threshold+5d Auto	1 (1)
Threshold+10d Auto	1 (1)
Threshold Delayed	2

Table 2.3 Number of threshold and automatic applications made for each treatment in 2011.

Treatment	Num. Applications Threshold (Auto)
Check	N/A
Threshold Only	4
Threshold+5d Auto	3 (3)
Threshold+10d Auto	2 (2)
Threshold Delayed	3

Table 2.4 Mean tarnished plant bug densities averaged across all sampling dates in 2010-2011.

Treatment	Mean TPB/3 row m	SEM
Untreated Check	17.11a	1.84
Threshold Delay	6.91b	1.09
Threshold+5	5.85b	1.06
Threshold	5.12b	1.15
Threshold+10	4.21b	0.74

Means followed by the same letter are not significantly different at ($P \leq 0.05$) (LSD=2.76421).

Table 2.5 Impact if tarnished plant bug spray regime on final cotton yields.

Treatment	Yield (kg/ha)	SEM
Threshold	1139.56a	162.59
Threshold+5	1141.78a	166.99
Threshold+10	1176.33a	143.39
Threshold Delay	1110.85a	137.28
Untreated Check	778.96b	159.93

Means followed by the same letter are not significantly different at ($P \leq 0.05$) (LSD=106.17).

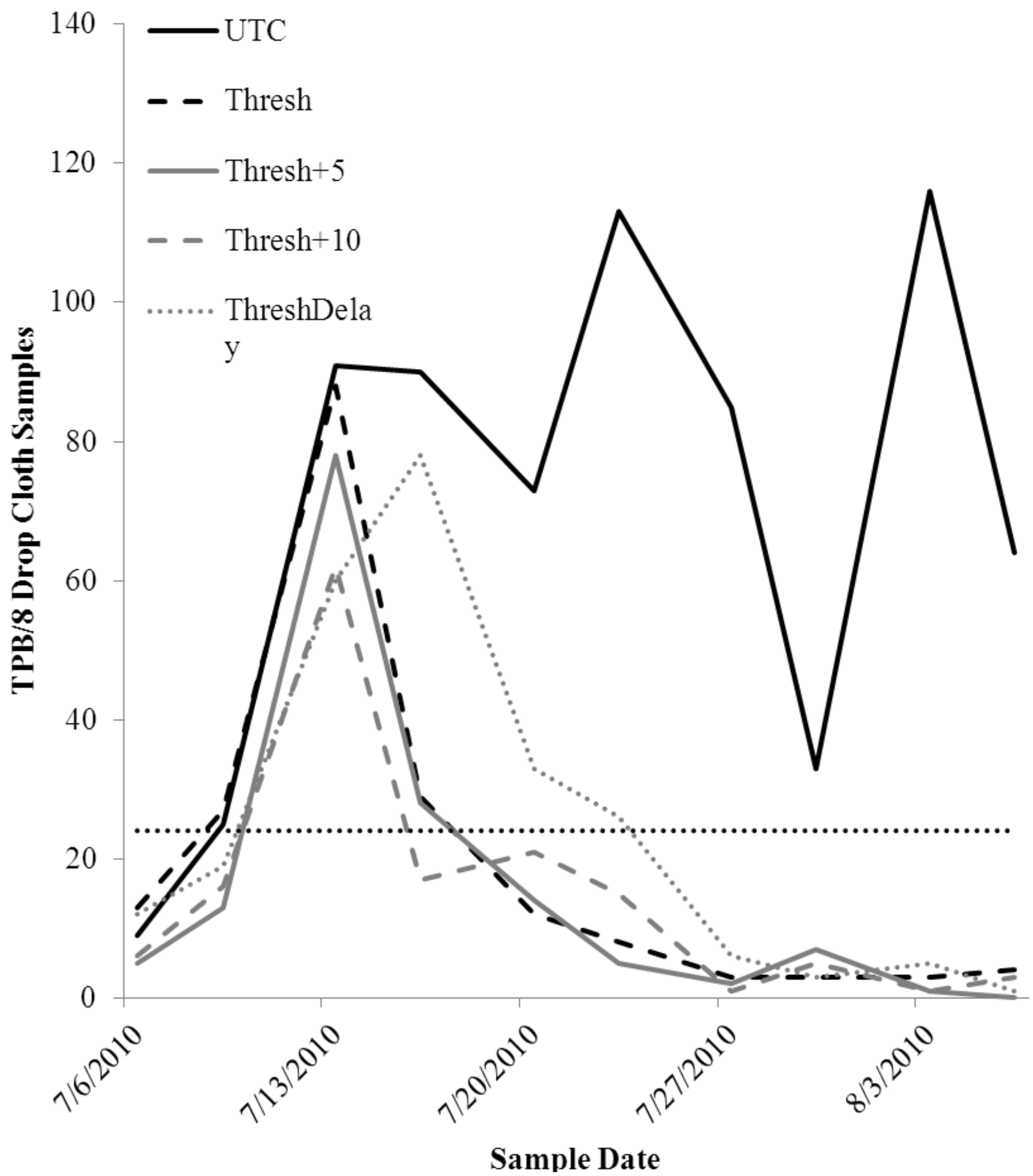

Figure 2.1 Tarnished plant bug densities/eight drop cloth samples at each sample date in 2010.

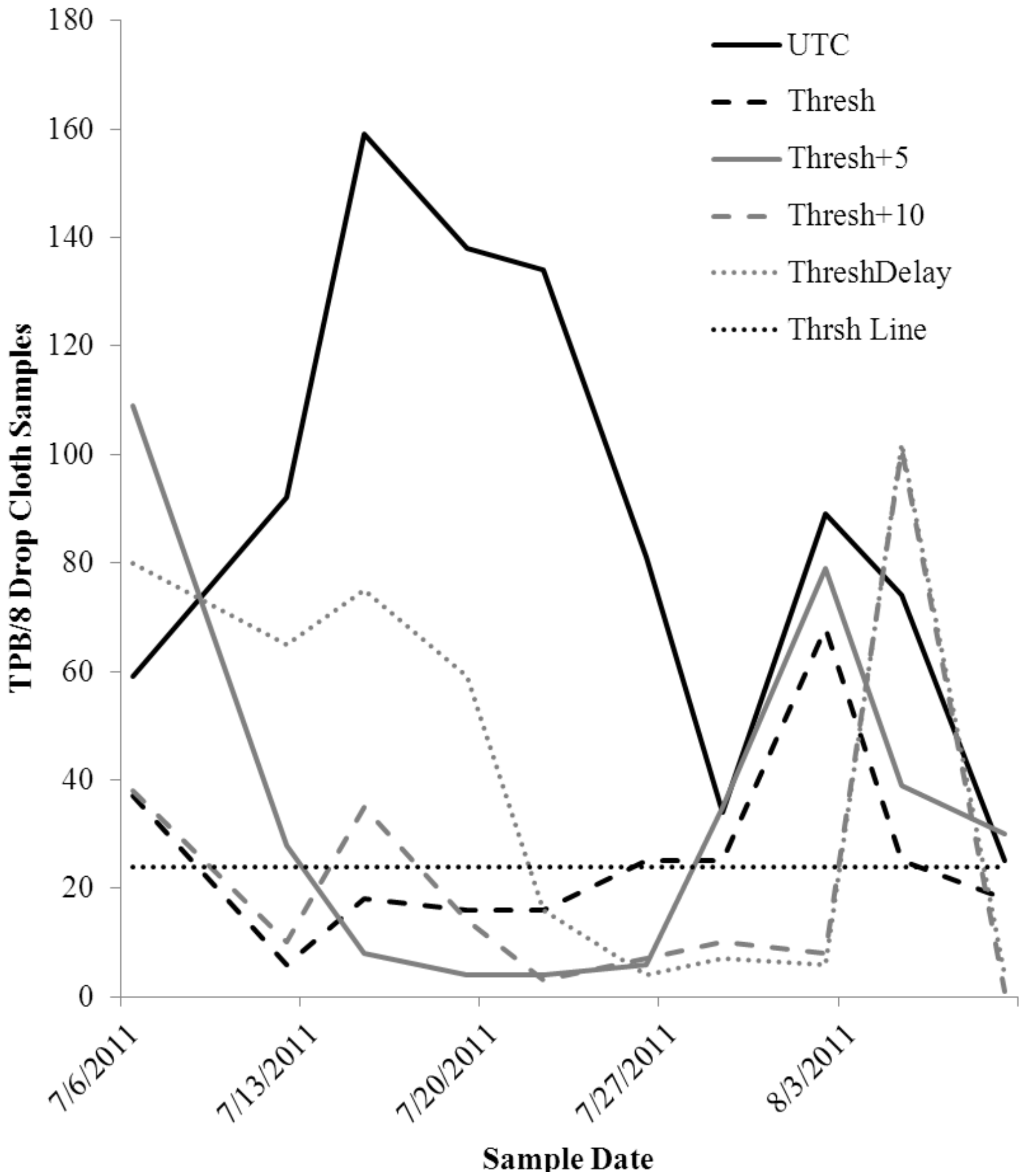

Figure 2.2 Tarnished plant bug densities/eight drop cloth samples at each sample date in 2011.

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CHAPTER III

THE IMPACT OF PLANTING DATE AND VARIETAL MATURITY ON TARNISHED PLANT BUG DAMAGE AND INSECTICIDE APPLICATION FREQUENCY IN COTTON

Abstract

A field experiment was conducted at the Delta Research and Extension Center in Stoneville, MS during 2010 and 2011 to investigate the impact of varietal maturity and planting date on tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), in cotton. Four planting dates were selected to encompass the standard cotton planting window for the Delta region of Mississippi. The planting dates included mid-April, early-May, mid-May, and early-June. An early maturing variety and a late maturing variety were planted at each planting date. Each plot was split into sprayed for tarnished plant bug and unsprayed. Plots were sampled weekly for tarnished plant bug densities from first square until physiological maturity. Plots were harvested at the end of the season and lint yields were determined. Planting dates one and two had significantly lower densities of tarnished plant bug than the latter two planting dates. Fewer foliar insecticide applications were needed at the earlier planting dates. Planting date one had the highest yields and each successive planting date decreased in yield significantly. Earlier planting dates also sustained less yield loss from tarnished plant bug than later planting dates. The early maturing variety yielded significantly more than the late maturing variety. Tarnished plant bug also had less impact on yield of the early variety as a result of

tarnished plant bug damage than on the late variety. Averaged across all other factors, the sprayed plots yielded significantly more than unsprayed plots. A significant spray by variety interaction occurred as a result of the larger difference in yield between the sprayed and unsprayed plots of the late variety compared to the early variety. These data demonstrate that later plantings of cotton in the Mississippi Delta are more impacted by tarnished plant bug than early plantings. Late season tarnished plant bugs have a greater impact on yield losses in cotton than earlier in the season. As a result, growers should manage their crop for earliness through planting date and varietal selection.

Introduction

Cotton, *Gossypium hirsutum* L., production in the midsouthern U.S. has decreased in recent years due to low commodity prices and rising input costs. Current input costs include technology fees associated with transgenic seed varieties, seed treatments for early season insect and disease control, increased weed control costs due to herbicide resistant weeds, higher fuel and fertilize costs, and costs of control for insect pests. Combined, these input costs make cotton less profitable and/or more risky than alternative crops to growers.

Tarnished plant bug, *Lygus lineolaris* (Palisot de Beavois), is the most important insect pest of cotton in Mississippi. During 2011 in the Mississippi Delta Region, a single application of an insecticide for tarnished plant bug averaged $34.25/ha (Williams 2012) . Growers in this region averaged 7 applications, resulting in nearly $240/ha cost of control for tarnished plant bugs alone. Resistance of tarnished plant bug to commonly used insecticides contributes to the current control issues. Resistance to the pyrethroid class of insecticides was first documented in field populations of tarnished plant bug in

Mississippi in 1992 (Snodgrass 1996). Snodgrass et al. (2009) also documented resistance to acephate in field populations of tarnished plant bug in Mississippi. Because of the increased input costs, an integrated approach that incorporates insecticides with other control methods is needed for sustainable management of tarnished plant bugs in the Mississippi Delta.

Early maturing varieties were often recommended to minimize the impacts of late season boll weevil, *Anthonomus grandis grandis* (Bohemanm), and pyrethroid resistant tobacco budworm, *Heliothis virescens* (F.), (Luttrell 1994). However, the boll weevil eradication program has eliminated the boll weevil as an economic pest of cotton in most areas of the U.S. (Williams 2012). Similarly, the introduction of cotton expressing *Bacillus thuringiensis* in 1996 significantly reduced the impact of the tobacco budworm in cotton (Williams 2012). *Bt* cotton provides complete control of tobacco budworm and no supplemental foliar insecticide applications have been needed for tobacco budworm on Bt cotton (Williams 2009). As a result, the need for early maturing varieties declined and longer season varieties are currently more common than they were in the 1990's.

Cotton is a perennial shrub managed as an annual crop. Due to being a perennial plant in nature, cotton has an indeterminate growth habit. This indeterminate growth allows it to flower over a long period of time, approximately 6-8 weeks, compared to other cultivated crops. As a result, cotton is more susceptible to economic damage from insect pests such as tarnished plant bug that prefer to feed on flowering plants. Reducing the amount of time spent flowering through varietal maturity selection could be beneficial in the management of tarnished plant bug. In the absence of late season insect pests, later maturing varieties tend to produce higher yields than earlier maturing varieties (Thaxton et al. 2007). Given the current levels of insecticide resistance in tarnished plant bug, varietal maturity and planting date are two cultural methods that need to be investigated to avoid yield losses from late season tarnished plant bug infestations.

Materials and Methods

To determine the impact of planting date and varietal maturity on tarnished plant bug management, an experiment was conducted in Stoneville, MS at the Delta Research and Extension Center in 2010 and 2011. The experiment was a split-split block design. Planting date served as the main plot factor and included four times during the recommended time frame for planting cotton in Mississippi. The four planting dates used in 2010 were April 20, May 6, May 19, and June 2. The four planting dates used in 2011 were April 14, April 29, May 15, and May 31. Cotton varietal maturity served as the sub-plot factor and included an early maturing variety and a mid-late maturing variety. Deltapine 0912B2RF was the early maturing variety and Deltapine 0949B2RF was the mid-late maturing variety. Cotton varieties expressing two Bt genes were used to minimize the impact of lepidopteran pests on final cotton yields. The sub-sub-plot factor was two levels of tarnished plant bug control. These levels included untreated for tarnished plant bug and treated for tarnished plant bug. The treated plots were sprayed as needed based upon economic thresholds listed in the current insect control guide (Catchot 2010; Catchot 2011) with insecticides and insecticide mixtures designed to maximize the level of tarnished plant bug control. Insecticides included organophosphates, neonicotinoids, and pyrethroids either applied alone or as tank mixtures. Application decisions were based on the average tarnished plant bug density of all 4 replications for a particular planting date/variety treatment. Plot size was sixteen rows by 23 m in length. Each variety was planted at 113,668 seeds/ha into raised conventional tilled beds with

1.02 m row spacing. Seed were treated with a commercial premix of thiamethoxam, abamectin, azoxystrobin, fludioxonil, and mefenoxam (Avicta Complete Pak, Syngenta Crop Protection, Greensboro, NC) to minimize the impacts of thrips, nematodes, and seedling disease. A preemergence application of herbicide was made over the entire area for control of summer annual weeds. Tarnished plant bug densities were monitored weekly in each plot. The outside six rows of each plot were used for sampling tarnished plant bug densities. During the pre-flowering stages, tarnished plant bug adult and nymph 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 per plot. Because different sampling methods were used throughout the season, numbers of adults and nymphs were converted to percent of threshold for each treatment, and recorded. Thresholds used were 8 tarnished plant bugs per 100 sweeps during the first two weeks of squaring, 15 tarnished plant bugs per 100 sweeps from the third week of squaring through first bloom, and 3 tarnished plant bugs per six row feet on a drop cloth throughout the bloom period (Catchot 2011). Nodes above white flower were determined by counting the number of main stem nodes above the uppermost first position white flower as described in Bourland et al. (1992). Nodes above white flower counts were used to terminate insecticide applications for each planting date by variety treatment. Russell et al. (1999) found that bolls that have accumulated at least 300 heat units were not damaged by tarnished plant bugs. Therefore, it can be assumed that the last harvestable bolls were safe from tarnished plant bug damage when plants averaged nodes above white flower 5 plus 300 heat units and insecticide applications were terminated at that point in this experiment. At the end of the season, the center two rows of each plot were harvested and seedcotton weights were recorded. Lint percentage was determined by taking 38 percent of the total harvested seedcotton weight. Lint yield was converted to kg/ha. In the model, planting date, variety, and treatment were designated as fixed effects, and replication and year were designated as random effects. Degrees of freedom were calculated using the Kenwood-Rogers method. Differences were considered significant for $\alpha=0.05$. All data were analyzed with analysis of variance (Littell et al. 1996) .

Results and Discussion

When averaged across years, planting dates, and varieties, mean tarnished plant bug densities exceeded the recommended threshold for most of the season (Figure 3.1). In general, tarnished plant bug densities were similar between the sprayed and unsprayed plots from first square to first flower (June-early July). Although it appears insecticide applications did not impact tarnished plant bugs, square retention remained at or near 80 percent in the sprayed plots. In contrast, square retention in the unsprayed plots declined to unacceptable levels (data not shown). During that time of year, the population was comprised of mostly migrating adults that were moving into and between plots, causing densities to appear similar in sprayed and unsprayed plots within a few days of an insecticide application. Throughout the rest of the season (July-August), the population was comprised of mostly nymphs and the sprayed plots had lower densities than the unsprayed plots. In 2010, both varieties briefly exceeded the recommended threshold during early July for the first planting date, but generally remained near or below threshold. Both varieties in the second planting date exceeded the threshold in 2010 more often than planting date one. In 2010, both varieties in the third planting date remained above the recommended threshold for the majority of the reproductive period of the cotton. Similar to planting date three, both varieties in the fourth planting date exceeded the recommended threshold for most of the season in 2010. In 2011, both varieties in the first planting date remained below threshold for much of the season and didn't exceed the threshold until the latter part of the growing season. Both varieties in the second planting date began to exceed the threshold earlier than planting date one and remained above current thresholds longer than planting date one. In 2011, both varieties in the third planting date began the season exceeding the threshold for tarnished plant bug, and rarely reached population levels below threshold throughout the season. Similar to planting date three, in 2011, the fourth planting date began the season exceeding threshold and rarely reached population levels below threshold throughout the season.

There was no significant planting date by variety by spray interaction (F=0.41; df=3, 105; *P*=0.74) on tarnished plant bug seasonal densities. There was no significant planting date by variety interaction (F=0.27; df=3, 105; *P*=0.85) on tarnished plant bug seasonal densities. There was no significant planting date by spray interaction (F=1.58; df=3, 105; *P*=0.2) on tarnished plant bug seasonal densities. There was no significant variety by spray interaction (F=0.07; df=1, 105; *P*=0.79) on tarnished plant bug seasonal densities. Due to having no interaction effects, the interactions were removed from the model. Planting date had a significant impact on tarnished plant bug seasonal densities expressed as a percent of threshold across both years (F=23.18; df=3, 115; *P*<0.01) (Table 3.1). For planting dates one and two, the mean percent threshold throughout the season was able to be maintained just below threshold through foliar insecticide applications (Table 3.1). For planting dates three and four, even with foliar insecticide applications being made, the mean seasonal percent of threshold remained above 100 percent. Generally, plant bug densities expressed as a percent of threshold were higher at later planting dates than at earlier planting dates (Table 3.1). Variety had no significant impact (F=1.06; df=1, 115; P= 0.30) on seasonal tarnished plant bug densities. Spray had a significant effect (F=134.05; df=1, 115; P<0.01) on seasonal tarnished plant bug densities. Sprayed plots had significantly lower seasonal densities of tarnished plant bugs than unsprayed plots (Table 3.1).

In 2010 and 2011, the number of foliar insecticide applications required to maintain tarnished plant bug levels below the current economic threshold were low at the first and second planting dates (Table 3.2). Both varieties in the first planting date required only three applications throughout the reproductive period. For the second planting date, the early maturing variety required three applications while the late maturing variety averaged four applications. The third and fourth planting dates required more foliar insecticide applications than the first two planting dates to maintain tarnished plant bug densities below the current economic threshold (Table 3.2). The early variety in the third planting date required six foliar insecticide applications for tarnished plant bug while the late variety in the third planting date required seven foliar applications for tarnished plant bug control. Both varieties in the fourth planting date required six foliar applications for tarnished plant bug control during the reproductive period of cotton.

There was no significant planting date by variety by spray interaction (F=0.3; df=3, 105; P=0.82) effect on yield. There was no significant planting date by variety interaction (F=0.63; df=3, 105; P=0.59) effect on yield. There was no significant planting date by spray interaction (F=0.81; df=3, 105; P=.49) effect on yield. The insignificant interactions were removed from the model. There was a significant interaction between variety and control level for yield (F=8.25; df=1, 114; P=0.01). The early variety yielded significantly more than the late variety for both sprayed and unsprayed plots (Table 3.3). Additionally, the difference between the sprayed and unsprayed plots was approximately 2-fold greater for the late maturing variety than for the early maturing variety. This is explained by the early variety spending less time in the reproductive growth stages than the late variety, which is the most susceptible stage to tarnished plant bug damage. This suggests that when planting a later maturing variety, a more aggressive tarnished plant bug management plan will be needed.

Planting date had a significant impact on yield when averaged across varieties and insecticide treatments (F= 27.12; df=3, 114; P<0.01). Planting date one produced the highest yield, and each successive planting date yielded significantly less than the previous planting date (Table 3.4). These data suggest that yield potential of cotton planted from mid-April through early-May is greater from an agronomic standpoint than planting from mid-May to early-June. The early planting dates completed flowering earlier in the season than later planting dates and did not experience the high population densities of tarnished plant bugs. Additionally, insecticide resistance levels increase as the season progresses and late season populations are more difficult to control (Snodgrass and Scott 2000). Producers managing tarnished plant bug as the primary pest could benefit from planting earlier in the planting window to avoid late season tarnished plant bugs during the critical reproductive stages of the crop.

Generally, as planting date increased later into the season, percent yield loss due to tarnished plant bugs increased (Table 3.5). Also, at each planting date, percent yield loss was less for the early maturing variety than for the late maturing variety.

Yield potential was higher at early planting dates and decreased as planting date increased. Also, later planting dates required more insecticide applications to maintain tarnished plant bug population levels below the economic threshold. Percent yield loss was also greater for the late maturing variety than for the early maturing variety. Producers have the potential to reduce insecticide applications by planting early to avoid the higher late season tarnished plant bug populations. Reducing the number of insecticide applications also could play a pivotal role in resistance management for tarnished plant bugs. Overall, managing for "earliness" through planting date and varietal maturity selection can maximize yields, reduce insecticide input costs, and make cotton production more sustainable.

Table 3.1 Mean percent of threshold of tarnished plant bug throughout the season at each planting date for sprayed and unsprayed plots across both years.

	Sprayed	**Unsprayed**	
Planting Date	**Mean (SEM)**	**Mean (SEM)**	**Mean (SEM)**
Planting Date 1	94.51 (10.9)	182.69 (15.5)	138.60 (9.8) c
Planting Date 2	96.69 (8.1)	199.05 (14.5)	147.87 (8.8) c
Planting Date 3	165.91 (16.5)	305.05 (21.3)	235.48 (14.1) a
Planting Date 4	136.60 (10.0)	228.83 (17.9)	182.71 (10.6) b
Mean (SEM)	123.42 (5.9) b	228.91 (8.9) a	

Means within a column followed by the same letter are not significantly different at ($P \leq 0.05$) (LSD=25.3). Means within a row followed by the same letter are not significantly different at ($P \leq 0.05$) (LSD=17.9).

Table 3.2 Mean number of insecticide applications for each variety at each planting date across both years.

	Varietal Maturity	
Planting Date	**Early Maturing**	**Late Maturing**
Mid April	3	3
Early May	3	4
Mid May	6	7
Early June	6	6

Table 3.3 Interaction between varietal maturity and insecticide application on mean cotton yield.

Variety + Treatment	Yield (kg/ha)	SEM
Early Sprayed	1390.48 a	50.18
Late Sprayed	1228.80 b	53.81
Early Unsprayed	1036.10 c	36.61
Late Unsprayed	688.54 d	40.56

Means followed by the same letter are not significantly different at ($P \leq 0.05$) (LSD=90.6447).

Table 3.4 Effect of planting date on mean cotton yield averaged across varieties and spray treatments.

Planting Date	Yield (kg/ha)	SEM
Mid April	1274.22 a	55.48
Early May	1162.54 b	70.10
Mid May	1019.97 c	56.30
Early June	887.20 d	57.57

Means followed by the same letter are not significantly different at ($P \leq 0.05$) (LSD=90.6447).

Table 3.5 Impact of planting date and varietal maturity on percent yield loss due to tarnished plant bug.

	Percent Yield Loss	
Planting Date	**Early**	**Late**
Mid April	22	37
Early May	21	44
Mid May	23	44
Early June	38	56

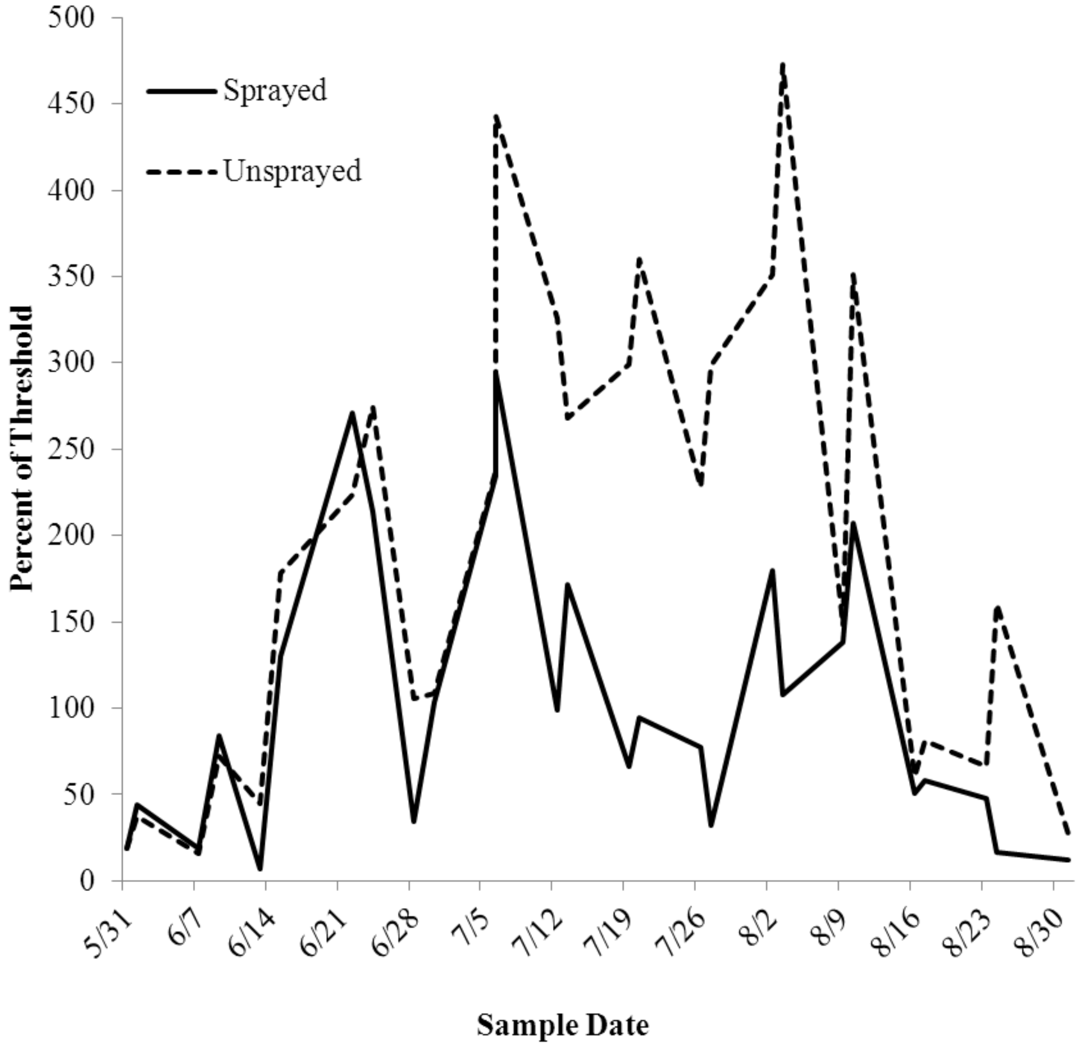

Figure 3.1 Mean densities of *L. lineolaris* across all planting dates and varieties at each sample date across both years. Densities are expressed as a percentage of the current recommended thresholds.

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CHAPTER IV

COMPARISON OF TARNISHED PLANT BUG DEVELOPMENT FROM THE DELTA AND HILLS REGIONS OF MISSISSIPPI

Abstract

A laboratory experiment was performed to compare fitness parameters of tarnished plant bug populations collected from the Hills and Delta regions of Mississippi. Each population was split into two cohorts to be reared on cotton or artificial diet to make comparisons of food source as well as region of collection. Data were analyzed using analysis of variance and regression analysis. Populations were collected from pigweed, *Amaranthus* spp., in four locations in each region. Each population was maintained separately and allowed to mate. Progeny from the F1 generation of each population were compared from each region and food source. Parameters measured included development times to fourth instar, fifth instar and adult, total nymphal survivorship, fecundity, and fertility. Populations collected from the Delta region and reared on cotton developed significantly faster to all life stages than other populations while populations from the Hills reared on cotton were significantly slower than other populations except Hills populations reared on artificial diet. There were no significant differences for percent survivorship for region of collection; however, populations on diet had significantly higher survivorship than those reared on cotton. Populations of tarnished plant bug from the Delta region laid significantly more eggs per female per day than populations from the Hills region. Populations reared on cotton also laid significantly more eggs per

female per day than those reared on diet. Populations collected in the Delta region laid significantly more viable eggs per female per day than those from the Hills region. Populations reared on cotton produced significantly more nymphs per female per day than those reared on diet. There were no significant differences in mean percent hatch of total eggs laid for region or food source. These data indicate there are differences in several fitness parameters between tarnished plant bug populations from the Hills and Delta regions of Mississippi.

Introduction

The tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), is an important pest of numerous crops in the U.S. (Nordlund 2000). An important factor contributing to the pest status of this insect is its adaptability to a wide range of environments. The tarnished plant bug has one of the broadest host ranges of any insect species with over 300 documented host plants (Young 1986). Similarly, Snodgrass et al. (1984) reported 169 plant species as hosts from the Delta region of Mississippi. The majority of plants preferred by tarnished plant bug include species that are generally abundant in disturbed or early successional type habitats (Layton 2000). Because of this broad host range, tarnished plant bug is able to utilize a succession of different hosts for feeding and reproduction throughout the year. As a result, tarnished plant bug is capable of building high population densities on weedy hosts prior to the crops in the area being attractive for feeding and reproduction.

The tarnished plant bug is an important pest of cotton in Mississippi. Cotton production in Mississippi can generally be separated into two distinct geographical regions, the Hills and the Delta. The Hills region is mostly comprised of smaller cultivatable fields interspersed across the landscape. Overall, land dedicated to row crop agriculture makes up a small percentage of the overall land area (NASS 2007). In contrast, cultivatable land accounts for a larger percentage of the land area in the Delta region. Fields dedicated to row crop agriculture are much larger and more contiguous in the Delta region than in the Hills region (NASS 2007). Although insecticide applications for tarnished plant bug occur annually in both regions, tarnished plant bug is a more economically important pest in the Delta region. During 2011, growers in the Mississippi Delta averaged 7 applications per hectare targeting tarnished plant bug with a total cost of nearly $240 per hectare (Williams 2012). In contrast, growers in the Hills region of Mississippi averaged approximately 1.75 applications per hectare targeting tarnished plant bug with a total cost of $60.51 per hectare (Williams 2012). One reason for this is the development of resistance to the pyrethroids and organophosphates by tarnished plant bugs in the Delta (Snodgrass 1996; Snodgrass et al. 2008a; Snodgrass et al. 2008b; Snodgrass et al. 2009).

Although resistance does not fully explain the discrepancy in the pest status of tarnished plant bugs between the Delta and the Hills regions of Mississippi. One theory that has been proposed to explain the observed difference in tarnished plant bug pressure in the two regions is that tarnished plant bugs in the Delta are better adapted to cotton than those in the Hills. This may have developed as a result of the relative ecological simplicity associated with the lower host diversity that is characteristic of heavily cropped environments (Layton 2000). The differences in the agricultural ecosystems of the Delta and the Hills and the continuous production of cotton over a large percentage of the land area for a long period of time are factors that could influence adaptation by an insect pest. Given the large gap in control costs, adaptability of the populations of tarnished plant bugs in the two distinct regions needs to be investigated to determine if there is a physiological difference between the two populations.

Materials and Methods

Four populations of tarnished plant bug adults were collected from both the Hills and Delta regions of Mississippi at two different dates, June 8, 2011 and August 1, 2011 for this experiment. All populations were collected from Palmer amaranth, *Amaranthus palmeri* (S. Wats). Collections were made by taking several sweeps with a sweep net in heavy patches of Palmer amaranth. Sweep nets were then emptied into a plastic container, and tarnished plant bug adults were removed with an aspirator. The adults were then placed in cricket cages for transport back to the rearing facility at Mississippi State University. Each of the four populations was placed in individual 8.3L plastic rectangular containers with self sealing lids (Rubbermaid Servin' Saver®). The lids on the containers were modified by removing the inner plastic so that only the sealing frame remained. The portion of the lid that was removed was replaced with a tuille fine mesh screen. All containers were washed prior to use with a solution consisting of hot soapy water and bleach, rinsed, and allowed to air dry. Tarnished plant bug colonies were maintained at 26.7˚C +/- 2˚C with a humidity level of 60% at a photoperiod of 16:8 hour (light: dark). Screens on the containers were changed once per week. The food source (diet packs) for the initial adult population consisted of a oligidic diet that contains blended whole chicken eggs, sterile water, sugar, Brewer's yeast, 50% honey solution, and a 10% acetic acid solution (Cohen 2000) presented in 5x5cm Parafilm (Bemis Company Inc., Neenah, WI) packets. Diet packs were changed every Monday, Wednesday, and Friday throughout the oviposition period. Two oviposition packs that consisted of a 4% solution of corageenan were also placed on the screen. Oviposition packs were collected and replaced on the same days that the feeding packets were replaced. Oviposition packs were maintained separately for the four populations. Each collection of the study was replicated three times. Date of oviposition served as blocks/replications in a randomized complete block design and nymphs consisted of cohorts from oviposition packs collected on the same days. One cohort from each population (F1 generation) was fed squares and the other cohort was fed artificial diet. Squares were changed daily while diet packs were changed on Monday, Wednesday, and Friday. Mortality and nymphal instar was recorded every three or four days to minimize handling of populations during the first collection of the experiment. Due to having too few data points for calculating development times, nymphal instar ratings for each cohort were taken daily during the second collection with mortality being measured every three to four days. Survival rates and time of development on cotton were compared to the cohort reared on diet packs. Survival rates and time of development for Hills populations were also compared to Delta populations. Once nymphs had molted into adults, the sex of each individual was determined. A target population of ten males and ten females from each colony was placed in new containers and allowed to mate unhindered if survivorship allowed. On populations that had low survivorship, as many surviving males and females that could be placed in new containers at a 1:1 male to female ratio were placed in the containers. All populations and cohorts at this stage were fed the oligidic diet that was previously described. Oviposition packs were placed on top of the screen. Eggs were counted on Mondays, Wednesdays, and Fridays to measure fecundity. The eggs laid in oviposition packs were monitored to determine the percentage of total eggs that produced viable offspring expressed as nymphs per female per day.

Development curves were calculated using regression analysis. The relationship for all colonies fit a quadratic equation (Table 4.1, Figure 4.1). Therefore, data were transformed by cubing the *y* variable (instar) to linearize the relationship (Ott 1993) so that the regression equation could be used to calculate days to fourth and fifth instar, and adulthood (Table 4.1, Figure 4.2). Regression equations were developed for each replication. Within each replication, the cube of each life stage (fourth and fifth instar, and adult) was used in the regression equation to solve for *x* (days). By cubing the life stage, back transformation was not needed to get the actual days. For the adult stage, six was used for the *y* variable. Regression equations were developed for each replication in order to perform analysis of variance on mean days to each life stage for each region and food source combination. Data for days to each life stage, total survivorship, numbers of eggs per female per day, and number of viable eggs per female per day were analyzed with analysis of variance (Proc Mixed SAS 1996). Percent fertility was calculated based on the numbers of eggs per female per day and nymphs per female per day and analyzed with analysis of variance. In the model, region, food, and region by food interaction were designated as fixed effects, and replication was designated as a random effect. Degrees of freedom were calculated using the Kenwood-Rogers method. Differences were considered significant for $\alpha=0.05$.

Results and Discussion

Fitness parameters of tarnished plant bug varied by region and food source in this experiment. There was no significant food by region interaction ($F= 0.21$; $df= 1, 39$; $P= 0.65$) effect on survivorship. Region ($F=1.34$; $df=1, 39$; $P=0.25$) of collection did not have a significant impact on survivorship of the F1 generations of each of the colonies

(Table 4.2). Food source ($F=13.25$; df=1, 39; $P<0.01$) had a significant impact on survivorship of the F1 generation when averaged across populations (Table 4.2). Overall, F1 generations of tarnished plant bugs had significantly higher survival rates on the oligidic diet than on cotton.

There was a significant food by region interaction for days to fourth instar ($F= 9.96$; df=1, 6; $P=0.02$), fifth instar ($F= 13.16$; df=1, 6; $P=0.01$), and adulthood ($F= 10.95$; df=1, 6; $P=0.02$) (Table 4.3). Populations from the Delta region reared on cotton developed significantly faster than all other food by region combinations. Additionally, development of populations collected from the Hills region and reared on cotton developed significantly slower than those collected in the Delta and reared on oligidic diet.

There was no significant food by region interaction effect ($F=0.51$; df= 1, 44; $P=0.48$) on number of eggs laid per female per day. Region ($F= 12.34$; df=1, 44; $P<0.01$) had a significant impact on number of eggs laid per female per day for the F1 generation (Table 4.4). Tarnished plant bug populations from the Delta region of Mississippi laid significantly more eggs than populations from the Hills region. Food source ($F=12.78$; df=1, 44; $P<0.01$) also had a significant impact on number of eggs laid per female per day for the F1 generations (Table 4.4). Tarnished plant bugs reared on cotton laid significantly more eggs per female per day than those reared on oligidic diet.

There was no significant food by region interaction effect ($F=1.6$; df= 1, 39; $P=0.21$) on number of nymphs per female per day. Region ($F=12.87$; df= 1, 39; $P<0.01$) had a significant impact on the number of nymphs per female per day for the F1 generation (Table 4.5). Tarnished plant bug populations collected from the Delta region of Mississippi produced significantly more viable offspring per female per day than those collected from the Hills region. Food source ($F=12.87$; df= 1, 39; $P<0.01$) also had a significant impact on the number of viable offspring produced by each female per day for the F1 generation (Table 4.5). Tarnished plant bug populations reared on cotton produced more nymphs per female per day than those reared on oligidic diet.

There was no significant food by region interaction effect ($F=0.81$; df= 1, 39; $P=0.37$) on percent hatch rate. Region did not significantly impact percent hatch rate ($F=0.29$; df=1, 39; $P=0.59$). Food source also did not significantly impact percent hatch rate for any of the colonies ($F=1.24$; df=1, 39; $P=0.27$). Percent hatch ranged from 27.20 to 36.63 percent for all of the populations (Table 4.6).

Although region of collection did not significantly impact survivorship of the F1 generation of tarnished plant bug, food source did have a significant impact. Survivorship was significantly higher for those populations on oligidic diet than those on cotton. This difference was to be expected as cotton is not known to be a preferred host of tarnished plant bug (Fleischer and Gaylor 1988). There was a food by region interaction on development times to fourth and fifth instar, and also to adulthood for the F1 generation. Tarnished plant bug populations from the Delta region reared on cotton developed significantly faster than all other food by region pairings. Overall, tarnished plant bug times of development to the adult stage ranged from 24.34 days for populations from the Delta that were fed cotton to 26.01 days for populations from the Hills that were fed cotton. These times are longer than previously reported development times on various plant hosts. Development times of nymphs ranged from 18 days on cotton at 25.6^0 C (Fleischer and Gaylor 1988) to 19.7 days on green bean, *Phaseolus vulgaris* L., at 25.0^0 C (Ridgway and Gyrisco 1960). Bariola (1969) reported that tarnished plant bugs required 33 days to complete a generation on cotton at 26.7^0 C, but that accounted for the pre-oviposition period in adults. The discrepancy in development times between previous research and the current experiment cannot be explained, but relative differences between regions and food sources in the current experiment are still valid. Although differences in development of populations collected were observed on the different food sources, development times of populations from the Hills region were not different among cotton and oligidic diet.

Overall, tarnished plant bugs collected in the Delta produced more offspring over a 6 week time period than those collected from the Hills. Although survival was higher for populations reared on oligidic diet, tarnished plant bugs reared on cotton produced significantly more nymphs per day. Percent hatch rate was not significantly different regardless of region of collection or food source. This suggests that using numbers of nymphs or eggs per female per day can be used to compare fertility between tarnished plant bugs in the Hills and Delta. Most of the fitness parameters measured in the current experiment suggest that tarnished plant bugs in the Delta region of Mississippi are more fertile and adapted to cotton than those in the Hills region. Although tarnished plant bugs are more intensely managed in the Delta region than the Hills region, these data may partially explain the differences in insecticide resistance between populations in the Delta and Hills regions of Mississippi (Snodgrass et al. 2008b). These data suggest that with the advanced development times, this could possibly accelerate the resistance ratios among Delta populations. It also suggest that these development times could potentially cause the Delta to be dealing with one extra generation per year compared to the Hills.

Results on a different host plant or under different environmental conditions may vary from what was observed in the current experiment. These data suggest that different biotypes of tarnished plant bug may exist in different regions of Mississippi. Additional research is needed that utilizes molecular markers and genetic analysis to confirm these differences. It also suggests that this potential biotype is more adapted to cotton and fertile than the one in the Hills region of Mississippi. This could further explain the contrast in control issues and control costs observed in the two regions, along with the larger monocultures and resistance issues. These data provide an important understanding of tarnished plant bug ecology in Mississippi. They will be valuable for developing life tables of tarnished plant bug development from the Delta and Hills regions on cotton.

Table 4.1 Regression equations used to develop days to each instar for each region and food combination.

	Raw Data		Transformed (y^3)	
Treatment	**Equation**	**P>F**	**Equation**	**P>F**
Delta Cotton	$y=-10.33+1.29x-.03x^2$	<0.01	y=17.2x-207.08	<0.01
Delta Diet	$y=-7.61+1.00x-.02x^2$	<0.01	y=16.81x-210.79	<0.01
Hills Cotton	$y=-7.57+.97x-.02x^2$	<0.01	y=16.14x-210.80	<0.01
Hills Diet	$y=-7.53+.97x-.02x^2$	<0.01	y=16.88x-219.55	<0.01

Table 4.2 Effect of region of collection and food source on survivorship rates of F1 generations of tarnished plant bug.

	Cotton	Diet	Mean
	Mean (Std. Err.)	**Mean (Std. Err.)**	**Mean (Std. Err.)**
Hills	61.92 (6.94)	81.20 (2.97)	71.56 A (4.2)
Delta	58.62 (5.76)	73.59 (4.02)	66.11 A (3.78)
Mean	60.27 b (4.42)	77.4 a (2.57)	

Means in a row followed by the same upper case letter and means in a row followed by the same lower case letter are not significantly different at ($P \leq 0.05$) (LSD=9.51705).

Table 4.3 Effect of food by region interaction on mean days to fourth and fifth instar and adulthood.

	Days to 4th Instar	Days to 5th Instar	Days to Adult
	Mean (Std. Err.)	**Mean (Std. Err.)**	**Mean (Std. Err.)**
Delta Cotton	15.86 c (0.21)	19.26 c (0.39)	24.34 c (0.66)
Delta Diet	16.45 b (0.24)	19.91 b (0.48)	25.07 b (0.86)
Hills Diet	16.89 ab (0.29)	20.32 ab (0.55)	25.44 ab (1.01)
Hills Cotton	17.13 a (0.31)	20.69 a (0.61)	26.01 a (1.05)

Means in a column followed by the same letter are not significantly different at ($P\leq 0.05$) (LSD=.45694), ($P\leq 0.05$) (LSD=.48651), ($P\leq 0.05$) (LSD=.68328) for 4^{th} instar, 5^{th} instar, and adults, respectively.

Table 4.4 Effect of region and food source on number of eggs laid per female per day for F1 generations of tarnished plant bug.

	Cotton	**Diet**	**Mean**
	Mean (Std. Err.)	**Mean (Std. Err.)**	**Mean (Std. Err.)**
Hills	2.24 (0.23)	1.35 (0.24)	1.79 B (0.19)
Delta	3.54 (0.46)	2.22 (0.25)	2.88 A (0.29)
Mean	2.89 a (0.28)	1.78 b (0.19)	

Means in a column followed by the same upper case letter and means in a row followed by the same lower case letter are not significantly different at (P≤ 0.05) (LSD=.62226).

Table 4.5 Effect of region and food source on F1 generations of tarnished plant bug production of viable offspring per female per day.

	Cotton	**Diet**	**Mean**
	Mean (Std. Err.)	**Mean (Std. Err.)**	**Mean (Std. Err.)**
Hills	0.62 (0.08)	0.37 (0.09)	0.49 B (0.07)
Delta	1.14 (0.14)	0.62 (0.11)	0.88 A (0.10)
Mean	0.88 a (0.10)	0.49 b (0.07)	

Means in a column followed by the same upper case letter and means in a row followed by the same lower case letter are not significantly different at (P≤ 0.05) (LSD=.21839).

Table 4.6 Effect of region and food source on F1 generations of tarnished plant bug total percent hatch rate.

	Cotton	**Diet**	**Mean**
	Mean (Std. Err.)	**Mean (Std. Err.)**	**Mean (Std. Err.)**
Hills	29.87 (4.86)	28.87 (6.33)	29.37 A (3.90)
Delta	36.63 (5.55)	27.20 (2.76)	31.92 A (3.19)
Mean	33.25 a (3.68)	28.04 a (3.38)	

Means in a column followed by the same upper case letter and means in a row followed by the same lower case letter are not significantly different at ($P \leq 0.05$) (LSD=9.4871).

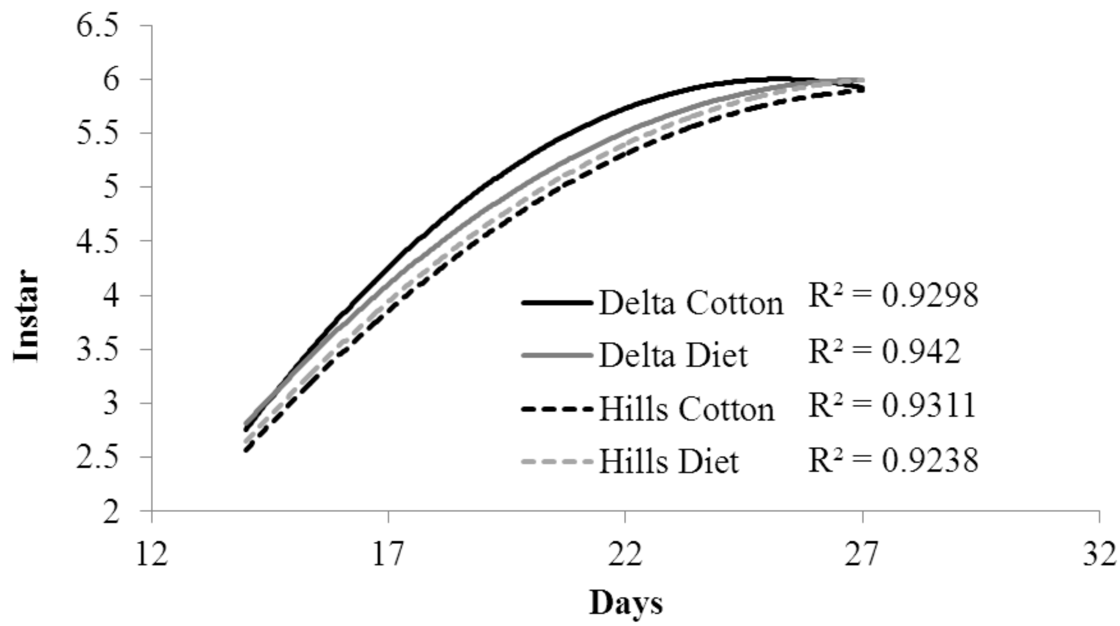

Figure 4.1 Development curves for tarnished plant bug collected from the Delta and Hills regions of Mississippi reared on cotton and artificial diet.

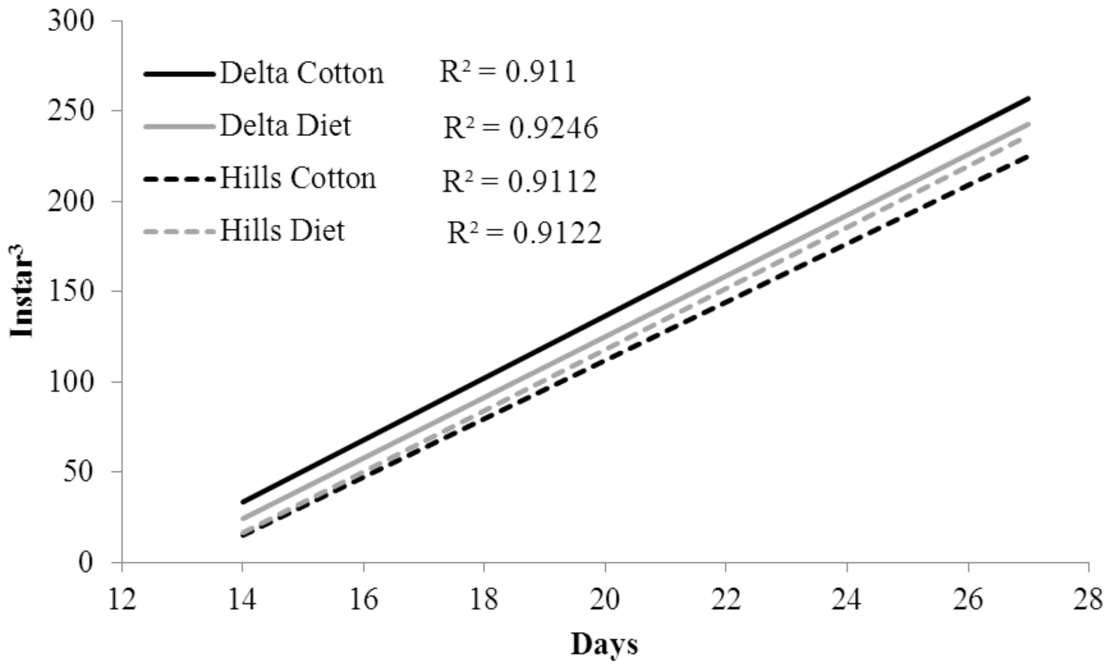

Figure 4.2 Cube transformed development curves for tarnished plant bug collected from the Delta and Hills regions of Mississippi reared on cotton and artificial diet.

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