ARTHROPOD MANAGEMENT & APPLIED ECOLOGY

Evaluation of Irrigation and Simulated Late-Season Tarnished Plant Bug Damage on Cotton Yield

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ABSTRACT

Experiments were conducted at the Delta Research and Extension Center in Stoneville, MS during 2022 and 2023 to investigate the impact of irrigation and simulated late-season damage of tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), in cotton. The whole-plot factor compared a 90-centibar irrigation threshold and a non-irrigated treatment. Subplot factor A involved simulated damage by manual removal of squares during the fourth and fifth week of bloom. Three levels of damage at 0, 50, and 100% removal of squares above the uppermost first position white flower was subplot factor B. To understand agronomic impacts and compensation, plant heights, total node counts, nodes above white flower (NAWF), and nodes above cracked boll measurements were recorded beginning at the first week of bloom. Yield was also recorded from each plot. Results from 2022 and 2023 showed significant increases in NAWF from 100% fruit removal during both removal weeks compared to all other removal treatments; however, all treatments remained below five NAWF. No significant yield differences were found among any factor except irrigation. Threshold irrigated cotton had significantly greater yields than non-irrigated cotton. Results from this experiment agree with previous research suggesting insecticide termination could occur after the fourth week of bloom with minimal impacts to plant maturity and yield in both irrigated and non-irrigated situations.

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Disappointing lint prices and increased costs for labor, equipment, and pest management have made it increasingly difficult for cotton producers to remain profitable in recent decades. Among many others, irrigation expenses have continued to increase. A recent survey showed that 86% of farms reported using some type of irrigation method in Mississippi (USDA-NASS, 2018). When irrigation is available, there are many economic benefits that can supplement the producer's goal of maximizing yield potential. Studies conducted in southeastern coastal plain soils have shown that yields of irrigated cotton can double that of non-irrigated cotton, 841 kg ha^{-1} for non-irrigated to approximately 1681 kg ha^{-1} for irrigated cotton in years when rainfall is limited (Perry and Barnes, 2012).

Previous research has demonstrated difficulty in measuring water usage trends by visual observation in cotton throughout the season. These studies have shown that scheduling irrigation based on cultural practices like crop condition and calendar timings often lead to under- or over-irrigating crops by not accurately accounting for soil moisture and water usage (Bryant et al., 2023). However, Bryant et al. (2023) showed that scheduling irrigation using soil moisture sensor readings could improve irrigation decisions and water usage by timing irrigation with plant demand. Previous research has indicated that incorporating moisture sensors with a season-long threshold of 90 centibars can maximize the yield-to-net-return ratio compared to cultural irrigation strategies (Plumblee et al., 2019). Contrary to popular belief, Plumblee et al. (2019) showed no yield advantage or increase in net returns using a 50-centibar threshold, which is relative to the current irrigation strategies used today. Moreover, in that study, net-return-above-irrigation costs were estimated at $350 per hectare more using a 90-centibar threshold compared to 50 centibars. Recent surveys reported 26% of farms in Mississippi used soil moisture sensors to schedule irrigation (USDA-NASS, 2018). Further

adoption of these tools could contribute to reduced water use for cotton production in Mississippi.

Seasonal water requirements for cotton vary by climate and sometimes year (Perry and Barnes, 2012). Traditionally, from planting to first square, water requirements are low and yield impacts from water deficiencies are minimal (Perry and Barnes, 2012). However, from first flower through peak bloom, water-use requirements per day increase (Janat, 2008; Perry and Barnes, 2012), accounting for 64% of total irrigation applied (Janat, 2008). More recent research agrees with this management scheme by showing the highest yielding treatment was that receiving no irrigation until first flower plus three weeks to first flower plus six weeks compared to many other schemes including season-long irrigation and no irrigation (Bednarz et al., 2003).

When reaching cutout, cotton can tolerate greater late-season water stress because the crop is less dependent on supporting immature bolls that are prone to stress-induced abscission (Grimes and El-Zik, 1990). Traditionally, cotton responds to water with an increase in production rates, however growth and development can decline when reaching maximum water-use efficiency (Grimes and Dickens, 1977). A gradual decrease in water volume and irrigation frequency can be effective in permitting boll maturation without promoting excess vegetative growth late season (Hake and Grimes, 2010).

Limited information exists relating to late-season irrigation and tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), management due to variability in annual rainfall. Nonetheless, studies show water and fertility management influence the vegetative and fruiting growth of crops as well as desirability to insects (Leigh et al., 1970). More specifically, the increased abundance of *Lygus* species can be found in high moisture environments (Bommireddy et al., 2003; Leigh et al., 1970). Research evaluating in-season remote sensing field maps showed that the location of feeding by tarnished plant bug differed by crop vigor (Willers et al., 1999). The healthier or vigorously growing cotton consistently showed higher tarnished plant bug populations compared to other areas (Willers et al., 1999).

Unnecessary irrigations promoting excess vegetative growth can increase the difficulty for management decisions with higher tarnished plant bug populations late season. Previous research showed initiating irrigation at peak flower can reduce the number of times tarnished plant bugs exceeded threshold and reduced maturity delays (Wood et al., 2019). Also, starting irrigation at peak flower could result in similar yields compared to irrigation initiated at squaring (Wood et al., 2019). Although an increase in nodes above white flower (NAWF) can be noticed with irrigation and plant bug feeding (Wood et al., 2019), it is likely the additional nodes produced later in the season provide little to no lint value. (Jenkins and McCarty, 1995).

Currently, the Mississippi State Insect Control Guide recommends terminating insecticides for tarnished plant bug at five NAWF plus 350 heat units (Crow et al., 2023). This also aligns with irrigation termination timing. Monge et al. (2007) showed a 12% increase in yield when irrigation was continued to five NAWF plus 360 DD(degree day)60s compared to 100 DD60s. Yield was not increased beyond this point in the study.

Additionally, Perry and Barnes (2012) found that irrigation applied 18 days past five NAWF would not increase yield enough to be profitable. Additional irrigation and insecticide applications to fill and protect immature bolls in the top of the plant can be overlooked without costly penalties with supplemental research. Further research in the relationship between late-season tarnished plant bug injury and irrigation strategies could influence the adoption of moisture sensors in cotton for potential decreases in costs.

MATERIALS AND METHODS

Studies were conducted at the Delta Research and Extension Center in Stoneville, MS in 2022 and 2023 to measure the relationship between irrigation using soil moisture sensors and tarnished plant bug damage in late flower on cotton yield. 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 was irrigation using a season-long threshold and non-irrigation treatment. Subplot factor A was timing of square removal at the fourth and fifth week of flower. Subplot factor B was square removal at levels of 0, 50, and 100% above the uppermost first position white flower. One hundred percent removal was achieved by manually removing squares on every fruiting position at all nodes above the uppermost first position white flower; 50% removal removed squares on every other fruiting position.

Deltapine 2055B3XF (Bayer CropScience, Research Triangle Park, NC) cotton was planted on conventionally tilled beds on 18 May 2022 and 8 May 2023. The planting population was 112,328 seeds ha^{-1} at a depth of approximately 2 cm. Subplots were four rows wide by 4.57 m in length on 1.01-m centers. Beginning at first square, plots were managed for tarnished plant bug by weekly scouting using a 38-cm diameter sweep net. At the third week of square, a black drop cloth measuring 0.76 m was used for sampling through the third week of bloom. All insecticide applications made followed recommended thresholds (Crow et al., 2023). Beginning at the fourth week of bloom, all plots were automatically sprayed following square removal. Insecticides were applied using a MUDMASTER^{TM}, 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.

A soil moisture sensor-based irrigation system was used season long to monitor water availability in the irrigated and non-irrigated blocks. Soil moisture sensor materials included a WATERMARK 200SS sensor (IRROMETER Company Inc., Riverside, CA), thin-walled 1.27-cm (13-mm) Class 315 polyvinyl chloride (PVC) pipe, a drill with a 0.24-inch (3-mm) bit, PVC primer and cement, flexible vinyl cap, PVC pipe cutter, permanent marker for labeling, a meter- stick for measurements, and various-colored electrical tape for marking installation depth and color differentiation of each sensor. Prior to installation, sensors were preconditioned through two cycles, which included two 30-min wetting periods and two complete drying periods. Installation depths of sensors included 15, 30, 61, and 91 cm. Tools required included a 22-mm soil probe, shovel, and a 19-L bucket of water. A mixture of soil and water was used to seal the soil around the PVC portion of the sensor. One sensor was placed in each whole-plot treatment directly beside the plants in the row. Each sensor was placed in the third replication between rows two and three of a plot in an area that accurately characterized each whole-plot treatment. A season-long 90-centibar threshold was set and electronic soil moisture readings were taken continuously at each depth to ensure an accurate representation of moisture levels. When soil moisture sensor levels reached 90 centibars, furrow irrigation was initiated using 30.5-cm diameter lay-flat polyethylene tubing placed perpendicular to the planted row. The polyethylene tubing was punctured in line with every furrow allowing water to flow evenly in the desired plots. Irrigation ceased at insecticide termination timing of five NAWF plus 350 heat units. Heat unit accumulation (DD60s) was calculated by averaging the daily maximum and minimum air temperatures and subtracting 60, providing the daily heat units used to determine insecticide and irrigation termination.

Plant characteristics were evaluated by sampling 10 plants from the center two rows of each plot beginning at first bloom. Plant heights and total node counts were taken at first bloom and first cracked boll. Weekly NAWF counts were measured by counting the nodes above the uppermost first position white flower beginning when the majority of plants were flowering (Bourland et al. 1992). At first cracked boll, weekly node above cracked boll (NACB) evaluations began until defoliation applications were made. NACB was measured by counting the number of nodes between the uppermost first position cracked boll and the uppermost harvestable boll. Lint yields were collected from the center two rows of each plot using a cotton picker modified for small-plot research.

All data were analyzed using analysis of variance (PROC GLIMMIX, SAS 9.4; SAS Institute, Cary, NC). Irrigation, week of removal, and level of removal were considered fixed effects. Replications nested within year were considered fixed effects, and the Kenward-Roger's degrees of freedom method was used. Means were separated by the LSMEANS statement using Tukey's Honest Significant Difference test at the 0.05 level of significance.

RESULTS

Plant Characteristics Prior to Removal. Throughout this experiment, soil moisture was adequate for growth and development of cotton with minimal irrigation needed early to mid-season when monitoring soil moisture sensor data. Prior to square removal, irrigation had not been initiated so plant height and total node evaluations are not included in the analysis. However, after irrigation was initiated, there were greater NAWF counts in irrigated plots than the non-irrigated plots during week four of bloom (F = 16.51; df = 1, 77; $p < 0.01$).

Fifth Week of Bloom. There was no interaction between irrigation, week of removal, and level of removal for NAWF (F = 0.10; df = 2, 83; p = 0.90). However, there was an interaction between week of removal and level of removal for NAWF (F = 13.87; df = 2, 83; p < 0.01). Removal of 100% of squares during the fourth week of bloom resulted in a greater NAWF than removal of 50% of squares and no removal of squares (Fig. 1). No differences were observed for NAWF among removal treatments that occurred during the fifth week of bloom because no fruit had been removed at that time. Lastly, NAWF was greater in irrigated cotton compared to non-irrigated cotton (F = 52.97; df = 1, 83; p < 0.01) (Table 1).

Sixth Week of Bloom. There was no interaction between irrigation, week of removal, and level of removal for NAWF in the sixth week of bloom (F = 0.80; df = 2, 77; p = 0.45). There was an interaction between week of removal and level of removal for
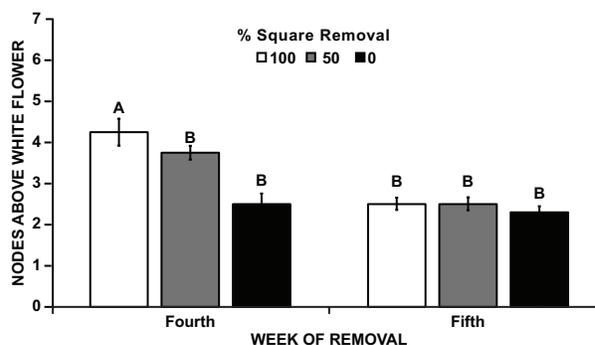

Figure 1. Interaction between removal level and removal during week four for NAWF (p < 0.01) during the fifth week of bloom across 2022 and 2023 in Stoneville, MS. Removal had not been done for the fifth week of flower plots. Means separated by a common letter are not significantly different at α = 0.05.

NAWF (F = 7.40; df = 2, 77; p = 0.01). Removal of 100% of squares during the fourth week of bloom resulted in greater NAWF counts compared to all other

Table 1. Analysis of variance for the impact of interactions on plant maturity measurements following manual removal of squares in Stoneville, MS in 2022 and 2023

| Fifth Week of Bloom NAWF	F	df	p
Irrigation	52.97	1, 83	<0.01
Week of Removal	38.21	1, 83	<0.01
Level of Removal	20.16	1, 83	<0.01
Irrigation*Week of Removal*Level of Removal	0.10	2, 83	0.90
Irrigation*Week of Removal	0.05	1, 83	0.82
Irrigation*Level of Removal	0.07	2, 83	0.94
Week of Removal*Level of Removal	13.87	2, 83	<0.01
Sixth Week of Bloom NAWF	**F**	**df**	**p**
Irrigation	9.0	1, 77	<0.01
Week of Removal	10.48	1, 77	<0.01
Level of Removal	70.81	1,77	<0.01
Irrigation*Week of Removal*Level of Removal	0.80	2, 77	0.45
Irrigation*Week of Removal	1.23	1,77	0.27
Irrigation*Level of Removal	2.95	2, 77	0.06
Week of Removal*Level of Removal	7.40	2, 77	<0.01
First Cracked Boll NACB	**F**	**df**	**p**
Irrigation	58.53	1, 77	<0.01
Week of Removal	0.02	1, 77	0.88
Level of Removal	0.97	1, 77	0.38
Irrigation*Week of Removal*Level of Removal	0.01	2, 77	0.99
Irrigation*Week of Removal	1.03	1, 77	0.31
Irrigation*Level of Removal	0.50	2, 77	0.62
Week of Removal*Level of Removal	0.57	2, 77	0.57
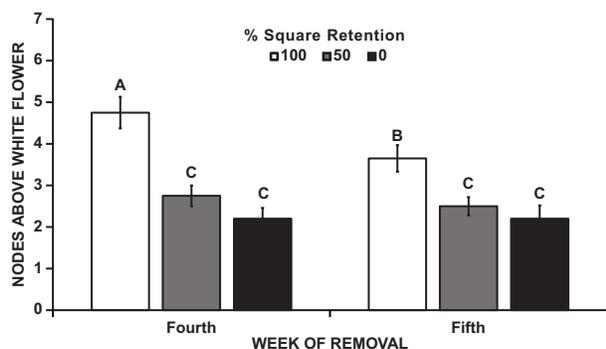
Figure 2. Interaction between removal level and week of removal for NAWF ($p < 0.01$) during the sixth week of bloom across 2022 and 2023 in Stoneville, MS. Removal of squares had been applied to all plots. Means separated by a common letter are not significantly different at α = 0.05.
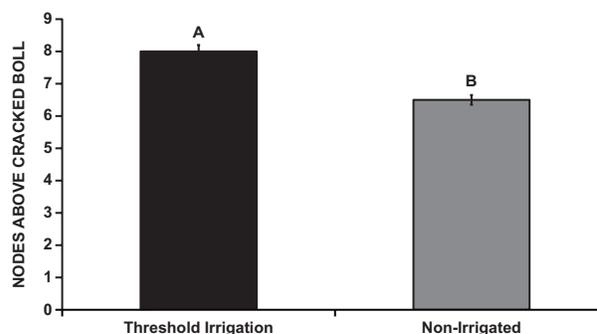

Figure 3. Impact of irrigation on NACB at first cracked boll ($p < 0.01$) across 2022 and 2023 in Stoneville, MS. Means separated by a common letter are not significantly different at α = 0.05.

timings and levels (Fig. 2). Again, irrigated cotton had greater NAWF counts compared to non-irrigated cotton (F = 9.0; df = 1, 77; $p < 0.01$) (Table 1).

Agronomics at First Cracked Boll. There was no interaction between irrigation, week of removal, and level of removal for plant height (F = 1.42; df = 2, 77; $p = 0.25$) or total node counts (F = 0.02; df = 1, 77; $p = 0.98$). No interaction was observed between level of removal and irrigation (F = 0.75; df = 2, 83; $p = 0.48$) or week of removal and irrigation (F = 0.49; df = 2, 85; $p = 0.49$) for total node counts. Additionally, no interaction was observed between week of removal and level of removal for total node counts (F = 1.93; df = 2, 83; $p = 0.15$). No interaction was observed between week of removal and irrigation (F = 0.40; df = 2, 85; $p = 0.53$) or level of removal and irrigation (F = 0.47; df = 2, 83; $p = 0.47$) for final plant height. Also, no interaction was observed between week of removal and level of removal for final plant height (F = 0.62; df = 2, 89; $p = 0.54$). Overall, the threshold irrigation resulted in greater plant heights (F = 34.73; df = 1, 77; $p < 0.01$) and total node counts (F = 10.63; df = 1, 77; $p < 0.01$) compared to no irrigation (Table 2). For NACB, no interaction was observed between irrigation, week of removal, and level of removal for NACB (F = 0.01; df = 2, 77; $p = 0.99$). Irrigated plots had higher NACB

counts compared to non-irrigated plots (F = 58.53; df = 1, 77; $p < 0.01$) (Fig. 3). Week of removal (F = 0.02; df = 1, 77; $p = 0.88$) nor level of removal (F = 0.97; df = 1, 77; $p = 0.38$) impacted NACB (Tables 1 and 2).

Yield. There was no interaction between irrigation, week of removal, and level of removal for yield (F = 0.82; df = 2, 83; $p = 0.44$). The main effect of irrigation was the only factor that impacted yield (F = 50.74; df = 1, 83; $p < 0.01$). Irrigated plots had higher lint yields when compared to plots receiving no irrigation (Fig. 4). Level of removal did not have a significant effect on lint yield (F = 0.20; df = 1,
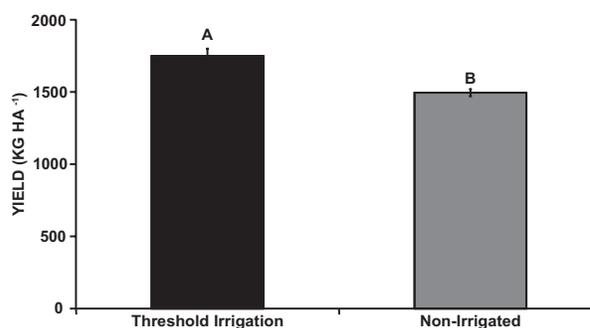

Figure 4. Impact of irrigation using a 90-kPa soil moisture threshold on cotton yield ($p < 0.01$) across 2022 and 2023 in Stoneville, MS. Means separated by a common letter are not significantly different at α = 0.05.

Table 2. Impact of irrigation using a 90-kPa soil moisture threshold on final average plant nodes and plant heights at first cracked boll across 2022 and 2023 in Stoneville, MS

	Heights (cm)	Total Nodes
Threshold Irrigation	110.21 (1.29)a	19.91 (0.17)a
Non-irrigated	100.76 (1.9)b	19.23 (0.15)b
p > F	<0.01	<0.01

Means within a column sharing the same letter are not significantly different (Tukey's HSD; $p < 0.05$).
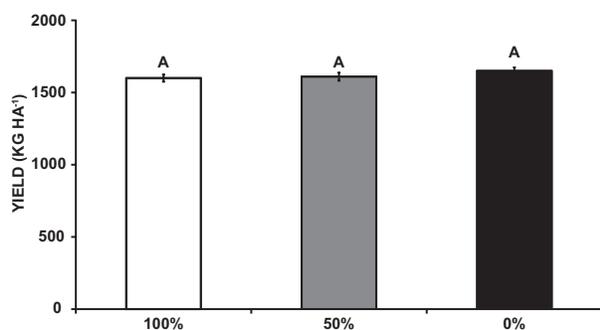
Figure 5. Impact of removal level on kilograms of lint per hectare (*p* = 0.82) across 2022 and 2023 in Stoneville, MS. Means separated by a common letter are not significantly different at α = 0.05.
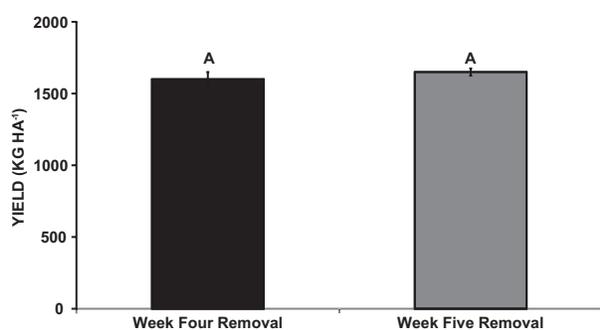

Figure 6. Impact of week of removal on kilograms of lint per hectare (p = 0.74) across 2022 and 2023 in Stoneville, MS. Means separated by a common letter are not significantly different at α = 0.05.

83; p = 0.82) (Fig. 5). Additionally, no significant differences were observed between week of removal on lint yield (F = 0.11; df = 1, 83; p = 0.74) (Fig. 6).

DISCUSSION

With rising input costs and increasing pressure to improve water-use efficiency, irrigation management has become a critical factor in sustaining cotton profitability. Optimizing irrigation not only influences yield potential but affects crop maturity, production costs, and pest management decisions. This research provides insight into how soil moisture sensor-based irrigation strategies can improve efficiency and support more economical cotton production in Mississippi.

Based on soil moisture sensors, soil moisture was adequate for growth and development of cotton during early to mid-season. In both years, irrigation was not triggered until the third week of bloom with two events in 2022 and one in 2023. However, noticeable yield differences were found between irrigated and non-irrigated plots. A two-year average of 265 kg ha^{-1} increase was shown using a soil moisture threshold of 90 centibars. Results from this study agree with Bryant et al. (2023), suggesting producers not using soil moisture sensors to trigger irrigations in cotton are likely applying excessive water with irrigation.

In the current experiment, the effect of irrigation, level of fruit removal, and week of removal differed between NAWF measurements taken among treatments. Prior to removal, the previous irrigation event likely drove the increase in NAWF in the irrigated plots compared to non-irrigated plots. However, it is important to note that both irrigated and non-irrigated plots had approached cutout with less than or equal to five NAWF before square removal was initiated in week four. In weeks five and six, NAWF in irrigated plots was significantly greater than in non-irrigated plots. However, in both weeks of bloom, all plots remained below five NAWF regardless of treatment. The amount of heat units accumulated in previous weeks most likely promoted cutout in both years (Fig. 1). Although plants remained cutout, the increase in nodes resulting from 100% removal during week four paired with an irrigated environment indicates plant maturity was impacted. However, 50% square removal during both weeks did not affect maturity compared to 100% square removal. Using NAWF counts to compare 0 to 50% square removal, limited maturity delays were observed regardless of the week of bloom square removal was imposed.

At first cracked boll, plant characteristics differed among irrigation practice. Irrigated plots had greater plant heights, total nodes per plant, and NACB than non-irrigated plots. Neither week of removal nor level of removal affected plant height, total nodes, or NACB when measured at first cracked boll. Because NACB measurements were taken upwards along the mainstem to the uppermost harvestable boll, this indicates that there were no significant differences in presence of harvestable bolls between removal levels.

Despite delays in maturity, no significant yield penalty was observed with any square removal level imposed during the fourth or fifth week of bloom. Results from this experiment indicate that terminating insecticides at the fourth week of bloom can result in similar yields and reduced expenses compared to season-long control. Additionally, monitoring soil moisture with sensors in this study demonstrated the potential to reduce irrigation expenses while maintaining optimum yields.

When incorporating these farming practices, it will be important to consider the environment and pest population year to year. In a study conducted during 2001, 2002, 2004, 2005, and 2007 using drip irrigation and manual infestations of laboratory-grown tarnished plant bugs, Teague et al. (2008) found significant yield penalties during 2004 from damage to upper canopy and outside bolls in high-yielding cotton after cutout. These results contradict findings from other years but are important to consider when evaluating current insecticide termination timings. Ultimately, with the current cost for tarnished plant bug control, $28.70 per hectare, these results indicate losses after cutout contribute small amounts to yield and insecticide applications might not pay for themselves beyond the fourth week of bloom.

Results from this research demonstrate that soil moisture sensor-based irrigation at a 90-centibar threshold increased lint yields by an average of 265 kg ha^{-1} compared to non-irrigated cotton, while reducing unnecessary water applications. Square removal treatments during bloom affected plant growth and maturity but did not result in yield penalties, supporting current insecticide termination guidelines for tarnished plant bug management. Taken together, these findings suggest that adopting soil moisture sensors can improve water-use efficiency, reduce input costs, and maintain profitable yields. Producers are encouraged to incorporate sensor-based irrigation strategies as a practical tool for optimizing both economic and pest management decisions in Mississippi cotton production. For further validation of this study, large scale experiments need to be conducted across the midsouthern U.S.

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REFERENCES

Bednarz, C.W., G. Ritchie, J. Hook, R. Yager, S. Cromer, D. Cook, and I. Griner. 2003. Cotton crop water use and irrigation scheduling. pp. 72–77 *In* O.L. May, P. Jost, and P. Roberts (eds.) 2003 Georgia Cotton Research and Extension Reports. Univ. of Georgia Extension Service, Tifton, GA.

Bommireddy, P.L., M.N. Parajulee, D.O. Porter, R.B. Shrestha, A.M. Cranmer, M. D. Arnold, and S.C. Carroll. 2023. Effect of irrigation regimes on insect populations in Texas High Plains cotton. pp. 1372–1374 *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 10-12 Jan. 2023. Natl. Cotton Counc. Am., Memphis, TN.

Bourland, F.M., D.M. Oosterhuis, and N.P. Tugwell. 1992. Concept for monitoring the growth and development of cotton plants using main-stem node counts. J. Product. Ag. 5:532–538.

Bryant, C.J., G.D. Spencer, D.M. Gholson, M.T. Plumblee, D.M. Dodds, G.R. Oakley, D.Z. Reynolds, and L.J. Krutz. 2023. Development of a soil moisture sensor-based irrigation scheduling program for the midsouthern United States. Crop, Forage, Turfgrass Manage. 9:e20217. https://doi.org/10.1002/cft2.20217

Crow, W.D., J. Gore, D.R. Cook, F. Musser, and B. Layton. 2023. Insect Control Guide for Agronomic Crops. Mississippi State Univ. Ext. Pub. 2417. Mississippi State University Extension Service, Mississippi State, MS.

Grimes, D.W., and K.M. El-Zik. 1990. Cotton. pp. 741–755 *In* B.A. Stewart and D.R. Neilsen (eds.), Irrigation of Agricultural Crops. No. 30. American Society of Agronomy, Madison, WI.

Grimes, D.W., and W.L. Dickens. 1977. Cotton responses to irrigation. California Agric. 31:16–17.

Hake, K.D., and G.W. Grimes. 2010. Crop water management to optimize growth and yield. pp. 255–264 *In* J.McD. Stewart, D. Oosterhuis, J.J. Heithold, and J.R. Mauney (eds.), Physiology of Cotton. Springer-Verlag GmbH., Heidelberg, Germany.

Janat, M. 2008. Response of cotton to irrigation methods and nitrogen fertilization: Yield components, water-use efficiency, nitrogen uptake, and recovery. Comm. Soil Sci. Plant Anal. 39:2282–2302.

Jenkins, J.N., and J.C. McCarty. 1995. Useful tools in managing cotton production: End of season plant maps. Bull. 1024. Mississippi Agricultural & Forestry Exp. Sta., Mississippi State, MS.

Leigh, T., H. Grimes, H. Yamad, D. Bassett, and J. Stockton. 1970. Insects in cotton as affected by irrigation and fertilization practices. Hilgardia. 24:12–14.

Monge, J.J., T.G. Teague, M.J. Cochran, and D.M. Danforth. 2007. Economic impacts of termination timing for irrigation and plant bug control. pp. 1396–1405 *In* Proc. Beltwide Cotton Conf., New Orleans, LA. 9-12 Jan. 2007. Natl. Cotton Counc. Am., Memphis, TN.

Perry, C., and E. Barnes. 2012. Cotton Irrigation Management for Humid Regions. Cotton Incorporated, Cary, NC.

Plumblee, M.T., D.M., Dodds, L.J., Krutz, A.L., Catchot Jr, J.T., Irby, and J.N., Jenkins. 2019. Determining the optimum irrigation schedule in furrow irrigated cotton using soil moisture sensors. Crop, Forage, Turfgrass Manage. 5(1):1–6. https//doi.org/10.2134/cftm2018.06.0047

Teague, T.G, J. Smith, D.M. Danforth, and P.F. O'Leary. 2008. Manually applied infestation of tarnished plant bug nymphs in late season cotton to identify the final stage of crop susceptibility. pp. 1239–1250 *In* Proc. Beltwide Cotton Conf., Nashville TN. 8-11 Jan. 2008. Natl. Cotton Counc. Am., Memphis, TN.

United States Department of Agriculture, National Agriculture Statistics Service [USDA-NASS]. 2018. Methods used in deciding when to irrigate: 2018 [online]. Available at https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Farm_and_Ranch_Irrigation_Survey/fris_1_0023_0023.pdf (verified 5 Nov. 2025).

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

Wood, W., J. Gore, A. Catchot, D. Cook, D. Dodds, and L.J. Krutz. 2019. Impact of irrigation timing on tarnished plant bug populations and yield of cotton. J. Cotton Sci. 23:21–27.