

ARTHROPOD MANAGEMENT & APPLIED ECOLOGY

Evaluation of Simulated Late Season Tarnished Plant Bug Damage on Cotton Yield in ThryvOn and non-ThryvOn Cotton Technology

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ABSTRACT

A split-split plot experiment was conducted in Stoneville, MS in 2022 and 2023 to establish more precise insect termination timing to reduce insecticide applications for tarnished plant bug during late bloom in cotton. The main-plot factor was cotton technology that included non-ThryvOn and ThryvOn cotton. The subplot factor was removal timing. In each year, manual removal of squares took place during the fourth or fifth week of bloom. The sub-subplot factor was level of square removal consisting of 0, 50, and 100% above the uppermost first position white flower. To understand plant growth, maturity measurements were taken beginning at the first week of bloom until defoliation. These measurements included plant height, total node counts, nodes above white flower, and nodes above cracked boll. Cotton yield was also recorded. Results from 2022 and 2023 showed differences in plant maturity when 100% square removal was done during the fourth week of bloom. Due to differences among varieties, ThryvOn cotton had greater yields than non-ThryvOn cotton. These data combined with previous research suggest that insecticide termination could occur after the fourth week of bloom without significant yield loss.

Two decades ago, Mississippi averaged nearly 450,000 ha of cotton, today the state plants less than half that amount (Cook et al., 2023; Williams, 2003, 2007, 2008, 2009, 2010). Low cotton prices combined with high input prices for cotton management and higher grain prices have been the

driving factors in the dramatic change towards grain production. These high input costs include transgenic Bt cotton varieties, pesticides, intensive labor, equipment costs, and time involved. The Mississippi State University 2023 planning budget calculated that total specified expenses for a 1681.28 kg ha⁻¹ crop reached \$3,267.30 ha⁻¹ in production costs to produce cotton in the Mississippi Delta (Mississippi State University, 2022). Using this budget, returns above total specified expenses equaled \$21.90 ha⁻¹ for a Bollguard 3 Xtendflex (B3XF) variety using furrow irrigation. According to the planning budget using input costs for 2022, insecticide control was \$257.81 ha⁻¹ for all in-season insecticide applications. This cost is similar to that reported by Cook et. al (2023) at an average of \$228.90 ha⁻¹ for cotton inputs targeting insects in Mississippi. Most of the money spent, \$129.55 ha⁻¹, was on insecticide applications targeting the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois) (Cook et al., 2023).

The damage and costs associated with tarnished plant bug led to its ranking as the number one economic pest of cotton in the Mid-South region of the U.S. (Luttrell and King, 2014). Although small squares typically abscise, tarnished plant bug feeding on larger squares can result in malformation of flowers and bolls leading to reduced lint or lint quality (Layton, 2000; Tugwell et al., 1976). Numerous cultivation tactics, such as earlier planting date, variety selection, reduced nitrogen rates, and irrigation management, can be used to reduce inputs for tarnished plant bug and improve crop profitability (Adams et al., 2013; Samples et al., 2019; Wood et al., 2019). Even with these control tactics, insecticide applications are still a sizeable component in tarnished plant bug management (Crow et al., 2020a).

The recent commercialization of ThryvOn (Bayer CropScience, Research Triangle Park, NC) technology in cotton adds to increased input costs. However, the use of this tool can lessen reliance on foliar insecticides for tarnished plant bug management and help decrease selection pressure for resis-

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tance (Graham and Stewart, 2018). Field trials have shown a decrease in insecticide sprays targeting the tarnished plant bug along with increased yields compared to non-ThryvOn cotton (Corbin et al., 2020; Graham and Stewart, 2018). An average of 1.25 (Graham and Stewart, 2018) to 1.5 (Corbin et al., 2020) fewer insecticide applications were needed in ThryvOn cotton than non-ThryvOn cotton at current thresholds (Corbin et al., 2020; Graham and Stewart, 2018). Further research in late season management can lead to opportunities in using ThryvOn as a tool for expanding thresholds or making insecticide termination decisions in certain weeks of bloom in cotton.

Previous research has been conducted to evaluate insecticide termination in cotton for tarnished plant bug as well as other arthropod pests using nodes above white flower (NAWF) counts and heat unit (HU) accumulation (Bourland et al., 1992). Using this method, Russell (1999) found that bolls will not abscise from the plant due to tarnished plant bug injury when greater than 300 HUs have been accumulated, but damage to the lint and seed can still occur up to 326.5 HUs. In contrast, Horn (1999) observed bolls that have accumulated 250 HUs after anthesis are relatively safe from feeding damage resulting in little to no yield loss. From this, Horn (1999) determined that terminating insecticide applications for tarnished plant bug could occur when bolls accumulated 300 HUs after anthesis. Despite previous research, some confusion still exists because consultants and growers managing various planting dates are unsure of when each field reached five NAWF plus the additional HUs needed to avoid yield losses (Crow et al., 2020a). Additional foliar insecticide applications are likely being applied to ensure protection of terminal fruiting forms and to avoid whips or switches forming in the plant terminals.

Recent research determined a more practical strategy for terminating tarnished plant bug sprays across broad geographies (Crow et al., 2020a; Wood et al., 2016). Researchers proposed using week of flower to determine when to terminate insecticide applications for tarnished plant bug in cotton. In the initial research, Wood et al. (2016) used different insecticide initiation and termination timings to determine that the first four weeks of flowering are the most critical for tarnished plant bug control in cotton. Crow et al. (2020a) used different insecticide termination timings across multiple states and determined that cotton is safe from tarnished

plant bug injury after the fifth week of flower. The authors assumed that with an average daily heat unit accumulation of 25 HUs per day, the crop required approximately two weeks past five NAWF to reach 350 HUs. This would align with the fifth week of bloom based on their research. At some locations, terminating insecticides before the fifth week of flower also showed yields similar to the season-long control (Crow et al., 2020a). Lack of pressure in those few locations likely allowed for similar yields, however for most locations tarnished plant bug densities peaked between weeks three and four causing yield losses (Crow et al., 2020a). Assuming variability in population size and resistance levels, opportunities to terminate insecticides before the fifth week of bloom can be achieved without significant yield penalties when effective control is achieved earlier in the flowering period (Crow et al., 2020a). The relationship between yield losses and costs associated with the timing of insecticide termination is an important topic, especially with the benefits of ThryvOn technology. Therefore, the purpose of this research was to determine the percentage of loss that can be observed during the fourth and fifth week of bloom and maintain yields similar to season-long control in ThryvOn and non-ThryvOn technology.

MATERIALS AND METHODS

Studies were conducted at the Delta Research and Extension Center in Stoneville, MS in 2022 and 2023 to establish management practices for tarnished plant bug in flowering cotton with an emphasis on late season termination of insecticide applications. The field study was implemented as a randomized complete block design with a split-split plot arrangement of treatments with four replications. The whole-plot factor included cotton technology using non-ThryvOn (Deltapine 2055 B3XF) and ThryvOn (Deltapine 2131 B3TXF) varieties (Bayer CropScience, Research Triangle Park, NC). The sub-plot factor was timing of square removal at the fourth or fifth week of flower. The sub-subplot factor was percentage fruit removal at 0, 50, and 100% of squares above the uppermost first position white flower. The 50% removal was performed by hand removing every other fruiting position at all nodes above the uppermost first position white flower. The 100% removal was achieved by hand removing every fruiting position at all nodes above the uppermost first position white flower.

Cotton was planted at a population of 129,865 seeds ha⁻¹ on conventionally tilled beds on 10 May 2022 and 16 May 2023. Plots were four rows wide by 4.57 m in length on 1.01-m centers. During the pre-flowering stages, plots were sampled weekly by taking 25 sweeps using a 38-cm diameter sweep net. Starting at the third week of square, plots were sampled weekly using a black drop cloth measuring 0.76 m. Management decisions were made using economic thresholds through the third week of bloom. Beginning at the fourth week of bloom, all plots were sprayed once or twice per week to minimize square loss from tarnished plant bug infestations. Foliar insecticides were applied using a MUDMASTER™ 4WD Multi-Purpose Sprayer (Bowman Manufacturing, Newport AR), calibrated to deliver 93.5 L ha⁻¹ at 413 kPa through TX-6 ConeJet Visiflow Hollow Cone spray tip nozzles (Teejet Technologies, Glendale Heights, IL). All other management decisions followed Mississippi State University Extension recommendations.

Data collection included NAWF, plant heights, total nodes, and nodes above cracked boll (NACB) counts. Ten random plants were evaluated from each plot at every sample. NAWF was evaluated weekly beginning at the first week of flower through crop maturity. NAWF was determined by counting the nodes above the uppermost first position white flower (Bourland et al., 1992). Plant heights and total nodes were collected at first flower and first cracked boll. Heights were measured from the ground to the apical meristem. At first cracked boll, NACB was determined by counting the nodes between the uppermost first position cracked boll and the uppermost first position harvestable boll prior to defoliation. Lint yields were collected from the center two rows of each plot using a cotton picker modified for small plot research. Seed cotton yields were converted to lint yield based on 40% lint.

All data were analyzed using analysis of variance (PROC GLIMMIX, SAS 9.4; SAS Institute; Cary, NC). Cotton technology, week of removal, and level of removal were considered fixed effects in the model. Replication nested within year served as the random statement, and the Kenward-Roger's degrees of freedom method was used. Yield data were evaluated for outliers using a Studentized Residual test and plots greater than two standard deviations from the mean were not included in the analysis. Means were estimated with the LSMEANS statement and

separated using Tukey's Honest Significant Difference test at the 0.05 level of significance.

RESULTS

Plant Characteristics Prior to Removal. Differences in height were found among cotton technology ($F = 17.68$; $df = 1, 77$; $p < 0.01$). ThryvOn cotton plants had significantly higher plant heights compared to non-ThryvOn cotton plants. No differences among treatments were found in total nodes at first bloom ($F = 0.37$; $df = 2, 77$; $p = 0.54$). Prior to removal, non-ThryvOn plants had greater NAWF compared to ThryvOn plants in the fourth week of bloom ($F = 24.43$; $df = 1, 77$; $p < 0.01$). (Table 1)

Fifth Week of Bloom Samples. There was no interaction between cotton technology, week of removal, and level of removal for NAWF ($F = 0.27$; $df = 2, 77$; $p = 0.76$). However, there was an interaction between week of removal and level of removal for NAWF ($F = 29.50$; $df = 2, 77$; $p < 0.01$). Greater NAWF counts were observed when 100% of squares were removed during the fourth week of bloom compared to when 50% of squares were removed during the fourth week of bloom or when no squares were removed (Fig. 1). In contrast, no differences in NAWF were observed for removal treatments during the fifth week of bloom due to removal timing (Fig. 2). For cotton technology, NAWF counts were greater in ThryvOn cotton than non-ThryvOn cotton ($F = 10.71$; $df = 1, 77$; $p < 0.01$) (Table 1).

Sixth Week of Bloom Samples. There was no interaction between cotton technology, week of removal, and level of removal for NAWF ($F = 0.03$; $df = 2, 77$; $p = 0.97$). However, there was an interaction between week of removal and level of removal for NAWF ($F = 9.82$; $df = 2, 77$; $p < 0.01$). When comparing percent removal for each week, 100% removal at the fourth week resulted in the highest NAWF (Fig. 2). All other treatments resulted in similar NAWF. Again, there were differences between ThryvOn and non-ThryvOn cotton varieties on NAWF where ThryvOn had slightly higher NAWF ($F = 6.81$; $df = 1, 77$; $p = 0.01$) (Table 1).

First Cracked Boll. There was no interaction between cotton technology, week of removal, and level of removal for NACB ($F = 0.59$; $df = 2, 77$; $p = 0.55$). There was an interaction between week of removal and level of removal for NACB ($F = 10.01$; $df = 2, 77$; $p = 0.01$). Removal of 100% of squares during the fourth week of bloom resulted in fewer

Table 1. Analysis of variance for the impact of interactions on node above white flower (NAWF) and node above cracked boll (NACB) plant maturity measurements following manual removal of squares in Stoneville, MS in 2022 and 2023

Effect	F	df	P
Fifth Week of Bloom NAWF			
Technology	10.71	1, 77	<0.01
Week of Removal	31.91	1, 77	<0.01
Removal Level	34.92	1, 77	<0.01
Technology*Week of Removal*Removal Level	0.27	2, 77	0.76
Technology*Week of Removal	0.11	1, 77	0.74
Technology*Removal Level	0.31	2, 77	0.73
Week of Removal*Removal Level	29.50	2, 77	<0.01
Sixth Week of Bloom NAWF			
Technology	6.81	1, 77	0.01
Week of Removal	13.82	1, 77	<0.01
Removal Level	28.41	1, 77	<0.01
Technology*Week of Removal*Removal Level	0.03	2, 77	0.97
Technology*Week of Removal	0.14	1, 77	0.71
Technology*Removal Level	0.28	2, 77	0.76
Week of Removal*Removal Level	9.82	2, 77	<0.01
First Cracked Boll NACB			
Technology	1.80	1, 77	0.18
Week of Removal	6.75	1, 77	0.01
Removal Level	15.65	1, 77	<0.01
Technology*Week of Removal*Removal Level	0.59	2, 77	0.55
Technology*Week of Removal	0.33	1, 77	0.56
Technology*Removal Level	0.21	2, 77	0.81
Week of Removal*Removal Level	10.01	2, 77	<0.01

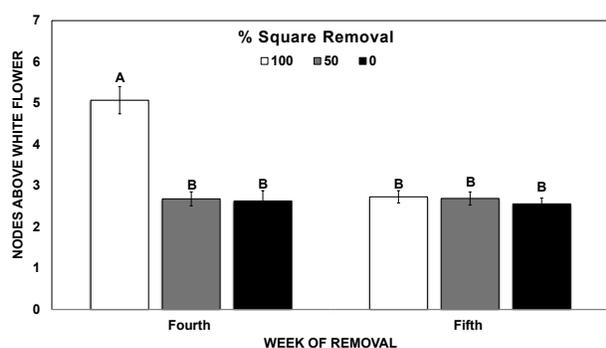


Figure 1. Interaction between removal level and removal week during week four on nodes above white flower (NAWF) ($p < 0.01$) during the fifth week of bloom across 2022 and 2023 in Stoneville, MS. Removal had not been applied to the 5th week of flower plots. Means separated by a common letter are not significantly different at $\alpha = 0.05$.

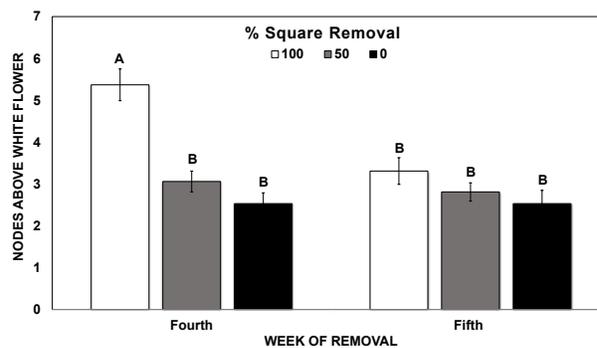


Figure 2. Interaction between removal level and week of removal on nodes above white flower (NAWF) ($p < 0.01$) during the sixth week of bloom across 2022 and 2023 in Stoneville, MS. Removal had been completed for all treatments. Means separated by a common letter are not significantly different at $\alpha = 0.05$.

NACB compared to all other treatments (Fig. 3). Additionally, there was an interaction between cotton technology and week of removal for total nodes ($F = 4.95$; $df = 1, 77$; $p = 0.03$). Square removal during the fourth week of bloom in the non-ThryvOn variety resulted in more total nodes than all other treatments (Fig. 4). No differences among factors were observed for final plant height (Table 1).

Yield Between Factors. There was no interaction between cotton technology, week of removal, and level of removal for yield ($F = 0.29$; $df = 2, 74.24$; $p = 0.75$). Cotton yields were greater for ThryvOn cotton than non-ThryvOn cotton ($F = 11.88$; $df = 1, 74.12$; $p < 0.01$) (Fig. 5). No differences in lint yield were observed for week of removal ($F = 0.27$; $df = 1, 74.26$; $p = 0.60$) or level of removal ($F = 1.77$; $df = 2, 74.11$; $p = 0.17$).

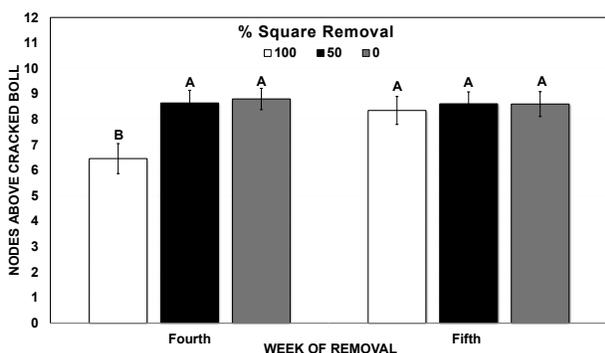


Figure 3. Interaction between removal level and week of removal on nodes above cracked boll (NACB) ($p = 0.01$) at first cracked boll across 2022 and 2023 in Stoneville, MS. Means separated by a common letter are not significantly different at $\alpha = 0.05$.

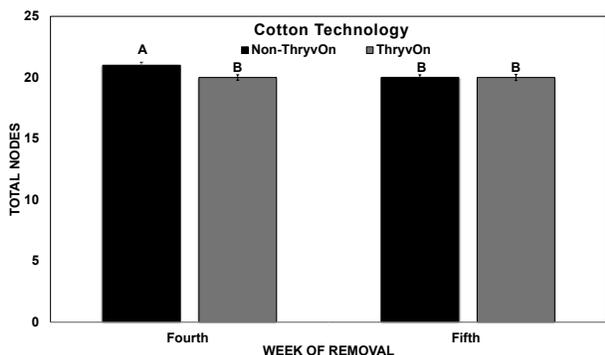


Figure 4. Interaction between cotton technology and week of removal on total nodes ($p = 0.03$) at first cracked boll across 2022 and 2023 in Stoneville, MS. Means separated by a common letter are not significantly different at $\alpha = 0.05$.

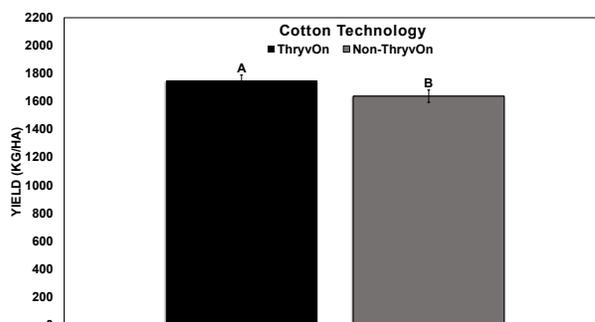


Figure 5. Impact of cotton technology on kilograms of lint per hectare ($p < 0.01$) across 2022 and 2023 in Stoneville, MS. Means separated by a common letter are not significantly different at $\alpha = 0.05$.

DISCUSSION

Overall, the objective of this experiment was to investigate levels of fruit loss that can occur during weeks four and five of bloom and estimate the value of the lost fruit to assess the relevance of costly insecticide applications for protecting cotton late bloom. Economic damage from tarnished plant bug feeding can occur from first square through early mid-bloom (Layton et al., 1995). This can potentially delay maturity and reduce yield (Layton et al., 1995). Musser et al. (2009) observed that yield loss was strongly linked to tarnished plant bug feeding during the late flowering period rather than the early flowering period. In contrast, more recent research found damage occurring in the early to middle flowering period resulting in significant yield losses (Wood et al., 2016). Also, delaying insecticide applications until the fourth week of bloom can cause significant yield losses, suggesting the critical management period is the second through fourth week of bloom (Wood et al., 2016). Cotton has a tremendous ability to compensate for lost fruiting forms due to its indeterminate nature (Gore et al., 2000a; Mann et al., 1997). However, compensation is highly dependent on timing of damage, length and severity of damage, and environmental conditions (Brook et al., 1992; Crow et al., 2020b; Herbert et al., 2006; Sadras, 1995). All these factors have been found to significantly affect cotton compensation in previous studies (Gore et al., 2000a; Herbert et al., 2006; Lei, 2002; Samples et al., 2015).

Gore et al. (2009b) reported significant delays in maturity and up to 27.5% yield loss from simulated bollworm, *Helicoverpa zea* (Boddie), feeding on bolls during the third and fourth weeks of bloom in

northeastern Louisiana. A similar study by Lei (2002) found no yield loss following simulated bollworm damage during early bloom in Australia but reported crop maturity delay similar to Gore et al. (2009b). In Virginia, Herbert et al. (2006) also examined cotton compensation through manual removal during early bloom but found no significant differences when comparing yields of multiple removal dates 10 to 23 days after first bloom of 10- to 14-day-old bolls (Herbert et al., 2006). The authors showed cottons ability to sustain losses of up to 20% in a shorter growing season with limited HU accumulation.

Comparable to previous studies, Samples et al. (2015) showed no significant differences in lint yield when comparing 50 to 0% manual removal of fruiting forms at first bloom in Mississippi. However, 100% removal resulted in significantly less yield. Samples et al. (2015) believed that the length of the growing season in the study was only sufficient for plant compensation of up to 50% and increased yield losses might have been seen in shorter-season environments such as northeast Arkansas or southeast Missouri.

The current experiment follows previous trends showing impacts to plant maturity through fruit loss, even when this occurs during late bloom in Mississippi. Starting at the fourth week of flower, the number of NAWF increased in plots with 100% removal compared to those with 50 or 0% square removal. However, removal of squares during the fifth week of bloom did not affect plant maturity, suggesting plants would be safe from tarnished plant bug feeding during this period. Despite the increase in NAWF seen with 100% removal during week four, yield was not impacted by increased levels of removal during either week of flower. This suggests the removed fruit in the upper canopy would not have made a significant contribution to yield following Hearn and Room's (1979) characterization of time-independent responses of cotton to lost fruit: (1) instantaneous tolerance, when damage occurs to fruiting forms that would have shed physiologically anyway or (2) instantaneous compensation, when resources that would have been directed to the lost bolls are absorbed by the remaining bolls and therefore increase their weight.

For the cotton technology portion of the experiment, ThryvOn cotton yielded higher than non-ThryvOn in both years regardless of treatment; this could be due to a number of factors including, but

not limited to, differences in the yield potential. This contradicts Graham and Stewart's (2018) findings of similar yields between ThryvOn and non-ThryvOn when using threshold approaches for tarnished plant bug management. Despite similarities in yield, the authors did find reduced insecticide applications by 1.25 in ThryvOn when terminating insecticides at five NAWF plus 350 HUs.

With support from previous research, this study indicates opportunities for reduced insecticide applications for tarnished plant bug management earlier than currently recommended in Mississippi cotton. Using ThryvOn technology could also achieve this. Given the decrease in insecticide applications found in ThryvOn (Graham and Stewart, 2018), there can be opportunities to increase the threshold late season for tarnished plant bugs to minimize costs. Currently, management prior to the fourth week of bloom is critical to avoid significant yield losses (Wood et al., 2016). However, our data suggest that tarnished plant bugs might not need to be managed beyond the fourth week of bloom in ThryvOn or non-ThryvOn cotton. Additional large-scale studies should be done across the Mid-South to confirm these findings and alter treatment thresholds for cotton producers in the region.

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