TEXAS A&M AGRILIFE RESEARCH & EXTENSION

COTTON ENTOMOLOGY RESEARCH REPORT 2022

TECHNICAL REPORT 23-4

TEXAS A&M AGRILIFE RESEARCH, CLIFF LAMB, DIRECTOR
THE TEXAS A&M UNIVERSITY SYSTEM, COLLEGE STATION, TEXAS

COTTON ENTOMOLOGY PROGRAM

RESEARCH ACTIVITY ANNUAL REPORT

2022

SUBMITTED TO:

PLAINS COTTON IMPROVEMENT COMMITTEE
PLAINS COTTON GROWERS, INC.

JAROY MOORE, CENTER DIRECTOR
TEXAS A&M AGRILIFE RESEARCH-LUBBOCK

BY:

Dr. Megha N. Parajulee
Professor, Faculty Fellow, and Texas A&M Regents Fellow
Texas A&M AgriLife Research Cotton Entomology Program
1102 East Drew Street, Lubbock, Texas 79403
Phone: (806) 746-6101; Fax: (806) 746-6528
Email: m-parajulee@tamu.edu

PARTICIPANTS

BEAU HENDERSON, Texas A&M AgriLife Research-Lubbock

BLAYNE REED, Texas A&M AgriLife Extension Service- Plainview

CASEY HARDIN, Texas A&M AgriLife Research-Halfway

DANIELLE SEKULA-ORTIZ, Texas A&M AgriLife Extension Service- Weslaco

DAVID KERNS, Texas A&M AgriLife Extension Service-College Station

DOL P. DHAKAL, Texas A&M AgriLife Research-Lubbock

DONNA MCCALLISTER, Texas A&M AgriLife Research-Lubbock

JANE DEVER, Texas A&M AgriLife Research-Lubbock

KATIE LEWIS, Texas A&M AgriLife Research-Lubbock

KERRY SIDERS, Texas A&M AgriLife Extension Service- Levelland

MEGHA PARAJULEE, Texas A&M AgriLife Research-Lubbock

MICHAEL BREWER, Texas A&M AgriLife Research-Corpus Christi

MICHAEL TOEWS, University of Georgia, Tifton

PRAMOD ACHARYA, New Mexico State University, Clovis

RAJAN GHIMIRE, New Mexico State University, Clovis

RAJU SAPKOTA, Eastern New Mexico State University, Portales

STEPHEN BILES, Texas A&M AgriLife Extension Service- Port Lavaca

SUHAS VYAVHARE, Texas A&M AgriLife Extension Service-Lubbock

WAYNE KEELING, Texas A&M AgriLife Research-Lubbock

WENWEI XU, Texas A&M AgriLife Research-Lubbock

FUNDING AND LOGISTICAL SUPPORT

USDA NIFA, Cotton Incorporated Core Program, CI State Support Committee, Texas A&M AgriLife Research, Texas A&M AgriLife Extension Service, Plains Cotton Improvement Program

TABLE OF CONTENTS

Introduction

Plains Cotton Growers, Inc. (PCG) has been a strong supporter of cotton insect research and extension activities in west Texas for many years. Most notably, PCG was instrumental in securing state funds for the Boll Weevil Research Facility at the Lubbock Center and provided both financial and political support to conduct boll weevil biology and ecology research even before the boll weevil became a significant economic pest of the High Plains region. After the initial entry of the boll weevil into the eastern edge of the High Plains, PCG promoted and along with USDA-APHIS administered the boll weevil diapause suppression program involving a team effort that continued to include Texas A&M University. PCG also supported Texas Cooperative Extension (now Texas A&M AgriLife Extension Service) efforts to annually evaluate the diapause suppression program, conduct applied research trials to develop boll weevil management practices that would enhance the diapause suppression program's efforts, and in the 1990s supported an annual survey of High Plains overwintering sites and grid trapping of cotton across the High Plains area. The team effort of PCG, Texas A&M AgriLife Research and AgriLife Extension Service over several decades resulted in a comprehensive understanding of boll weevil ecology and behavior. Under the strong and cooperative leadership of PCG, the boll weevil eradication program for the High Plains area progressed much more rapidly than anticipated. Now, the successful boll weevil eradication program has eliminated the boll weevil from this region for two decades.

With a successful boll weevil eradication program and increased adoption of the transgenic *Bt* technology (now >70%), the cotton insect research and extension program focus has changed considerably during the last 20+ years. Our current research/extension focus is on developing ecologically intensive strategies for cotton pest management, including crop phenology, cultivar, non-crop habitat, irrigation, and fertility management towards reducing insect pest pressure. Our research has demonstrated the need for continuing investigation of basic behavior and life patterns of insects while having strong field-based applied research to bridge the gap between basic, problem-solving science and producer-friendly management recommendations. We have assembled a strong group of people to work as a team to examine multiple disciplines within the broad theme of Cotton IPM. We invest considerable time and manpower resources in investigating the behavior and ecology of major cotton pests of the High Plains with the goal of developing management thresholds based on cotton production technology and economics, with particular focus on limited water production system. Our Program has successfully leveraged research funds based on the funding provided by PCIC to support our research effort. We are excited about and greatly value our Cotton Entomology research and extension partnerships with multidisciplinary scientists at the Texas A&M AgriLife Research Center in Lubbock and statewide field crop entomologists, together with area IPM agents in the region, to continue this partnership as we challenge ourselves to deliver the best cotton insect-pest management recommendations to our Texas High Plains producers. Together, we have maintained the Texas High Plains area as a characteristically low cotton insect-pest prevalence region in the U.S. cotton belt.

Texas A&M AgriLife Research & Extension Center at Lubbock

COTTON ENTOMOLOGY PROGRAM

Megha N. Parajulee, Ph.D.
Professor, Faculty Fellow, and Texas A&M Regents Fellow

PROGRAM OVERVIEW: The Cotton Entomology Program at Lubbock combines basic and applied research with strong outreach, industry, and grower partnerships to produce information to enhance the ability of the cotton industry in the Texas High Plains to mitigate cotton yield losses due to insect pests through the use of ecologically intensive integrated pest management. Selected projects of the Program are briefly highlighted in this exhibit.

EFFECT OF NITROGEN FERTILITY ON COTTON CROP RESPONSE TO INSECT DAMAGE

A long-term study investigating the effects of differential nitrogen fertility on cotton aphids and cotton fleahopper population dynamics in a typical drip-irrigation Texas High Plains cotton production system has been ongoing since 2002. Differential nitrogen fertility (0, 50, 100, 150, and 200 lbs N/acre) is being examined for its effect on cotton plant physiological parameters, thereby influencing cotton insect injury potential and plant compensation. Recent focus has been to examine the effect of residual nitrogen on crop response to simulated cotton fleahopper damage.

Cotton fleahopper augmentation in multi-plant cages to quantify the response of variable rates of N to FH injury

SEASONAL ABUNDANCE PATTERNS OF BOLLWORM AND TOBACCO BUDWORM MOTHS IN THE TEXAS HIGH PLAINS

A long-term study is investigating the seasonal moth flight activity patterns of bollworm and tobacco budworm in the Texas High Plains. The regional adoption of cotton and corn cultivars incorporating *Bt* technology has contributed to reduced level of these lepidopteran pests in recent years; however, constant threat of insect resistance to transgenic technology and diminishing underground water availability for irrigation is necessitating lower crop inputs, such as transgenic seed costs, for increasing dryland crop acreage, increasing the importance of these pests.

Texas Pheromone (TP) and "Bucket" traps used to monitor moths

COTTON FLEAHOPPER SUSCEPTIBILITY OF PRE-FLOWER COTTON UNDER LIMITED IRRIGATION PRODUCTION

The objective of this project is to investigate the growth and fruiting response of cotton after cotton fleahopper infestation at three discrete cotton fleahoper susceptible stages (prior to visible squares, 1-2 square, and 3-4 square stages) of cotton under three irrigation water levels. We also quantify cotton compensatory potential following cotton fleahopper induced square loss under phenological stage x irrigation treatments.

Cotton fleahopper augmentation at three crop phenological stages and inspection to determine insect colonization and crop injury

ECONOMIC EVALUATION OF INSECT-PEST MANAGEMENT IN WATER-DEFICIT COTTON PRODUCTION

Reduced water availability, low rainfall, higher pumping cost of limited water, and increased input cost limit cotton productivity in the Texas High Plains and correspondingly lower profit margins, warranting for higher water use efficiency in our crop production. The impact of two key insect-pests at two distinct cotton phenological stages (thrips – seedling stage and cotton fleahopper – early squaring stage) will be evaluated with five combinations of single versus multiple-species infestations under two water-deficit (dryland and full-irrigation) conditions (10 pest management scenarios). This study will enable development of research-based action thresholds considering variable yield potential under different water deficit scenarios. These data will be utilized to develop a dynamic optimization economic model that maximizes the net returns from management of single versus multiple pest infestations under water-deficit crop production conditions. This will enable real-world decision support under various production settings and empower producers to optimize input resources for profitable cotton production.

Predictable occurrence of thrips at seedling stage and cotton fleahopper during the early squaring stage in the Texas High Plains

STATEWIDE RESEARCH-EXTENSION PROJECT TO ADDRESS CURRENT COTTON INSECT MANAGEMENT ISSUES

Multi-year statewide studies are being conducted at several Texas locations to represent cotton fields surrounded by variable vegetation/crop complexes and regional insect population pressure in cotton. Study objectives are to evaluate the value of cover crop, cultivar sensitivity to cotton fleahopper herbivory, fleahopper threshold, and cotton bollworm pyrethroid resistance. Research and Extension entomologists from south, central, and north Texas, including IPM agents from throughout Texas cotton production regions collaboratively conduct research to address these project objectives. Lubbock Cotton Entomology Project focuses on cover crop, cotton fleahopper cultivar susceptibility, and threshold.

Cover crop x irrigation evaluation of thrips abundance, seedling health, and crop compensation

EFFECT OF NITROGEN FERTILITY ON COTTON CROP RESPONSE TO SIMULATED COTTON FLEAHOPPER AND LYGUS DAMAGE

M.N. Parajulee, D. P. Dhakal, and K. L. Lewis

Objective: The study was designed to evaluate the effect of artificial injury to cotton squares and bolls mimicking acute cotton fleahopper and *Lygus* damages, respectively, under variable nitrogen application rates on cotton fiber yield and quality.

Methodology: A high-yielding cotton cultivar, DP1820B3XF, was planted at a targeted rate of 47,000 seeds/acre on May 26, 2022. The experiment was laid out in a split-plot randomized block design with five nitrogen fertility rate treatments (0, 50, 100, 150, and 200 lb N/acre) applied for 21 years as main plots (16-row plots) and three fruit loss treatments (artificial cotton square injury treatment mimicking acute cotton fleahopper infestation, 20% boll removal treatment to mimic late-season Lygus infestation, and control) as sub-plots with four replications (total 60 experimental units). Within each of the five main-plot treatments included pre-bloom side-dress applications of N augmentation using a soil applicator injection rig on July 6, 2022. Pre-treatment soil samples (consisting of three 0 to 12 and 12 to 24-inch depth soil cores each) were collected from each of the 20 main-plots on April 14, 2022. Ten leaves per plot were collected twice (August 13 and September 14) for leaf dry weight and nitrogen analysis. Within each main-plot, three 10-ft. sections of uniform cotton were flagged in the middle two rows, each receiving hand removal of 100% cotton squares three weeks into squaring, 20% bolls removed from top canopy of the plants at crop cut-out or control (no square or boll removal). Treatment plots were hand-harvested on November 2 for lint yield and fiber analysis.

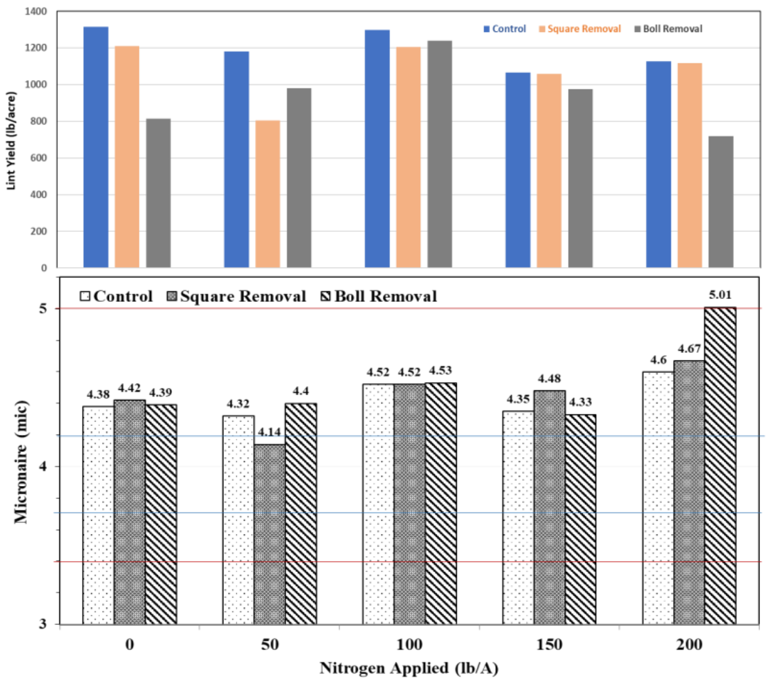

Fig. 1. Lint yield and micronaire values affected by simulated cotton fleahopper and Lygus damage across variable N rates.

Results: Significantly higher soil residual nitrogen was recorded from plots that received high rates of soil N augmentation (150 and 200 lb/acre) in preceding 21 years than control plots. Lint yield did not significantly vary across simulated insect treatments or N augmentation treatments, owing to considerable variation in data due to poor stand establishment and excessive drought during the growing season. Nevertheless, simulated Lygus damage reduced lint yield at zero- and 200 N treatments compared to other N treatments. Similarly, the lint quality, measured in terms of micronaire values, did not generally vary with the simulated cotton fleahopper or *Lygus* damage. Micronaire values were mostly on the base range (Fig. 1).

TITLE:

Cotton yield response to simulated cotton fleahopper and western tarnished plant bug infestations as influenced by irrigation level and cultivar treatments, Lamesa, TX, 2022.

AUTHORS:

Megha Parajulee – Professor, Faculty Fellow, and Regents Fellow
Dol Dhakal - Senior Research Associate
Wayne Keeling - Professor

MATERIALS AND METHODS:

Plot Size:	4 rows by 300-700 feet, 3 replications
Planting Date:	May 16, Rye cover planted November 20, 2021, terminated April 27, 2022
Varieties:	DP 2143NR B3XF FM 2498 GLT

Herbicides:

Gramoxone 32 oz/A + Caparol 32 oz/A	5/19/22
Roundup 32 oz/A + Warrant 32 oz/A	6/9/22
Aim (hooded) 1 oz/A	7/11/22
Roundup 32 oz/A + Liberty 32 oz/A	7/22/22

Fertilizer: 80-0-0

Irrigation:

	Low	Base	Base Plus
Preplant/Emergence	7.25”	7.25”	7.25”
In-season	0.0”	6.95”	9.25”
Total	7.25”	14.2”	16.5”

Treatments: Three treatments included c*ontrol, manual removal of 100% squares three weeks into squaring (July 14) to time cotton fleahopper susceptible stage, and removal of 20% bolls from the top of the plant to simulate Lygus infestation (August 18)*.

Harvest date: November 16 (hand-harvested)

Effect of manual removal of early-stage versus late-stage fruits was evaluated on two cotton cultivars, FM 2498 GLT and DP 2143NR B3XF, as influenced by two irrigation (low and high) water levels. The experiment comprised of two water levels, two cultivars, and three simulated fruit loss events [control, pre-flower 100% square loss mimicking the cotton fleahopper injury-induced loss, and 20% small bolls (<3 cm diameter) loss mimicking the Lygus boll injury-induced small fruit abortion at cut-out], replicated three times, totaling 36 plots. The test plots were monitored for the occurrence of any other insects, but no such occurrences were observed during the growing season.

RESULTS AND DISCUSSION:
Combined over two cultivars and three insect simulation treatments, significantly higher lint yield was recorded from 'high' water regime (891 lb/acre) compared to that in 'low' water regime (128 lb/acre). No significant difference in lint yield was recorded between insect simulated (cotton fleahopper or Lygus) and control plots regardless of the water regime (Fig. 1). Lint yield under low water regime was abnormally low in 2022 due to prolonged drought, resulting in no insect simulation treatment difference. However, the late season fruit removal mimicking Lygus injury reduced lint yield by 375 lb/A compared to an early season fruit removal mimicking cotton fleahopper injury under high water regime (Fig. 1), indicating a greater pest risk at cut-out than for pre-flower cotton. While Lygus simulation consistently reduced lint yield across all irrigation water level X cultivar combinations, FM 2498 GLT at high water treatment showed the most impact (Fig. 2).

All 12 treatment combinations (2 Water x 2 Cultivar x 3 Insect Infestation treatments) resulted in micronaire values >5.0 (5.2 in FM 2498 GLT-High Water-Control to 5.8 in FM 2498 GLT-High Water-FH Simulation), rendering the entire test crop to a discount range. Irrigation water treatment significantly impacted the Short Fiber Index (SFI), with SFI values of 8.67 in 'high' water and 12.18 in 'low' water treatments. Similarly, early-season square removal improved SFI (8.97) compared to control (10.88) and late-season boll removal (11.44), suggesting a significant fiber quality impact by late-season Lygus infestation. Similarly, 'high' water plots produced stronger fiber (31.8) than 'low' water plots (29.7). A significant interaction of water x cultivar x insect simulation influenced fiber strength. Six of the 12 treatment combinations resulted in very strong fiber, four produced strong fiber, one intermediate, and one weak fiber (Fig. 3).

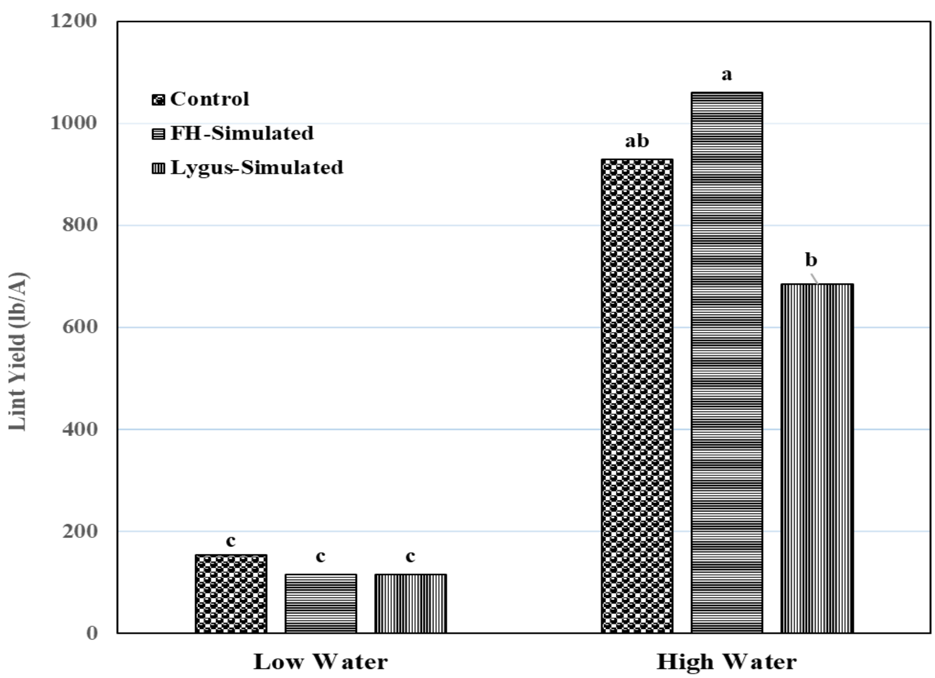

Figure 1. Average lint yield under low and high irrigation regimes following cotton fleahopper and Lygus infestation simulation versus control, Lamesa, Texas, 2020.

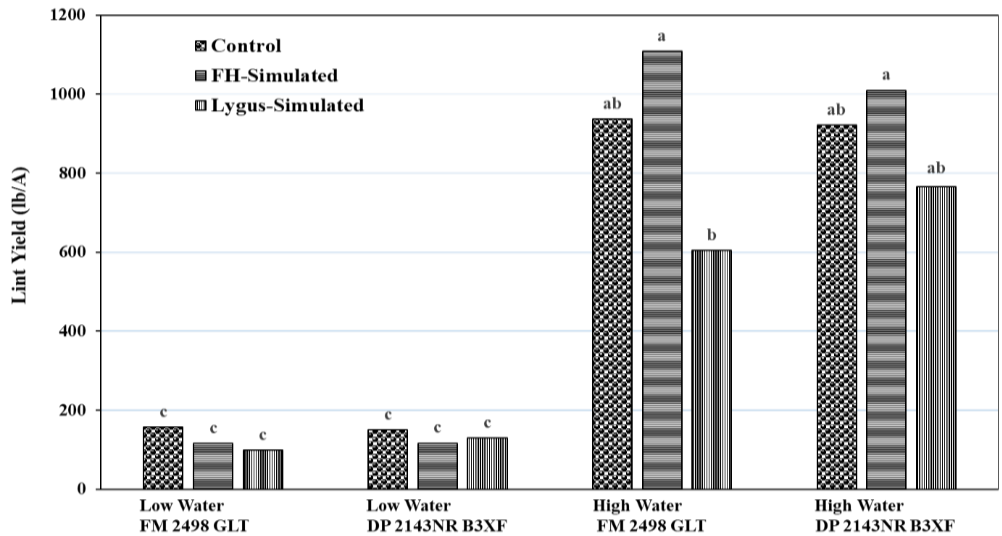

Figure 2. Average lint yield influenced by simulated cotton fleahopper versus *Lygus*-induced fruit removal in two cotton cultivars under low and high irrigation regimes, Lamesa, Texas, 2022.

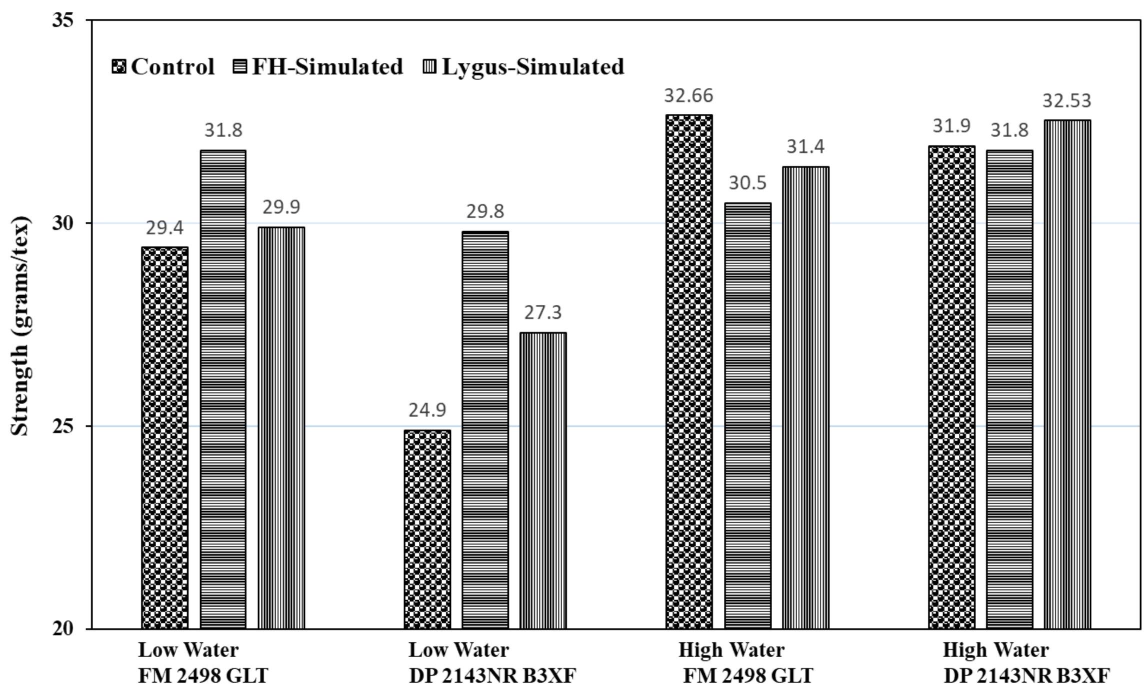

Figure 3. Average fiber strength values (grams/tex) influenced by early-season simulated cotton fleahopper damage and simulated *Lygus*-induced fruit removal in late season in two cotton cultivars under low and high irrigation regimes, Lamesa, Texas, 2022. Interpretation of fiber strength: Very strong ≥31, Strong 29-30, Average 26-28, Intermediate 24-25, and Weak ≤23.

Cotton fleahopper susceptibility and compensatory potential of three distinct phenological stages of pre-flower cotton in water-deficit production scenario

Cotton Incorporated – Core Program
Project Number: 20-246

Megha N. Parajulee
Texas A&M AgriLife Research and Extension Center, Lubbock, Texas

Project Summary

The recent increase in limited-irrigation cotton production in the Texas High Plains has demanded development of pest management strategies at low-input production system. Our current understanding is that cotton fleahoppers can be injurious to cotton during 3-weeks of squaring until about the appearance of first flower. That may warrant possible management of cotton fleahoppers up to three discrete stages of cotton prior to flowering as stated earlier. Impact of cotton fleahoppers on pre-squaring stage, especially when fleahoppers migrate to cotton prior to the occurrence of visible squares, and late squaring/first-flower stage is not quantified. Our earlier work on cotton fleahopper compensation studies suggest that cotton plants can tolerate up to 20% fruit loss. This project aims to investigate the growth and fruiting response of cotton after cotton fleahopper induced square loss at three discrete cotton fleahoper susceptible stages of cotton under deficit-irrigation scenario. The specific objectives of the study were to 1) quantify the damage potential of cotton fleahopper (feeding injury and/or square abortion) at square initiation (prior to visible squares), 1-2-square, and 4-5-square stages of cotton under dryland, deficit irrigation versus full irrigation, 2) determine cotton growth parameters and fruiting profiles as influenced by cotton fleahopper injury at three discrete cotton fleahopper susceptible stages of cotton under deficit-irrigation scenario, and 3) quantify cotton compensatory potential following cotton fleahopper induced square loss under phenological stage x irrigation treatments.

This study is expected to generate a significant amount of data to elucidate the damage potential of cotton fleahoppers at three discrete cotton fleahopper susceptible stages under two drought-stress conditions, including low/supplemental irrigation (drought stress) and full irrigation (no drought stress), and cotton's response to cotton fleahopper injury under each production scenario. The data regarding how the cotton fleahopper injury x drought-stress conditions impact cotton performance at three discrete phenological stages will be useful in making management decisions based on economic models.

Cotton fleahopper infestation at pre-squaring stage reduced cotton lint yield across all irrigation treatments, although significant only under dryland and full irrigation condition. It is plausible that fleahoppers fed on growing terminals and likely damaged the invisible squares which ultimately reduced the lint yield. Cotton fleahoper infestations also impacted fiber quality, with improved micronaire values under full irrigation. The two-year study clearly suggests that there is an apparent interaction between fleahopper-induced injury to cotton and irrigation water availability for plants to overcome the injury effect, thereby influencing the lint yield and fiber quality. An additional two years of studies will provide more insight into these results.

Introduction

The cotton fleahopper, *Pseudatomoscelis seriatus* (Reuter), is a significant economic pest of cotton in the Texas High Plains. Injury by cotton fleahoppers to squaring cotton often causes excessive loss of small squares during the early fruiting period of plant development (first 3 weeks of squaring). There has been some evidence that cotton fleahoppers also infest pre-squaring cotton plant terminals, perhaps when squares are developing on the plant. Both adults and immatures feed on new growth, including small squares. Greater damage is observed on smooth leaf varieties than on hirsute varieties, which may extend the susceptible period into early bloom, especially under a high-input production regime. Generally, cotton is affected by cotton fleahopper injury from about the fifth true leaf through first week after initiation of flowering. Squares up to pinhead size are most susceptible to damage, and yield loss is most likely from feeding during the first three weeks of fruiting. Cotton fleahopper damage also delays crop maturity and thus increases the vulnerability of cotton to late season pests such as Heliothine caterpillars and *Lygus* bugs, particularly when natural enemies are destroyed by insecticides directed against cotton fleahoppers.

Predominantly, cotton fleahoppers feed upon pinhead-sized or smaller squares, which results in abortion of these young fruits, thereby impacting yields. While cotton fleahopper feeding preferences serve as a baseline for their management in cotton fields, a detailed understanding of cotton plant responses to fleahopper damage remains unachieved. Because cotton vulnerability to cotton fleahoppers spans over a period of 3-4 weeks, information on acute infestation of cotton fleahopper at phenologically-specific crop stages may help cotton producers make appropriate management decisions in low-input, water-deficit production systems. Cotton plant growth is sensitive to numerous environmental and management input factors, particularly irrigation and cultivar traits. Cotton growth responses to various input factors are well-documented and growth models have been developed. However, the specific cotton plant responses to cotton fleahopper injury at phenologically discrete cotton fleahopper susceptible stages remain uninvestigated. This research project proposes to evaluate the cotton crop growth parameters and lint yield following cotton fleahopper acute infestations at three distinct cotton fleahopper susceptible cotton stages (pre-squaring, 1-2-square stage, 4-5-square stage) under deficit-water versus full-irrigation production regimes.

Methodology

The study was conducted at the Texas A&M AgriLife Research farm in Lubbock. A 5-acre subsurface drip irrigation system has been in place for this study. Main-plot treatments included full irrigation, supplemental irrigation, and dryland. The full irrigation water level was created via 90% replenishment of evapotranspiration (ET) requirement for THP, whereas the supplemental irrigation treatment received 30% ET replenishment. Cotton cultivar DP 1820B3XF was planted on 18 May 2020. In 2021, cotton cultivar DP1845B3XF was planted on 18 May, but the crop was destroyed by repeated rain and hailstorm events and the test was replanted on 9 June. Sub-plot treatments included three discrete phenological stages of cotton that is considered susceptible to cotton fleahopper damage: 1) prior to the occurrence of visible squares on seedling cotton or "pre-square" cotton, 2) cotton at 1-2 visible squares stage or early squaring stage, and 3) cotton with 4-5 squares and close to the occurrence of first flower or late squaring).

Two 3-ft sections of uniform cotton were flagged in the middle two rows of each treatment plot (3 irrigation treatments x 3 phenological stages x 2 insect augmentation treatments x 4 replications = 48 experimental units) for insect treatment deployment. At each phenological stages, 5 cotton fleahopper nymphs per plant versus no fleahopper augmentation as control were deployed in these designated row sections to simulate an acute infestation of cotton fleahoppers.

Woolly croton, a cotton fleahopper weed host, was harvested from locations in and near College Station, Texas, in early February and stored in cold storage until fleahoppers were needed for the study. Conditions conducive to cotton fleahopper emergence were simulated in a laboratory environment to induce hatching of overwintered eggs embedded in the croton stems, and emerged cotton fleahoppers were subsequently reared using fresh green beans as a feeding substrate.

Considerable effort was expended to ensure synchronization of rearing efforts with cotton crop development for optimal release timing for each of the three cotton phenological stages. A single release nymphal cotton fleahopper was timed to simulate the acute heavy infestation of cotton fleahoppers (3-4 days of feeding) at each stage. This arrangement ensured significant damage on treatment plots to quantify the variation in damage potential as influenced by cotton phenological stage. The actual release dates in 2020 were 20 June (pre-square), 1 July (early square), and 21 July (late square). Cotton fleahopper rearing cages were installed about a month prior to the first release (e.g., 20 May 2020 for 20 June 2020 release) and staggered the cage installation for the next 4-5 weeks to ensure a continuous supply of cotton fleahopper nymphs for the study. In 2021, actual release dates for pre-square, early square and late-square cotton stages were 2 July, 16 July and 26 July, respectively.

The release was accomplished by manually placing second- to third-instar cotton fleahopper nymphs from the laboratory colony onto the terminals of plants in each treatment plot at the rate of 5 nymphs per plant; the control plots received no fleahoppers and were kept fleahopper-free during the entire study period. Because natural infestation of cotton fleahopper was absent at the experimental farm, the control plots received no insecticidal intervention. An insecticide (acephate 97% 6 oz/acre) was used to kill all remaining cotton fleahoppers after the one-week feeding period in all experimental units to ensure complete removal of released cotton fleahoppers. The entire test was kept insect-free for the remainder of the study to isolate the effect of cotton fleahopper injury only.

Data collection included monitoring of flowering patterns, fruit abscission, and plant height. In 2020, flower monitoring was initiated on 20 July and conducted every 2-3-day intervals with total of 14 sample dates, and in 2021, flower monitoring was started on 7 August and ended on 10 September with a total of 18 sample dates. Harvest aids Boll'd® 6SL (Ethephon [(2-chloroethyl) phosphonic acid] @ 1 qt//acre (boll opener) and Folex® 6 EC (S, S, S-tributyl phosphorotrithioate) 1 pint/a (defoliant) were applied on 12 October in 2020, and in 2021, Boll'd® 6SL (Ethephon [(2-chloroethyl) phosphonic acid] @ 1 qt//acre (boll opener) and Gramoxone® SL 2.0 (Paraquat dichloride (1,1'-dimethyl-4,4'-bipyridinium dichloride) were applied on 25 October and 5 November, respectively, to accelerate opening of matured unopened bolls and begin the defoliation process. Test plots were hand-harvested on 11 and 12 November. Hand-harvested yield samples were ginned, and the samples were analyzed for fiber quality parameters (HVI) at Cotton Incorporated.

Results and Discussion

2020 Study

Cotton fleahopper induced square injuries exerted very low level of square abscission (10-15%). Irrigation water level significantly influenced the cotton lint yield, as expected, with significantly higher yield with increased level of irrigation. Averaged across cotton fleahopper augmentation treatments, dryland produced the lowest lint yield (1102 lb/acre), followed by low water (1420 lb/acre), and the highest lint yield was observed under full irrigation (1691 lb/acre) (Fig. 1). Despite low insect injury, cotton fleahopper infestation at pre-squaring stage (before the onset of visible squares) reduced cotton lint yield across all three irrigation treatments, although the value was statistically significant only under dryland condition (Fig. 2). Even though not significant due to high data variation, lint yields were conspicuously reduced in both supplemental and full irrigation treatments when cotton fleahoppers were augmented at pre-square stage (Fig. 2). It is plausible that fleahoppers fed on growing terminals and likely damaged the invisible squares which ultimately reduced the lint yield. Also, cotton fleahopper infestations at early as well as late squaring (pre-flower) cotton did not reduce lint yield at any of the three irrigation regimes. Figure 2 suggests that cotton compensated or overcompensated (numerically) any fruit loss due to fleahopper-induced injury, ultimately showing no significant effect on lint yield. Early square stage of cotton appeared to be more susceptible to cotton fleahoppers than late squaring cotton under dryland condition; however, irrigated cotton did not show such differential responses. Manual removal of squares (100% squares removed at the time of first flower coinciding with the fleahopper infestation at late squaring stage) significantly reduced the lint yield under dryland condition, but plants compensated the manually removed fruit abscission under both irrigated conditions.

Cotton fleahopper infestation also impacted fiber quality while the plant response to cotton fleahopper injury was influenced by irrigation water level. High water treatment resulted in micronaire values in the premium range for all fleahopper augmentation sub-plot treatments (Fig. 3). Interestingly, lint fiber from the uninfested control plots had micronaire in the premium range, but the micronaire values increased and moved away from premium range to base range for all FH-augmented plots (Fig. 3). All sub-plot treatments resulted in micronaire values at base range under supplemental irrigation. Manual removal of squares resulted in premium micronaire value under dryland and base value under both irrigation regimes. Other fiber quality parameters varied marginally with insect augmentation X irrigation interactions (Table 1). These data clearly suggested an apparent interaction between fleahopper-induced injury to cotton and irrigation water availability for plants to overcome the injury effect, thereby influencing the lint yield and fiber quality.

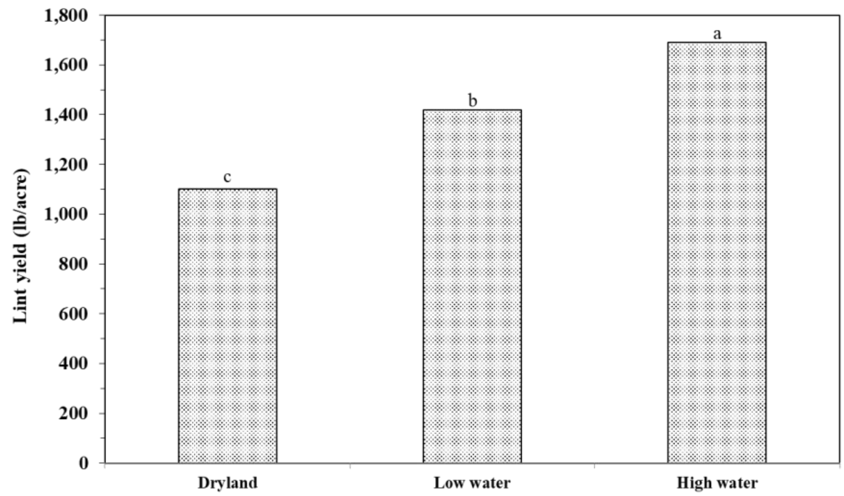

Fig. 1. Average cotton lint yield across cotton fleahopper augmentation treatments under three irrigation water regimes, Lubbock, Texas, 2020. Different lowercase letters indicate treatment means were significantly different from each other.

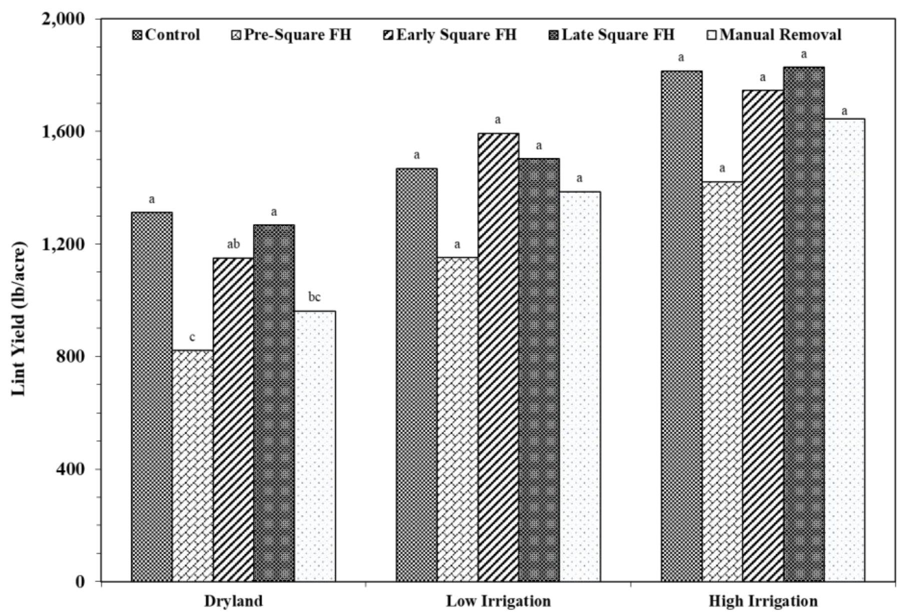

Fig. 2. Cotton lint yield following cotton fleahopper infestations at three cotton phenological stages and manual square removal at first flower under three irrigation water treatments, Lubbock, Texas, 2020. Average values were compared across five treatments within each irrigation treatment; same lowercase letters indicate treatment means were not significantly different from each other. Pre-square FH = fleahoppers augmented prior to the occurrence of visible squares in plants; Early square FH = fleahoppers released at 1-2 visible squares; Late square FH = fleahoppers released when cotton was about to begin flowering; Manual Removal = all visible squares removed from plants at first flower.

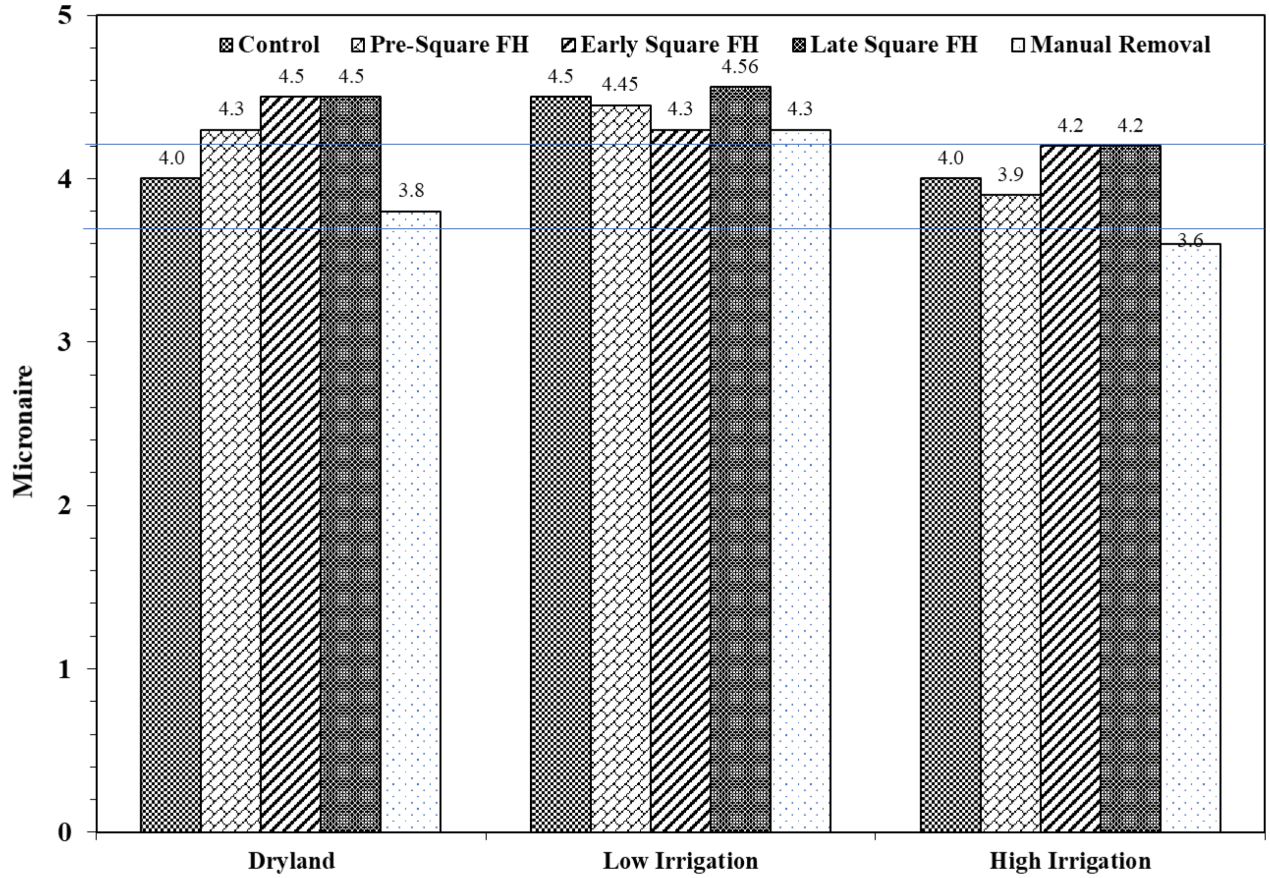

Fig. 3. Cotton fiber micronaire values (units) following cotton fleahopper infestations at three cotton phenological stages and manual square removal at first flower under three irrigation water treatments, Lubbock, Texas, 2020. Two blue lines indicate the region of micronaire values for the premium lint value. Pre-square FH = fleahoppers augmented prior to the occurrence of visible squares in plants; Early square FH = fleahoppers released at 1-2 visible squares; Late square FH = fleahoppers released when cotton was about to begin flowering; Manual Removal = all visible squares removed from plants at first flower.

Table 2. HVI fiber quality parameters influenced by cotton fleahopper augmentation treatments under three irrigation water treatments, Lubbock, Texas, 2020

Fiber Parameters	Irrigation Treatment	Fleahopper Simulation	Uninfested Control	Pre-Square Fleahopper	Early square Fleahopper	Late-square Fleahopper
Micronaire	Dryland	3.08	3.40	4.36	4.51	4.54
Fiber length	Dryland	1.10	1.13	1.14	1.16	1.14
Uniformity	Dryland	80.18	80.43	81.33	81.60	81.50
Strength	Dryland	30.95	31.80	32.13	32.35	32.30
Elongation	Dryland	7.73	7.68	7.65	7.83	7.73
Micronaire	Low	3.43	3.83	4.45	4.30	4.56
Fiber length	Low	1.15	1.16	1.14	1.16	1.16
Uniformity	Low	81.44	81.66	81.55	81.63	82.00
Strength	Low	31.91	31.60	31.88	32.00	31.93
Elongation	Low	7.84	7.99	7.73	7.93	7.85
Micronaire	High	3.00	3.39	3.93	4.24	4.22
Fiber length	High	1.17	1.17	1.20	1.21	1.20
Uniformity	High	80.73	80.94	82.08	82.23	82.60
Strength	High	31.61	31.71	32.15	31.78	31.00
Elongation	High	8.04	8.11	8.28	8.30	8.30

2021 Study

The effect of pre-square cotton fleahopper release was assessed when plants already had significant number of squares on the plant (10 days post-release) which showed 10% square loss, whereas early-square stage had 32% square loss and 21% square loss was observed at late-square stage. Flower initiation began around 7 August and continued beyond 10 September. Peak flower initiation was recorded on 26 August at all water level treatments; however, the highest number of flowers were recorded in dryland plots (Fig. 4) which was largely attributed to incessant rainfall during the cotton flowering stages that likely equalized all irrigation main treatment plots.

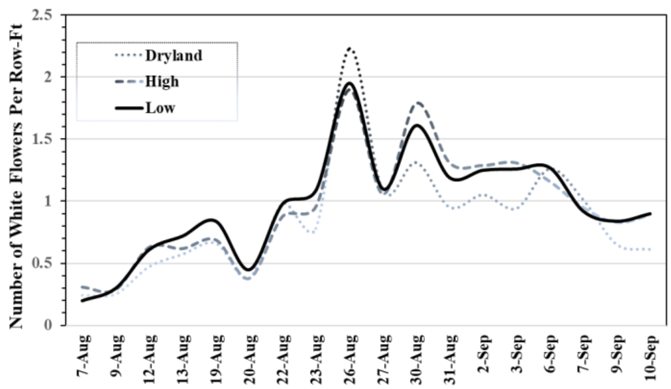

Figure 4. Temporal abundance of white flowers (number of white flowers per row-ft per sample date) recorded from cotton fleahopper infested plots under dryland versus irrigated production conditions, Lubbock, Texas, 2021.

Irrigation level did not significantly influence the lint yield. Replanting of the test delayed the crop maturity and reduced the overall yield. As stated previously, frequent rain events equalized the lint across three irrigation treatments (Fig. 5). Averaged across cotton fleahopper augmentation treatments, dryland produced 570 lb/acre, followed by 763 in low water and 697 in full irrigation treatments (Fig. 1). Insect release treatments significantly affected lint yield in dryland plots, with 627, 453, 793, and 407 lb/acre lint yield in uninfested control, thrips only, cotton fleahoppers only, and thrips+cotton fleahoppers plots, respectively. Even though thrips-induced damage was not apparent during the seedling stage, lint yield was dampened in thrips-release plots in dryland, albeit not statistically significant, and thrips+cotton fleahopper plots had significantly the lowest lint yield (Fig. 6) Lint yield did not vary amongst insect management treatments in low or high irrigation water treatments.

Cotton fleahopper infestation impacted fiber quality while the plant response to cotton fleahopper injury was influenced by irrigation water level (Fig. 7, Table 3). Micronaire values ranged from poor quality (<3.4) to premium (3.7-4.2) fiber across all three water treatments. Two insect-infested treatments in high water treatment had micronaire values in the premium range, but none on low water or dryland plots had micronaire in the premium range. There was no clear explanation for the observed variation in micronaire across treatments. Other fiber quality parameters varied marginally with insect augmentation X irrigation interactions (Table 3). These data suggested an apparent interaction between fleahopper-induced injury to cotton and irrigation water availability for plants to overcome the injury effect, thereby influencing the lint yield and fiber quality.

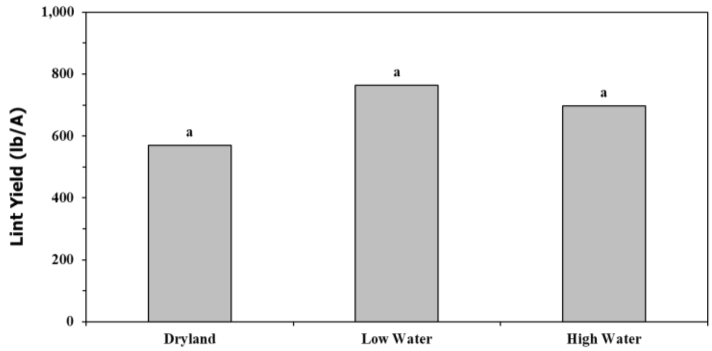

Figure 5. Average cotton lint yield across cotton fleahopper augmentation treatments under three irrigation water regimes, Lubbock, Texas, 2021. Same lowercase letter for each value indicates treatment means were not significantly different from each other.

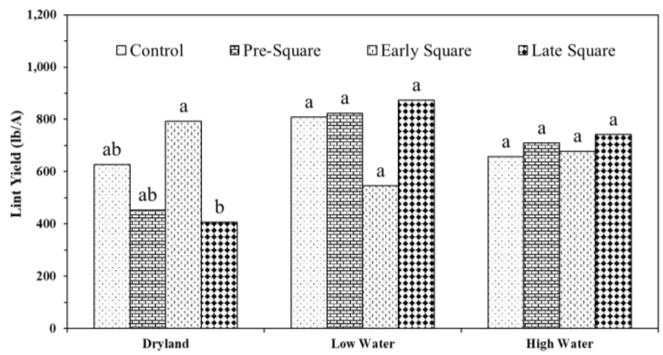

Figure 6. Cotton lint yield following cotton fleahopper infestations at three cotton phenological stages under three irrigation water treatments, Lubbock, Texas, 2021. Average values were compared across five treatments within each irrigation treatment; same lowercase letters indicate treatment means were not significantly different from each other.

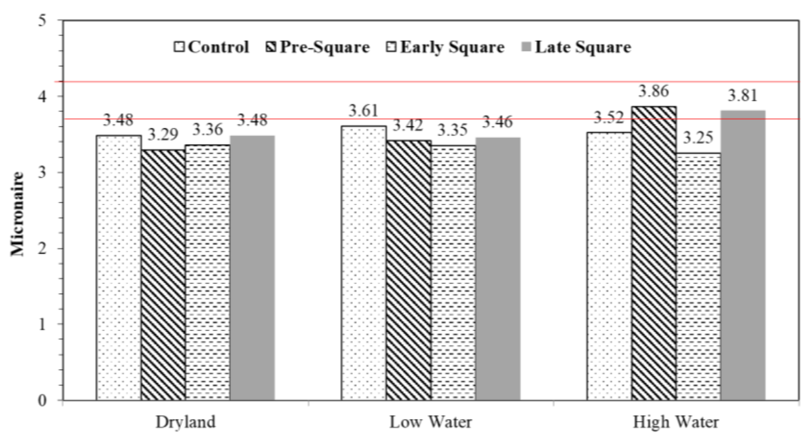

Figure 7. Cotton fiber micronaire (units) values influenced by cotton fleahopper infestation timing under three irrigation treatments, Lubbock, Texas, 2021.

Table 3. HVI fiber quality parameters influenced by cotton fleahopper augmentation treatments under three irrigation water treatments, Lubbock, Texas, 2021.

Parameters	Irrigation	Control	Pre-Square	Early Square	Late Square
Micronaire	Dryland	3.48	3.29	3.36	3.48
Fiber length	Dryland	1.15	1.17	1.18	1.18
Uniformity	Dryland	80.20	79.62	80.77	80.37
Strength	Dryland	31.67	32.07	32.77	31.65
Elongation	Dryland	7.20	7.27	7.37	7.42
Micronaire	Low	3.61	3.42	3.35	3.46
Fiber length	Low	1.16	1.17	1.18	1.16
Uniformity	Low	80.47	81.00	80.10	80.75
Strength	Low	31.42	32.30	32.82	32.52
Elongation	Low	7.75	7.80	7.60	7.47
Micronaire	High	3.52	3.86	3.25	3.81
Fiber length	High	1.19	1.18	1.16	1.18
Uniformity	High	81.20	80.70	80.47	81.95
Strength	High	32.82	30.45	31.77	32.57
Elongation	High	7.80	7.77	7.70	7.67

2022 Study

The effect of “pre-square” cotton fleahopper release was assessed two weeks after fleahoppers were augmented in test plots with no visible squares (squares were already forming but not visible), which showed 24% [18, 28, and 25% square loss, respectively, in dryland, supplemental irrigation, and full irrigation plots] square loss, whereas early-square stage had 17% square loss (19, 17, and 15% for dryland, supplemental, and full irrigation plots) and 20% square loss (22, 22, and 17% for dryland, supplemental, and full irrigation plots) was observed at late-square stage (Fig. 8).

Flower initiation began around mid-July and continued through late August. Peak flower initiation was recorded around 10 August at all water level treatments (Fig. 9). Flowering dynamics were significantly altered by cotton fleahopper infestations. Uninfested control plots had much higher flower densities in irrigated treatment plots compared to that in dryland plots, whereas flower densities were dampened, and flowering profiles altered when cotton fleahopper infestations occurred. Interestingly, cotton fleahopper infestations at pre-square stage of cotton, while the flowering dynamics were altered, did not significantly reduce the total flower densities while delaying the major flower activity. It suggests that the cotton fleahopper infestation in pre-squaring cotton will likely damage the plant terminal along with developing squares that are not yet visible, thereby delaying the plant's reproductive growth.

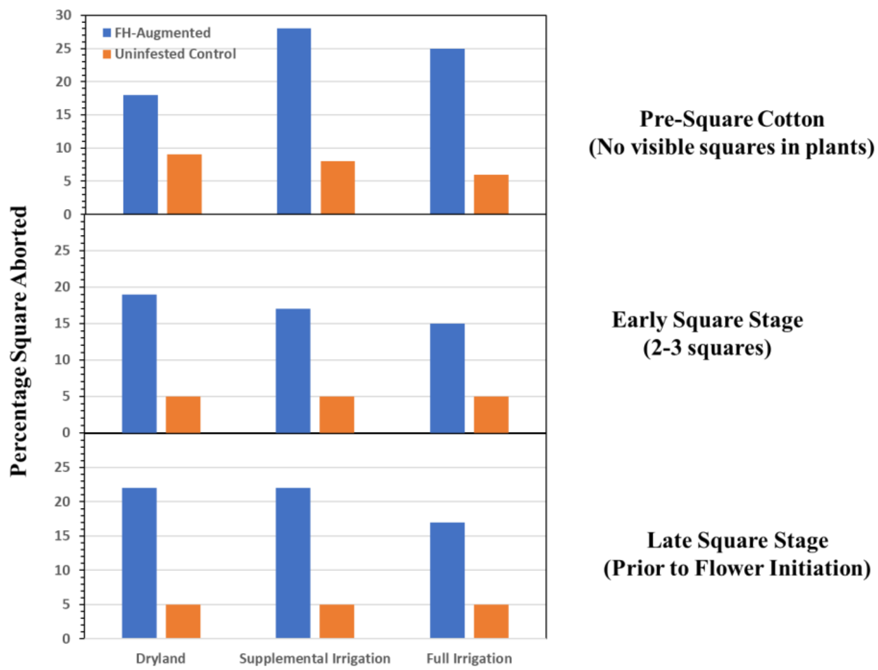

Figure 8. Average percentage square aborted during pre-, early, and late square stages of pre-flower cotton under dryland versus irrigated production conditions, Lubbock, Texas, 2022.

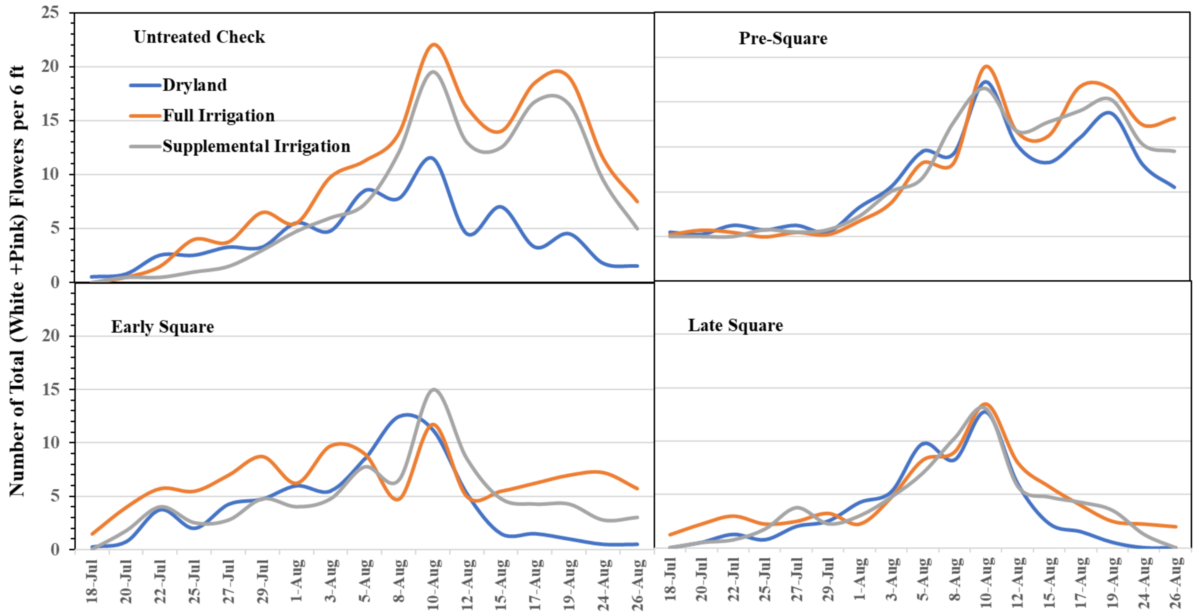

Figure 9. Temporal abundance of white+pink flowers (number of total flowers per 6 row-ft per sample date) recorded from cotton fleahopper infested plots under dryland versus irrigated production conditions, Lubbock, Texas, 2022.

Lint yield did not significantly vary across irrigation treatments due to unusually hot and dry growing conditions. Nevertheless, fleahopper infestations during pre-square stage reduced yield in both dryland and full irrigation regimes, whereas cotton fleahopper infestations at late squaring stage drastically reduced yield under dryland conditions (Fig. 10). Cotton fleahopper infestations also impacted fiber quality parameters (Table 4).

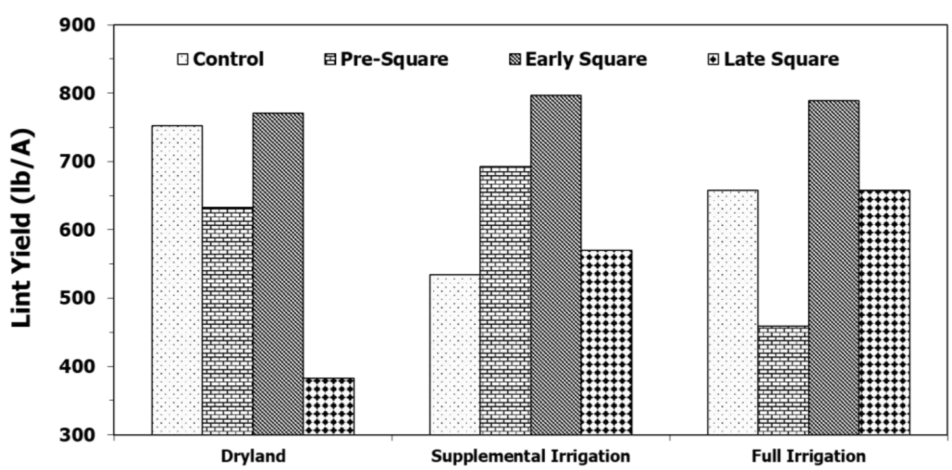

Figure 10. Cotton lint yield following cotton fleahopper infestations at three cotton phenological stages under three irrigation water treatments, Lubbock, Texas, 2022.

Table 4. HVI fiber quality parameters influenced by cotton fleahopper augmentation treatments under three irrigation water treatments, Lubbock, Texas, 2022.

Parameters	Irrigation	Control	Pre-Square	Early Square	Late Square
Micronaire	Dryland	4.49	4.31	4.37	4.67
Fiber length	Dryland	1.16	1.13	1.13	1.15
Uniformity	Dryland	81.80	80.55	80.90	81.10
Strength	Dryland	28.35	29.20	29.65	29.93
Elongation	Dryland	7.56	6.90	6.98	6.95
SFC	Dryland	9.10	10.23	10.03	9.28
Micronaire	Low	4.96	4.80	4.59	4.12
Fiber length	Low	1.13	1.14	1.15	1.12
Uniformity	Low	81.80	80.55	81.55	80.08
Strength	Low	30.28	30.10	29.30	29.00
Elongation	Low	6.75	6.45	6.90	6.50
SFC	Low	9.18	9.63	9.38	11.48
Micronaire	High	4.53	4.10	5.34	4.67
Fiber length	High	1.18	1.14	1.09	1.09
Uniformity	High	81.60	80.18	81.10	79.75
Strength	High	31.03	28.25	30.30	28.38
Elongation	High	6.63	7.05	6.30	6.40
SFC	High	9.53	11.08	9.78	11.53

Acknowledgments

Research funding which facilitated this study came from Cotton Incorporated Core Program and Plains Cotton Improvement Program. Dol Dhakal provided the technical help.

Economic Evaluation of Insect-Pest Management in Water-Deficit Cotton Production

Cotton Incorporated - Texas State Support Committee

Project Number: 18-099TX
PI: Megha N. Parajulee
CO-PIs: Abdul Hakeem, Suhas Vyavhare, Katie Lewis, Wayne Keeling, and Donna McCallister

PROJECT SUMMARY

The Texas High Plains (THP) is a semi-arid region with characteristic low rainfall, with production agriculture supported by limited irrigation or rain-fed. As a result, the cropping system in this region is largely low-input and the producer decision-making in economically profitable input use is a challenge. THP has been facing some significant drought conditions in recent years, causing disproportionate depletion of the underground water, significantly shifting the cotton production outlook in THP to even more low-input with dryland acreage reaching to >65%. The shift in cotton production system due to devastating droughts in an already semi-arid region has altered our input resources, cultivars, and management practices. Low cotton market price, increased nitrogen fertilizer price, and reduced water availability have forced farmers to move toward reorganizing available input resources to sustain their production enterprise. Thus, transitioning to the new crop production reality via developing economic data-based input management practices has become our priority to sustain producer profitability.

The objectives of this project were to: 1) quantify the impact of single (thrips or cotton fleahoppers) versus sequential (thrips and cotton fleahoppers) pest infestations on cotton lint yield and fiber quality under three irrigation water regimes, and 2) develop a dynamic optimization economic model that maximizes the net returns from management of single versus sequential pest infestations under water-deficit crop production conditions. Thus, the scope of this proposed work entails integrating production practices and pest management options under numerous cotton management scenarios and the management options would be developed based on breakeven value and net return of each option for farmers to choose depending on irrigation water availability.

Thrips and cotton fleahoppers impacting cotton production risks were evaluated during 2018-2021 with five combinations of single versus sequential infestations under three water (full irrigation, supplemental, dryland) regimes. Water deficit conditions and insect infestations impacted crop growth profile as well as lint yield. Thrips alone reduced lint yield across all water regimes, but significantly in dryland and full irrigation, whereas cotton fleahopper was not a significant yield reducer by itself. However, sequential infestation of thrips and cotton fleahopper increased yield loss, and the effect of sequential infestation increased with increasing water level. Thrips and thrips+cotton fleahoppers significantly reduced lint yield compared to cotton fleahopper treatment in dryland and full irrigation, but the effect was less pronounced under low-water treatment, indicating the impact of drought conditions on modulating the effect of insect pests as well as plant's compensatory ability. Thrips alone reduced gross margins across all three water levels, whereas cotton fleahopper reduced gross returns only under full irrigation ($90/acre). Sequential infestations of thrips and cotton fleahopper reduced gross returns by $128, $65, and $182 per acre. Dryland and full irrigation systems are quite vulnerable to thrips and cotton fleahopper sequential infestations.

Economic Evaluation of Insect-Pest Management in Water-Deficit Cotton Production

INTRODUCTION

The Texas High Plains (THP) is a semi-arid region with characteristic low rainfall (average annual rainfall of 15-18 in.), with production agriculture supported by limited irrigation or rain-fed. As a result, the cropping system in this region is largely low-input and the producer decision-making in economically profitable input use is a challenge. THP has been facing some significant drought conditions in recent years, resulting in disproportionate depletion of underground water and significant shift in the cotton production outlook in THP to even more low input with dryland acreage reaching to about 65%. The shift in cotton production system due to recurring droughts in already a semi-arid region has altered our input resources, cultivars, and management practices. Low cotton market price, increased nitrogen fertilizer price, and reduced water availability have forced farmers to move toward reorganizing available input resources to sustain their production enterprises enterprise (Dhakal et al. 2019, Lascano et al. 2020). While the drought and heat conditions are unpredictable, the anticipated changes in global climate patterns may exacerbate the water-deficit conditions further in the Texas High Plains. Thus, transitioning to the new crop production reality via developing economic data-based input management practices has become our priority to sustain producer profitability and for future success of the U.S. cotton industry.

Much has been reported on direct and indirect effects of drought stress on cotton, but the effect of drought stress on cotton insect pest dynamics, feeding potential, and plant's response to insect injury under drought-stressed conditions are limited. In addition, the paucity of information on integration of pest management decisions and crop production decisions has hindered producers' ability to predict economic risks of optimizing limiting input resources. Predicting pest populations under different water-deficit crop production scenarios and understanding how these conditions influence those populations to impact crop production risks, are critically important components for implementing pest management strategies as crop cultivars and other input variables continue to change. Reduced water availability, low rainfall, higher pumping cost of limited water, and increased input cost may result in lower yields and correspondingly lower profit margins, warranting for higher water use efficiency in our crop production and optimal use of inputs. Therefore, cotton producers must carefully consider costs of pest management options against potential benefits to overall net profit margin of the crop production enterprise. The objectives of this project were to: 1) Quantify the impact of four combinations of single versus sequential infestations of two major insects (thrips and cotton fleahoppers) on cotton lint yield and fiber quality under three irrigation water regimes (water-deficit treatments – dryland, low irrigation, and full irrigation), and 2) Develop a dynamic optimization economic model that maximizes the net returns from management of single versus sequential pest infestations under water-deficit crop production conditions. Thus, the goal of this project was to integrate production practices and pest management options under numerous cotton management scenarios and the management options are being developed based on breakeven value and net return of each management option for farmers to choose depending on the availability of water resource on their farms.

METHODOLOGY

A 5-year study (2018-2022) was conducted on a five-acre subsurface drip irrigation cotton field located at the Texas A&M AgriLife Research farm in Lubbock, Texas.

Irrigation water level treatments. Three irrigation water levels (dryland, supplemental irrigation, and full irrigation) simulated three water-deficit production conditions, including high water-deficit (dryland condition), limited water condition, and no water-deficit. A high-water treatment maintained >90% evapotranspiration replenishment through subsurface drip irrigation throughout the crop growing season, supplemental irrigation maintained about 40% ET replenishment, and the dryland treatment received pre-planting irrigation to facilitate proper seed germination and no additional irrigation for the remainder of the growing season. In 2018, only dryland and full irrigation main plot treatments were available; 2019-2021 had all three water levels.

Planting and field management. The 2018 study followed the conventional tillage system of cotton cultivation and regionally adopted production practices were followed, including pre-planting application of 80 lb N/acre. Cotton cultivar DP 1646 B2XF (seed with no insecticide or fungicide seed treatment) was planted on 31 May 2018. In 2019, wheat was planted on 14 February 2019 as a cover crop to minimize pre-planting soil erosion and prevent cotton seedlings from sandblasting during May/June. Cotton cultivar DP 1646 B2XF was planted on 14 May 2019 and the wheat was terminated on 20 May 2019 with Roundup WEATHERMAX® (48.8% glyphosate) @ 32 oz./acre to facilitate thrips movement to emerging cotton seedlings. Other field management activities included the tank-mixed application of herbicide XTENDIMAX® (48.8% dicamba) @ 22 oz./Acre and Roundup WEATHERMAX® (48.8% glyphosate) @ 32 oz./Acre on 17 June 2019 for weed management, field cultivation on 24 June 2019 for soil aeration and weed management, and fertilizer application (100 lb. N/acre) via side-dressing on 23 July 2019. In 2020, cotton cultivar DP1820B3XF was planted on 18 May 2020 following pre-plant fertilizer application @ 80 lb N/acre. Weed management was achieved via Roundup WEATHERMAX® (48.8% glyphosate) @ 32 oz/acre and XTENDIMAX® (48.8% dicamba) @ 22 oz/acre tank-mix applications on 18 May 2020 and 3 June 2020 and field cultivation on 21 July 2020 for soil aeration and weed management. In 2021, Treflan @ 1qt/acre. was incorporated with field preparation. Wheat was planted on 7 April as cover crop to minimize pre-planting soil erosion and prevent cotton seedlings from sandblasting during May/June. Cotton cultivar DP 1845 B3XF was planted on 12 May 2021 following pre-plant fertilizer application of @ 60 lb N/acre on 22 April 2021. Due to heavy rain events and hailstorm, the first planting crop was damaged, and the same cultivar was replanted on 9 June 2021. Weed management in 2021 was achieved via Roundup WEATHERMAX® (48.8% glyphosate) @ 32 oz/acre and XTENDIMAX® (48.8% dicamba) @ 16 oz/acre tank-mix applications on 14 July and three field cultivation trips during the growing season for weed management. In 2022, cultivar Deltapine 1646 B2XF without seed treatment was planted on 16 May. Because the Texas High Plains went through an extended drought condition throughout winter and spring months, a pre-plant irrigation was applied on 7 May 2022, to field saturation across all irrigation treatment plots to ensure sufficient moisture for germination.

Insect infestation treatments. Two key insect-pest species (thrips and cotton fleahoppers) impacting cotton production risks were evaluated with five combinations of single versus sequential infestations under three water-deficit (zero, medium, and high) regimes, replicated four times (total 60 plots); only zero and high water-deficit regimes were evaluated in all (2018-2021) studies. Five possible insect infestation scenarios were evaluated where the infestations were simulated during the most vulnerable stage of cotton for each target insect (Table 1). Targeted insect management options were achieved via natural colonization and/or artificial augmentation of insect pests. Because THP cropping conditions rarely warrant more than a single insecticide application to suppress either of the two major insect pest groups (thrips at seedling stage and cotton fleahoppers at early squaring stage), this study was designed to infest the treatments at the most vulnerable stage of crop for the species infested.

Table 1. Five insect management scenarios evaluated under three irrigation water treatments, Lubbock, Texas, 2018-2021.

Treatment #	Insect Infestation Treatment Simulated via Artificial Infestation
1	All insects suppressed (No insect infestation) (sprayed control)
2	Thrips occurring at 1-2 true leaf stage
3	Cotton fleahoppers occurring during the first week of squaring
4	Thrips and cotton fleahoppers infested sequentially
5	No insect management (untreated control)

2018 study

Thrips. Thrips were released to seedling cotton on 19 June 2018 when the crop was at 1-2 true leaf stage. Thrips infested alfalfa terminals were excised from a healthy alfalfa patch and these terminals were laid at the base of young cotton seedlings. Thrips were expected to move onto the cotton seedlings as excised alfalfa sections began to dry. Approximately 6 thrips per seedling were released to two 5 row-ft sections (approximately 12 plants per section) per plot (approximately 140 thrips per thrips-augmented plot). Thrips were released on all 16 thrips-augmentation plots (treatments #2 and #4 x 2 water levels x 4 replications) on the same day. Thrips were released on four additional plots to estimate thrips movement onto the cotton seedling via absolute sampling of seedlings and washing of thrips 3 days post-release. Data showed that the seedlings received an average of 1.2 live thrips per seedling which is the threshold density for 1-2 leaf stage seedling cotton.

Uncharacteristic high daytime temperatures for the next 7 days following the thrips release (103-107 ^{o}F) contributed to low thrips feeding performance and perhaps high thrips mortality after the thrips moved to the seedlings. Consequently, no visible signs of thrips-feeding effect were observed in thrips-augmented plots.

Cotton fleahoppers. Woolly croton, with embedded overwintering fleahopper eggs, was harvested from rangeland sites near College Station, Texas, in early February 2018 and then placed into cold storage. Eighty 1-gallon sheet metal cans, each containing 4 ounces of dry croton twigs per can, were initiated to generate the required number of cotton fleahopper nymphs for the experiment. Conditions conducive to cotton fleahopper emergence were simulated in a laboratory environment in order to induce hatching of overwintered eggs embedded in the croton stems, and emerged cotton fleahoppers were subsequently reared on fresh green beans. The single release of nymphal cotton fleahoppers (2nd instars) was timed to simulate the acute heavy infestation of cotton fleahoppers (4-5 days of feeding) while cotton was highly vulnerable to the fleahopper injury (1st week of squaring). The release was accomplished on 10 July 2018 by transferring second-instar fleahoppers from the laboratory colony into 15 cm X 10 cm plastic containers, then cautiously depositing them onto the terminals of plants in each treatment plot at the rate of 5 nymphs per plant. Immediately after cotton fleahoppers were released onto the fleahopper-augmentation plots (treatments #3 and #4; total 16 plots), control plots were sprayed with Orthene® 97. All treatment plots, except treatment #1, were sprayed with Orthene® 97 on 17 July 2018 and kept insect-free for the remainder of the study to isolate the effect of various treatments.

The flowering profile was monitored from all 40 experimental plots for five sample dates (31 July, 6 August, 9 August, 15 August, and 28 August 2018) to determine the effect of insect infestation and water-deficit condition on fruiting delays and/or flowering patterns. Plant height was also recorded from all plots at the time of harvest. Hand harvesting was done on 16 November 2018 from flagged area and cotton was ginned on 17 December 2018. Lint samples were analyzed at Cotton Incorporated for fiber parameters.

2019 study

Thrips. Wheat cover was terminated on 20 May 2019 with glyphosate to facilitate thrips movement to emerging cotton seedlings to achieve natural infestation of thrips on experimental plots. Uncharacteristic heavy rain events during 23-26 May (4.51" rainfall) with associated small hail event compromised the study field for desired plant stand. Thrips were all dislodged from the wheat cover as well as those already transferred to cotton seedlings. Therefore, thrips were manually augmented on two 5-ft sections per treatment plots on 4 June 2019 via collecting immature thrips from nearby alfalfa terminals and releasing them onto the cotton seedlings, by placing thrips-infested alfalfa terminals at the base of each seedling @ approximately 5 thrips per cotton seedling. This rate of infestation is expected to result in about 1 thrips per seedling after 80% mortality of released thrips. Unexpected storms occurred on 5 and 6 May with additional 1" of rain dislodging all released thrips. We re-released thrips on 7 June 2019, but the ensuing hot and windy days following the second release did not allow thrips to colonize in the experimental plots. Consequently, we assumed no thrips effect on our experimental plots. Nevertheless, we conducted the visual ranking of the experimental plots on 11, 17, and 22 June 2019 to discern if any thrips-induced injury was inflicted on the seedlings. We found no thrips-inflicted injury nor observed any thrips colonization.

Cotton fleahoppers. Woolly croton, with embedded overwintering fleahopper eggs, was harvested from rangeland sites near College Station, Texas, 18 February 2019 and then placed into cold storage. Eighty 1-gallon sheet metal cans, each containing 4 ounces of dry croton twigs per can, were initiated on 10 May 2019 to generate the required number of cotton fleahopper nymphs for the study. Conditions conducive to cotton fleahopper emergence were simulated in a laboratory environment in order to induce hatching of overwintered eggs embedded in the croton stems, and emerged cotton fleahoppers were subsequently reared on fresh green beans. Cotton fleahopper emergence began on 19 June 2019. The single release of nymphal cotton fleahoppers (2^{nd} instars) was timed to simulate the acute heavy infestation of cotton fleahoppers (4-5 days of feeding) while cotton was highly vulnerable to fleahopper injury (1^{st} week of squaring). The release was accomplished on 4 July 2019 by transferring second instar fleahopper nymphs from the laboratory colony onto the terminals of plants in each treatment plot at the rate of 5 nymphs per plant. Control plots had no insect activity to warrant any insecticide intervention. Unfortunately, heavy rainfall occurred on 6 July 2019 (2.75") and dislodged the released cotton fleahoppers and the treatment deployment was totally ineffective. The field was too wet to re-augment the cotton fleahopper within the next 2-3 days, but another storm passed through west Texas on 11 July 2019 that brought a damaging hail onto our field, causing significant damage to the test plots. Consequently, the crop stand was very poor with significant hail damage to the growing terminals for the crop to perform normally. Nevertheless, we introduced a manual square-removal treatment to selected control plots to evaluate the simulated fleahopper-induced square removal and resulting crop growth profile across three irrigation treatments. However, the unusual rainfall patterns might have already compromised our irrigation treatments. Treatments #1 and #3 were sprayed with BRACKET® 97 (acephate 97%) @ 3 oz./acre on 7 and 17 June 2019 to ensure insect-free plots to isolate the effect of insect-release plots. Square removal treatment was deployed on 26 July 2019 by removing 100% squares from all plants in two 5-row ft sections per plot. Plant mapping was conducted 10 days after cotton fleahopper release to assess the fruit set on all experimental plots.

We also monitored flowering profile by counting number of white flowers in two 5-row ft sections per experimental plots twice a week (23, 26, and 30 July, 2, 5, 9, 12, 16, 19, 23, 26, and 30 August, and 3 and 11 September) during the cotton flowering period (total 14 sample dates). Pre-harvest plant mapping was done on 30 October 2019 and hand harvesting was done on 1 November 2019 from flagged area. Cotton was ginned on 14 November 2019 and the lint samples were sent to Cotton Incorporated for fiber analysis.

2020 study

Thrips. Thrips sampling was performed via whole-plant removal of 10 seedlings per plant in a mason jar for later processing of the samples in the laboratory to extract thrips from plant washing technique. Thrips samplings were done on 29 May, 1 June, 4 June, and 11 June 2020. Treatments #1 and #3 were sprayed with BRACKET® 97 (acephate 97%) @ 3 oz./acre on 29 May and 8 June to ensure insect-free plots to isolate the effect of thrips. Because natural thrips colonization was insignificant, thrips were manually augmented on two 6-ft sections per treatment plots on 20 June 2020 via collecting immature thrips from nearby alfalfa terminals and releasing them onto the cotton seedlings, by placing thrips-infested alfalfa terminals at the base of each seedling @ approximately 10 thrips per cotton seedling. This rate of infestation was expected to result in about 2 thrips per seedling after 80% mortality of released thrips. Thrips-released plots were visually inspected three times to assess for thrips colonization. We found no apparent thrips-inflicted injury on these test plots.

Cotton fleahoppers. Woolly croton, with embedded overwintering fleahopper eggs, was harvested from rangeland sites near College Station, Texas, 2 February 2020 and then placed into cold storage. Forty 1-gallon sheet metal cans, each containing 4 ounces of dry croton twigs per can, were initiated on 15 June 2020 to generate the required number of cotton fleahopper nymphs for the study. Conditions conducive to cotton fleahopper emergence were simulated in a laboratory environment in order to induce hatching of overwintered eggs embedded in the croton stems, and emerged cotton fleahoppers were subsequently reared on fresh green beans. Cotton fleahopper emergence began on 24 June 2020. The single release of nymphal cotton fleahoppers (2^{nd} instars) was timed to simulate the acute heavy infestation of cotton fleahoppers (4-5 days of feeding) while cotton was highly vulnerable to fleahopper injury (1^{st} week of squaring). The release was accomplished on 2 July by transferring second-instar fleahoppers from the laboratory colony onto the terminals of plants in each treatment plot at the rate of 5 nymphs per plant. Control plots had no insect activity to warrant any insecticide intervention. Unfortunately, a heavy windstorm occurred in the evening of 2 July and likely compromised the fleahopper colonization in the plant.

In addition, we introduced a manual square-removal treatment to selected plots to evaluate the crop growth profile across three irrigation treatments. Plant mapping was performed on July 28 to assess the cotton fleahopper-induced injury.

Temporal flower patterns were monitored for 14 sampling dates, starting on 20 July and conducted every 2-3-day intervals. Harvest aids Boll'd® 6SL (Ethephon [(2-chloroethyl) phosphonic acid] @ 1 qt//A (boll opener) and Folex® 6 EC (S, S, S-Tributyl phosphorotrithioate) 1 pint/A (defoliant) were applied on 12 October to accelerate opening of matured unopened bolls and begin the defoliation process. Test plots were hand-harvested on 23 October. Hand-harvested yield samples were ginned, and fiber analysis was performed at Cotton Incorporated for HVI parameters.

2021 study

Thrips. Visual observation of test plots indicated that we had no thrips colonization in our study site due to late planting (replanted crop) and frequent inclement weather events. Because natural thrips colonization was non-existent, thrips were manually augmented on two 6-ft sections per treatment plots on 18 June 2021 via collecting immature thrips from nearby alfalfa terminals and releasing them onto the cotton seedlings, by placing thrips-infested alfalfa terminals at the base of each seedling @ approximately 10 thrips per cotton seedling. This rate of infestation was expected to result in about 2 thrips per seedling after 80% mortality of released thrips. We again released thrips on all thrips-release plots (T2, T4 plots) as previously released thrips failed to cause noticeable injury to the test plot seedlings. We still found no apparent thrips-inflicted injury on these test plots 7 days after the second release.

Cotton fleahoppers. Woolly croton, with embedded overwintering fleahopper eggs, was harvested from rangeland sites near College Station, Texas, 8 February 2021 and then placed into cold storage. Sixty 1-gallon sheet metal cans, each containing 4 ounces of dry croton twigs per can, were initiated on 20 June 2021 to generate the required number of cotton fleahopper nymphs for the study. Conditions conducive to cotton fleahopper emergence were simulated in a laboratory environment to induce hatching of overwintered eggs embedded in the croton stems, and emerged cotton fleahoppers were subsequently reared on fresh green beans. Cotton fleahopper emergence began on 27 June 2021. The single release of nymphal cotton fleahoppers (2nd instars) was timed to simulate the acute heavy infestation of cotton fleahoppers (4-5 days of feeding) while cotton was highly vulnerable to fleahopper injury (1st week of squaring). The release was accomplished on 16 and 19 July by transferring second-instar fleahopper nymphs from the laboratory colony onto the terminals of plants in each treatment plot at the rate of 5 nymphs per plant. Control plots had no insect activity to warrant any insecticide intervention.

Temporal flower pattern was monitored for 18 sampling dates, from August 7 to September 10. Harvest aids Boll'd® 6SL (Ethephon [(2-chloroethyl) phosphonic acid] @ 1 qt//acre (boll opener) and Folex® 6 EC (S, S, S-Tributyl phosphorotrithioate) 1 pint/acre (defoliant) were applied on 21 October to accelerate opening of matured unopened bolls and begin the defoliation process. Test plots were hand-harvested on 11-12 November and ginned on 23 November 2021. Fiber analysis was performed at Cotton Incorporated for HVI parameters.

2022 study

Thrips. Cotton germination began five days after planting and the expected plant stand of >40,000 plants per acre was achieved (actual plant stand was 44,000 plants per acre). A heavy rain/hailstorm on 24 May, followed by heavy rain on 2 June damaged some seedlings and compromised the plant stand, but the crop quickly recovered. Thrips sampling was conducted on 2, 6, and 20 June. Sufficient thrips density was achieved through repeated augmentation on June 2, 6, and 15 to ensure desired thrips pressure on Treatments #2 and #4. Treatments #1 and #3 were sprayed with acephate @ 5 g/l following thrips sampling on each sample date to ensure no thrips or any other insects on those treatment plots.

Cotton fleahoppers. Cotton fleahopper treatment was deployed on 15 July (Treatments #3 and #4) @ 5 cotton fleahopper nymphs per plant in all plants within the designated section (10-12 plants) when the crop was about 2-3 square stage. Cotton fleahopper damage assessment was done on 26 July. Overall, cotton fleahopper augmentation achieved 15-20% square shed.

Cotton fruiting and flowering profiles were monitored twice a week from 18 July to 26 August (total 18 sample dates). Harvest aids Boll'd® 6SL (Ethephon [(2-chloroethyl) phosphonic acid] @ 1 qt//acre (boll opener) and ET®X (Pyraflufen ethyl) 1.5 fl oz/acre (desiccant) were applied on September 30 to accelerate opening of matured unopened bolls and begin the defoliation process. Gramoxone® SL 3.0 @ 24oz/A was sprayed on 20 October to ensure complete crop defoliation. Test plots were hand-harvested on 6 November and ginned on 22 November. Samples were analyzed for HVI fiber parameters at Cotton Incorporated.

RESULTS

2018 study

Extremely high temperatures during the seedling stage complicated the study in 2018, especially the released thrips failed to exert the desired significant infestation on the young cotton seedlings. As a result, thrips damage to seedlings was not apparent on visual observation. Cotton fleahoppers caused about 20% square loss overall across all experimental plots. Because cotton fleahoppers were released when plants had 2-3 total squares (all were fleahopper susceptible squares), the effect was not apparent immediately and plants outgrew the effect of early season fleahopper-induced square loss. Nevertheless, insect injury manifested some noticeable effect on flowering patterns, plant height, and lint yield.

Untreated control plots showed slightly higher flower densities in irrigated versus dryland cotton effect all throughout the month-long monitoring period, with significantly higher flower densities in late August. Contrasting to this phenomenon, the flowering patterns were near identical between irrigated and dryland plots when cotton fleahoppers were infested singly or sequentially with thrips infestation (Fig. 1). When thrips were infested alone, flowering patterns between dryland and irrigated main-plot treatments were generally similar to what was observed in untreated or sprayed control plots. Overall, average flower abundance was similar across five insect augmentation treatments within each irrigation treatment (Fig. 2). While cotton flowering occurs daily during the active flowering period and the average of flower monitoring only five times may not reflect the production potential of cotton, these patterns clearly indicate that insect infestation, particularly cotton fleahoppers, rendered overall flowering patterns between irrigated and dryland similarly (Figs. 1-2). The average flower abundance was significantly lower in dryland compared to that in irrigated cotton only at untreated control plots while all other treatments were not significantly different between the two irrigation regimes (Fig. 2). These data suggest that the insect infestation during pre-flower stage exerts some significant physiological response to cotton during the flowering stage. Multi-year data will hopefully add more insights into this phenomenon.

Pre-harvest plant measurement showed that insect-augmented plots in irrigated cotton had significantly taller plants compared to that in untreated control plots, but the effect was considerably diminished under dryland conditions (Fig. 3). There was significant “noise” on plant height data under dryland condition in which fleahopper-infested plants resulted in the tallest plants while thrips followed by fleahoppers resulted in the shortest plant heights. We find no reasonable explanation for why cotton fleahopper-infested plots resulted in both tallest and shortest plants.

Lint yield was significantly higher in irrigated cotton compared to that in dryland cotton across all five treatment combinations (Fig. 4). This suggests that the dryland plots were sufficiently water-stressed during the growing season, despite several rainfall events during the crop maturation phase in late September - early October. The highest lint yield under irrigation treatment was observed in the untreated control treatment (1,607 lb/acre), while the lowest (1,253 lb/acre) was recorded in the thrips+fleahopper sequential infestation treatment (Fig. 4). Lint yield in other treatments (spray control, thrips only, and fleahoppers only) did significantly differ from the untreated control or thrips+fleahopper sequential treatments (Fig. 4). Lint yield did not significantly vary across five insect augmentation treatments. As expected, the yield threshold in dryland cotton was much lower than that for irrigated cotton and thus the lower yield across all treatments can be partially attributed to lack of insect treatment effect on lint yield.

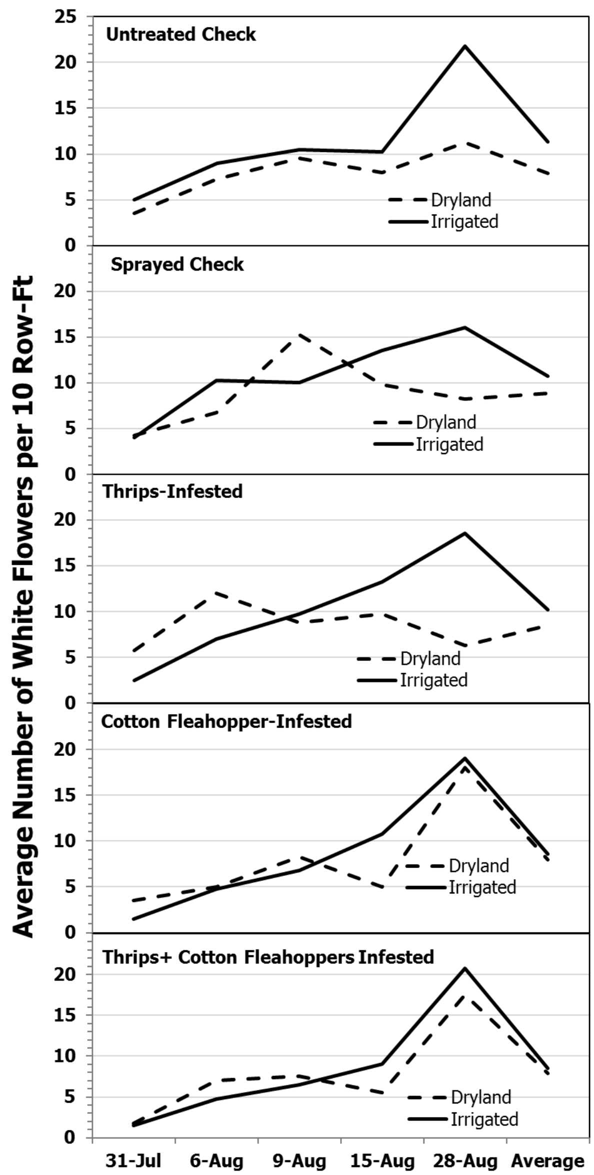

Figure 1. Temporal abundance of white flowers (number of white flowers per 10 row-ft per sample date) recorded from thrips and fleahopper infested plots under dryland versus irrigated production conditions, Lubbock, Texas, 2018.

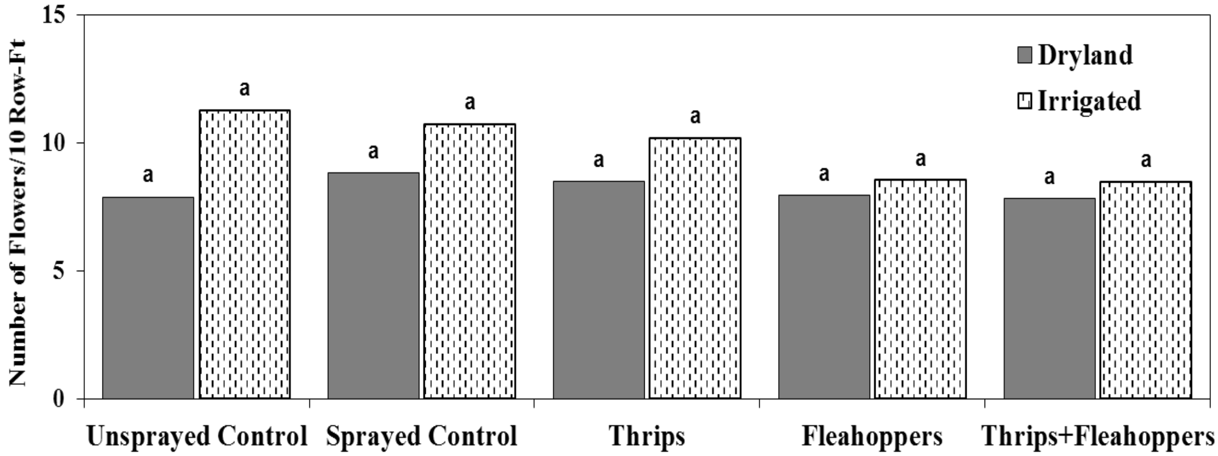

Figure 2. Average abundance of white flowers (number of white flowers per 10 row-ft; n=5 sample dates) recorded from thrips and fleahopper infested plots under dryland versus irrigated production conditions, Lubbock, Texas, 2018. Average values were compared across five treatments within each irrigation treatment; same lowercase letters indicate treatment means were not significantly different from each other.

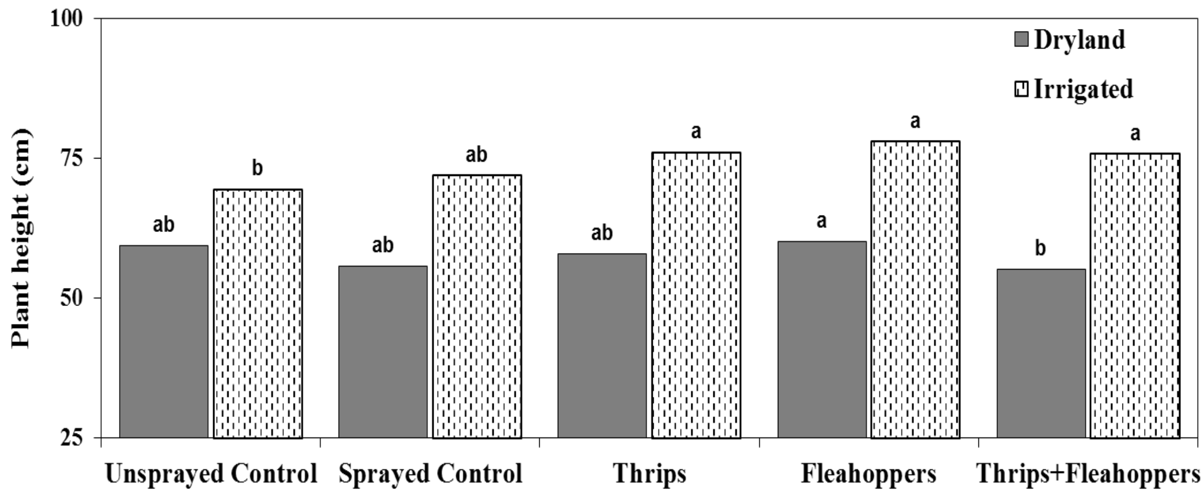

Figure 3. Plant height impacted by thrips and fleahopper infestations under dryland versus irrigated production conditions, Lubbock, Texas, 2018. Average values were compared across five treatments within each irrigation treatment; same lowercase letters indicate treatment means were not significantly different from each other.

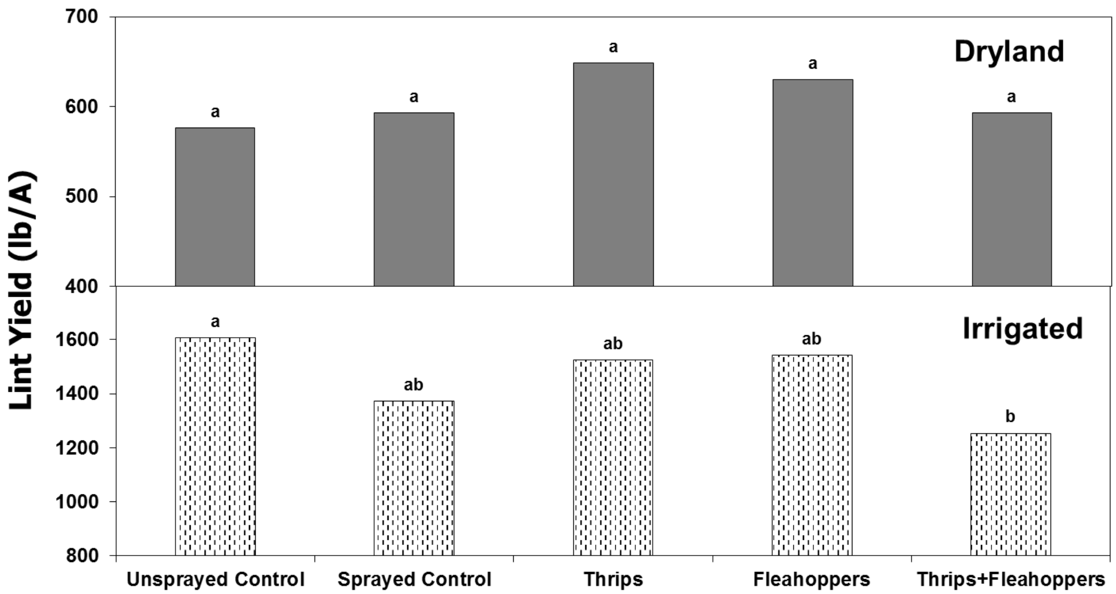

Figure 4. Cotton lint yield losses due to thrips and fleahopper infestation under dryland versus irrigated production conditions, Lubbock, Texas, 2018. Average values were compared across five treatments within each irrigation treatment; same lowercase letters indicate treatment means were not significantly different from each other.

2019 study

Atypical heavy rain events during the pre-squaring stage of cotton with associated small hail event compromised the early season portion of the study. Thrips were all dislodged from the wheat cover as well as those already transferred to cotton seedlings. Manually augmented thrips also suffered from recurring storm events and thrips could not colonize in the study plots. As stated in the Methods section above, we effectively abandoned the possibility of exerting thrips-induced injury effect on seedling cotton. Visual ranking of the experimental plots indicated no evidence of thrips-inflicted injury nor we observed any thrips colonization.

Cotton fleahopper augmentation resulted in 50-55% square abortion compared to 15-20% abortion in control plots; square abortion was similar between dryland and full irrigation plots (Fig. 5). While significant weather events occurred soon after cotton fleahoppers were released, the fleahopper augmentation exerted significant square loss as desired.

Untreated control plots and sprayed control plots showed higher flower densities in both irrigated and dryland cottons compared with that in insect augmented plots; this difference was more pronounced in irrigated plots than in dryland plots (Fig. 6). Full irrigation and supplemental irrigation plots displayed similar flowering patterns throughout the season. The plots with manual square removal to mimic cotton fleahopper-induced square loss displayed synchronized fruiting patterns across irrigation treatments. Overall, average flower abundance was similar amongst unsprayed control, sprayed control, and manual square removal plots, whereas the flower abundance on these three treatments were generally higher than that in all other insect augmented treatments; this trend was similar across all three irrigation water levels (Fig. 6). These patterns clearly indicate that insect infestation, particularly cotton fleahoppers, rendered overall flowering patterns between irrigated and dryland similarly. The average flower abundance was significantly lower in dryland compared to that in irrigated cotton at control plots while other treatments were not consistent across water treatments. These data suggest that the insect infestation during pre-flower stage exerts some significant physiological response to cotton during the flowering stage.

Pre-harvest plant measurement showed that insect augmentation treatments did not result in increased plant heights as observed in 2018. It was expected because the early rain/hailstorm events had severely thinned out the plant stand which allowed plants to grow laterally rather than adding the mainstem nodes following insect infestations. Nevertheless, plots in irrigated cotton had significantly taller plants compared to that in dryland plots as expected.

Lint yield was significantly higher in irrigated cotton (both full and supplemental) compared to that in dryland cotton across all five treatment combinations (Fig. 7). This suggests that the dryland plots were sufficiently water-stressed during the growing season, despite several rainfall events during the early to mid-season; there was a noticeable drought condition during the latter part of the growing season. The highest lint yield under full irrigation treatment was observed in the untreated control treatment (1,268 lb/acre), while the lowest (883 lb/acre) was recorded in the fleahopper infestation treatment (Fig. 7). These were the only treatments that resulted in significant yield difference. Lint yield did not significantly vary across insect augmentation treatments. Under dryland condition, lint yield did not significantly vary across treatments. As expected, the yield threshold in dryland cotton was much lower than that for irrigated cotton and thus the lower yield across all treatments can be partially attributed for lack of insect augmentation treatment effect on lint yield. Also, lint yield was generally similar between supplemental and full irrigation main treatments, owing to frequent rainfall events during early and mid-season that provided sufficient moisture profile in root zones in supplemental irrigation plots to carry the crop's water demand through the season. Thrips only treatment resulted in significantly lower yield under supplemental irrigation compared to that in other treatments (Fig. 8). However, we are unable to speculate the reason for this yield reduction since there were no visible thrips injury during the early growth period of the crop.

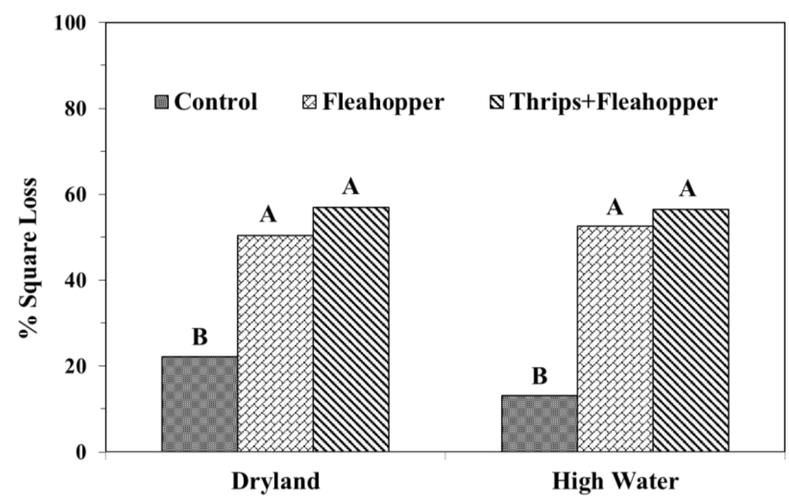

Figure 5. Percentage square loss (number of missing squares with respect to total squares set per plant) recorded following cotton fleahopper infestations in dryland versus full irrigation production conditions, Lubbock, Texas, 2019.

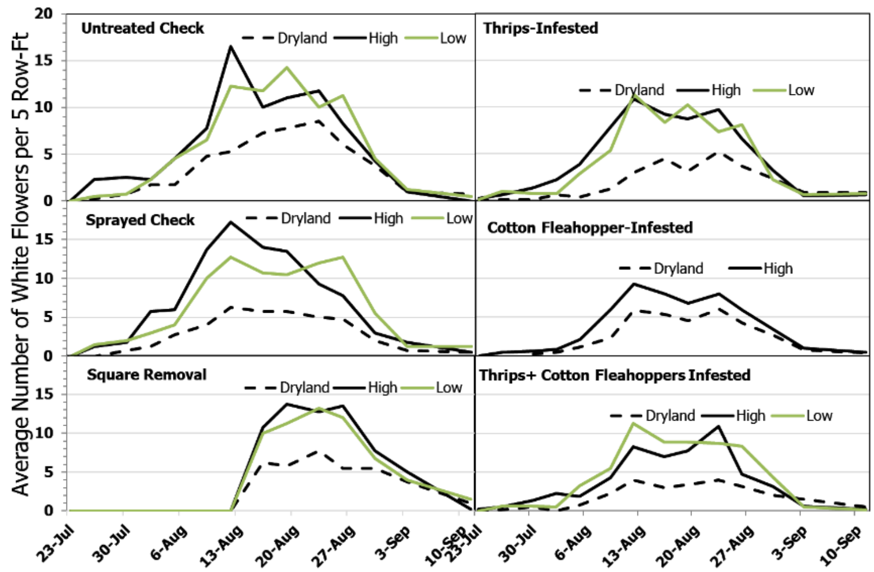

Figure 6. Temporal abundance of white flowers (number of white flowers per 5 row-ft per sample date) recorded from insect-release treatment plots under dryland, supplemental (low), and full (high) irrigation production conditions, Lubbock, Texas, 2019.

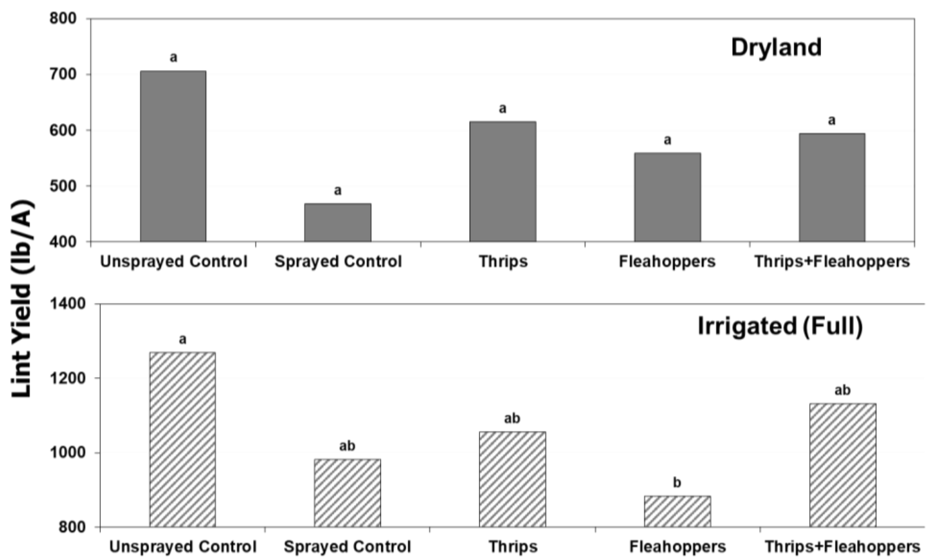

Figure 7. Cotton lint yield losses due to thrips and fleahopper infestations under dryland versus full irrigation production conditions, Lubbock, Texas, 2019. Average values were compared across five treatments within each irrigation treatment; same lowercase letters indicate treatment means were not significantly different from each other.

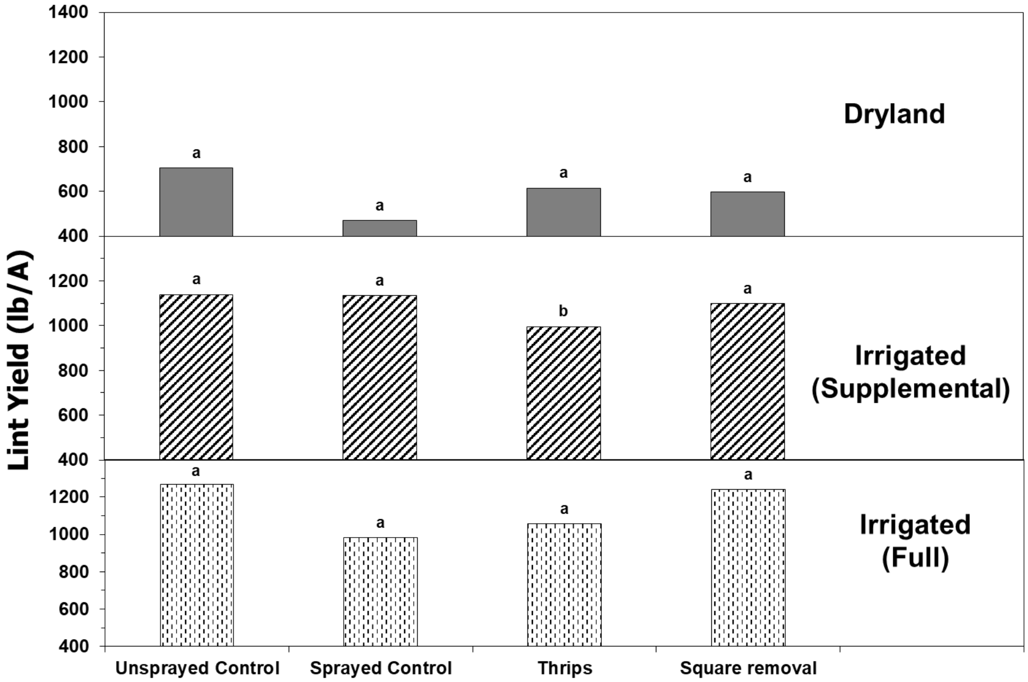

Figure 8. Cotton lint yield losses due to thrips and manual square removal (100% squares pruned at first flower stage to mimic severe cotton fleahopper damage) under three irrigation water regimes, Lubbock, Texas, 2019. Average values were compared across four treatments within each irrigation treatment; same lowercase letters indicate treatment means were not significantly different from each other.

2020 study

The natural thrips colonization was also insignificant in 2020 as in previous two years. Because natural colonization was inconsequential, thrips were manually augmented per treatment plots. Nevertheless, environmental conditions (e.g., incessant dry wind) did not allow thrips to colonize and exert significant injury to the plants in test plots. Therefore, the manual augmentation did very little to exert injury pressure on cotton plants. Similarly, a heavy windstorm occurred in the evening of 2 July and likely compromised the fleahopper colonization in the plant. As a result, cotton fleahoppers exerted mild injury pressure on plants, which caused about 10-14% square abscission and only increased plant height and more nodes on mainstem compared to that in control plots. The plant height effect, too, was only evident under dryland conditions as the irrigated plots all compensated for this low level of early fruit abscission.

Because fleahopper-induced square loss was not significant, flowering profile was generally similar across all treatments. Nevertheless, considerable variations existed amongst treatments on temporal flowering patterns. Uninfested and sprayed control plots showed greater flower densities earlier than cotton fleahopper and thrips+cotton fleahopper infested plots (Fig. 9). Clearly, insect infested plots delayed peak flowering and even had slightly fewer total flowers than the uninfested plots. Limited irrigation plots showed greater flower densities in most treatments, but insect-infested treatments had conspicuously lower flower densities for limited irrigation plots during the early reproductive phase of the crop compared to that for uninfested plots (Fig. 9, left versus right panel). High irrigation plots had the lowest flower densities compared to low irrigation or dryland plots under thrips+fleahopper infested treatment. The plots with manual square removal to mimic cotton fleahopper-induced square loss displayed similar fruiting patterns across irrigation treatments. Even at low rate of insect-induced square removal during pre-flower stage, significant physiological responses can be exerted to cotton during the flowering stage.

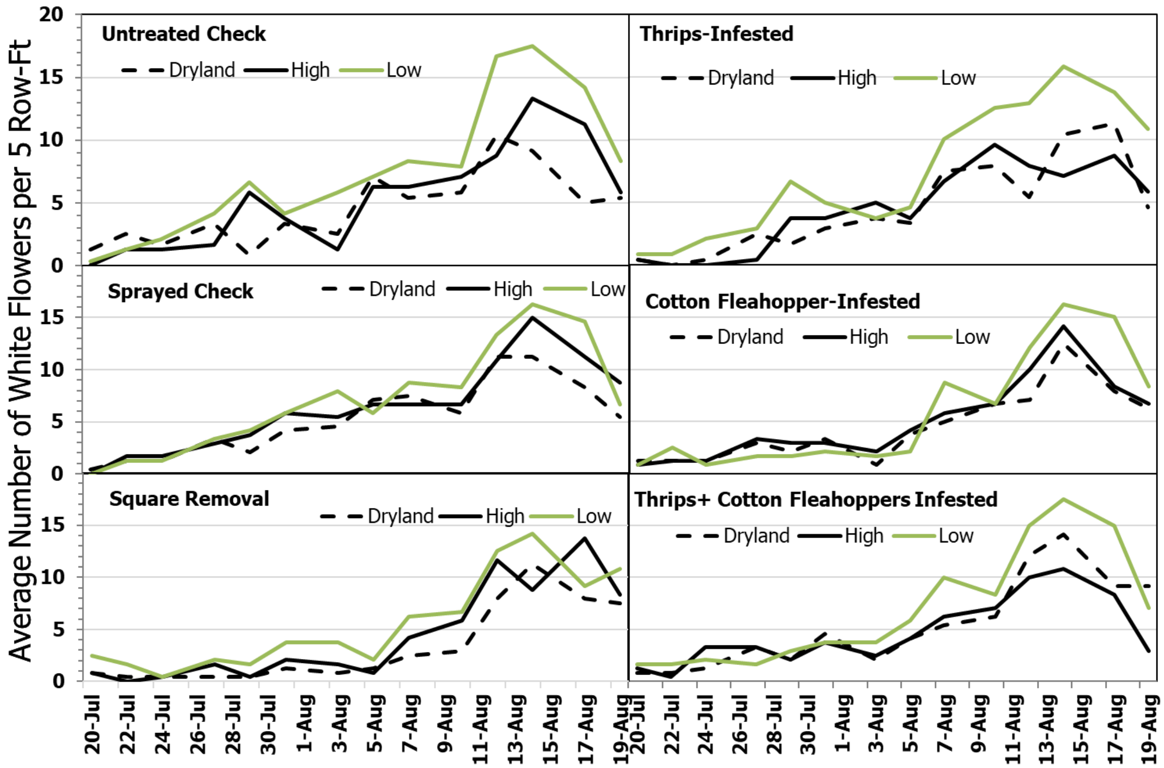

Figure 9. Temporal abundance of white flowers (number of white flowers per 5 row-ft per sample date) recorded from insect-release treatment plots under dryland, supplemental (low), and full (high) irrigation production conditions, Lubbock, Texas, 2020.

As expected, lint yield varied with irrigation treatments. Lint yield was significantly higher in irrigated cotton (High irrigation: 1623 lb/acre; Low irrigation: 1350 lb/acre) compared to that in dryland (1046 lb/acre) cotton across all five treatment combinations (Fig. 10). This suggests that the dryland plots were sufficiently water-stressed during the growing season. The highest lint yield under full irrigation treatment was observed in the uninfested control treatment (1877 lb/acre), while the lowest (890 lb/acre) were recorded in the thrips and thrips+fleahopper infestation treatments (Fig. 10). Overall, thrips+fleahopper treatment resulted in the lowest yield across all three irrigation treatments, although statistically significant only under dryland conditions. Another conspicuous trend was that fleahopper alone treatment that exerted only 10-14% square loss did not significantly render the yield loss. It is known from past studies that a low level of fleahopper injury compensates or even overcompensates the insect-induced fruit loss. However, when fleahopper caused even a low-level injury sequentially with a low-level thrips injury, yields were reduced considerably across all irrigation treatments. The lack of statistical significance across sub-treatments under irrigated treatments can be attributed to a large variation in data. Although thrips infestation and thrips-induced injuries were insignificant, lint yields were numerically (irrigated plots) or significantly (dryland) lower across all irrigation treatments.

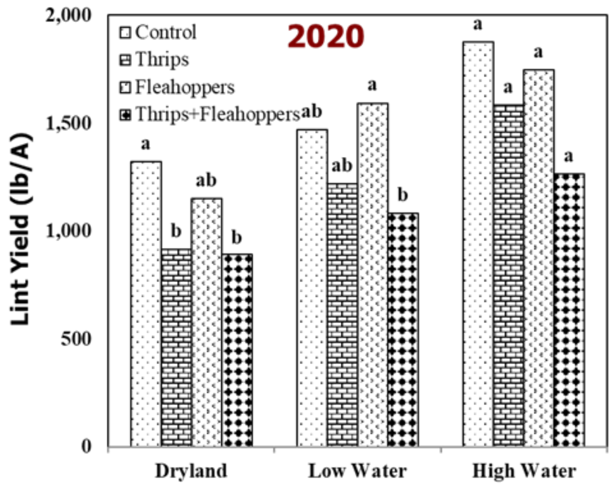

Figure 10. Cotton lint yield losses due to thrips and cotton fleahopper infestations under three irrigation water treatments, Lubbock, Texas, 2020. Average values were compared across four treatments within each irrigation treatment; same lowercase letters indicate treatment means were not significantly different from each other.

Overall, irrigation treatments did not significantly alter the HVI parameters. However, there was a considerable irrigation x insect infestation interaction in influencing the fiber parameters (Fig. 11). In general, low levels of thrips and fleahopper injuries appeared to increase micronaire values, except for low irrigation. In fact, uninfested control plots had the micronaire in the discount range under both dryland and high irrigation treatments, whereas all insect-infested plots had micronaire in premium range (high irrigation) or premium/base range (dryland). It was interesting to note that the micronaire values were at base range for low irrigation treatment for all insect-augmentation treatments. Other fiber parameters, including fiber length, uniformity, strength, and elongation were generally similar across all insect-infestation treatments within each irrigation level (Table 2). Irrigation water treatment had only a marginal effect on other HVI parameters.

Table 2. HVI fiber quality parameters influenced by thrips and cotton fleahopper infestation singly as well as sequential infestation of both insects under three irrigation water treatments, Lubbock, Texas, 2020.

Fiber Parameters	Irrigation Treatment	Uninfested Control	Thrips	Fleahopper	Thrips+ Fleahopper
Micronaire	Dryland	3.40	4.39	4.51	4.24
Fiber length	Dryland	1.13	1.14	1.16	1.14
Uniformity	Dryland	80.43	80.88	81.60	80.90
Strength	Dryland	31.80	31.35	32.35	31.13
Elongation	Dryland	7.68	7.68	7.83	7.70
Micronaire	Low	3.83	4.42	4.30	4.30
Fiber length	Low	1.16	1.15	1.16	1.15
Uniformity	Low	81.66	82.05	81.63	81.90
Strength	Low	31.60	31.63	32.00	31.75
Elongation	Low	7.99	7.90	7.93	7.93
Micronaire	High	3.39	3.96	4.24	4.16
Fiber length	High	1.17	1.20	1.21	1.19
Uniformity	High	80.94	81.35	82.23	82.28
Strength	High	31.71	31.55	31.78	32.03
Elongation	High	8.11	8.15	8.30	8.15

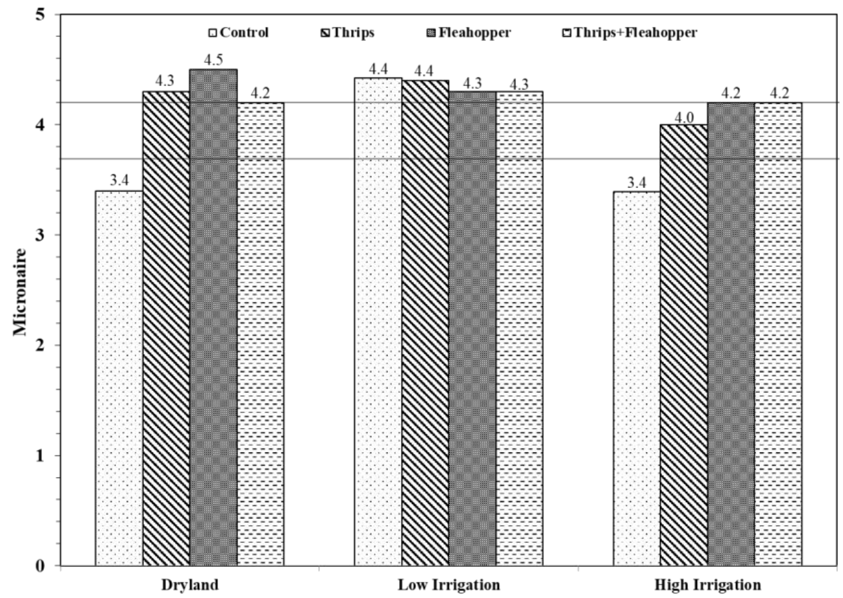

Figure 11. Cotton fiber micronaire (units) values influenced by thrips and cotton fleahopper infestations under three irrigation water treatments, Lubbock, Texas, 2020. Average values between 3.7-4.2 indicate premium cotton fiber.

2021 study

The natural thrips colonization was insignificant in 2021 as in previous two years. Visual observation of test plots indicated that we had no thrips colonization in our study site due to late planting (replanted crop) and frequent inclement weather events. Manually augmented thrips also failed to colonize and exert significant injury to the plants in test plots. Cotton fleahoppers exerted significant injury pressure on plants, which caused about 32% square abscission and increased plant height and more nodes on mainstem compared to that in control plots.

Because cotton fleahopper-induced square loss was significant, variations existed amongst treatments on temporal flowering patterns. Uninfested control plots showed greater flower densities earlier than cotton fleahopper and thrips+cotton fleahopper infested plots (Fig. 12). Clearly, cotton fleahopper infested plots delayed peak flowering than the uninfested plots. Flowering dynamics were influenced by irrigation water and insect infestation treatment interactions.

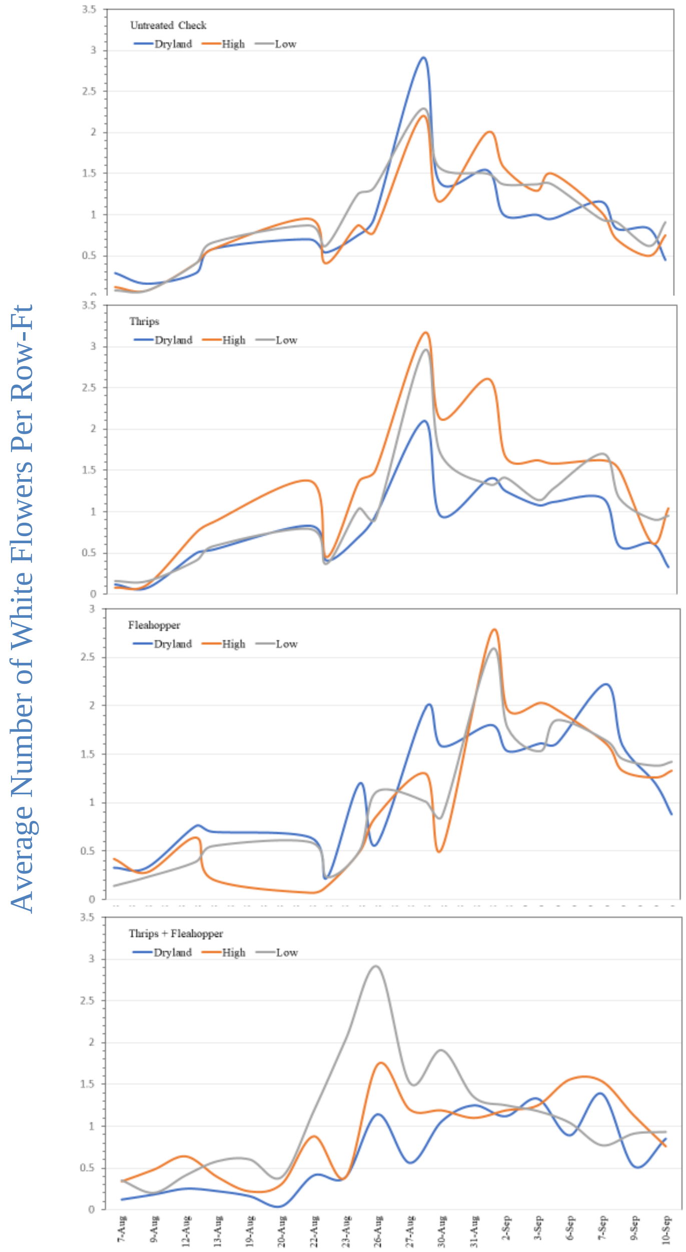

Figure 12. Temporal abundance of white flowers (number of white flowers per row-ft per sample date) recorded from insect-release treatment plots under dryland, supplemental (low), and full (high) irrigation production conditions, Lubbock, Texas, 2021.

The 2021 study suffered with frequent early-season rain events. Replanting of cotton delayed plant growth, fruiting and crop maturity, resulting in overall low lint yield across all main-plot treatments. Lint yield was similar across irrigation treatments as well as insect management treatments, except for the lowest yield in thrips+cotton fleahopper treatment in dryland condition (Fig. 13). Also, thrips and thrips+fleahopper treatments significantly reduced lint yield compared to only fleahopper treatments in dryland, however, lint yield was similar across all insect treatments in low water and high-water treatments, indicating the impact of drought conditions on modulating the effect of insect pests as well as the plant's compensatory ability. Maturity delay caused an overall decrease in lint quality parameter values across all treatments in 2021. Micronaire values were all in the base range (Table 3).

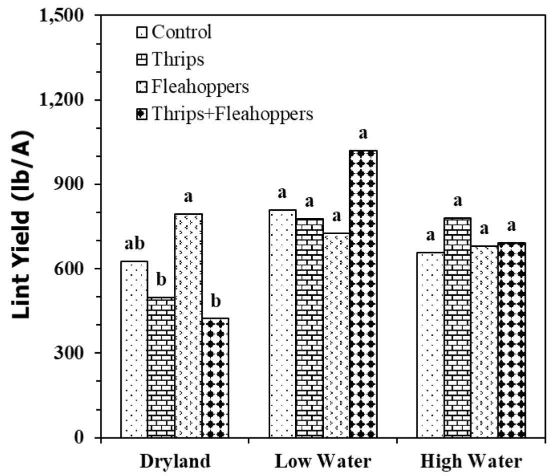

Figure 13. Cotton lint yield losses due to thrips and cotton fleahopper infestations under three irrigation water treatments, Lubbock, Texas, 2021. Average values were compared across four treatments within each irrigation treatment; same lowercase letters indicate treatment means were not significantly different from each other.

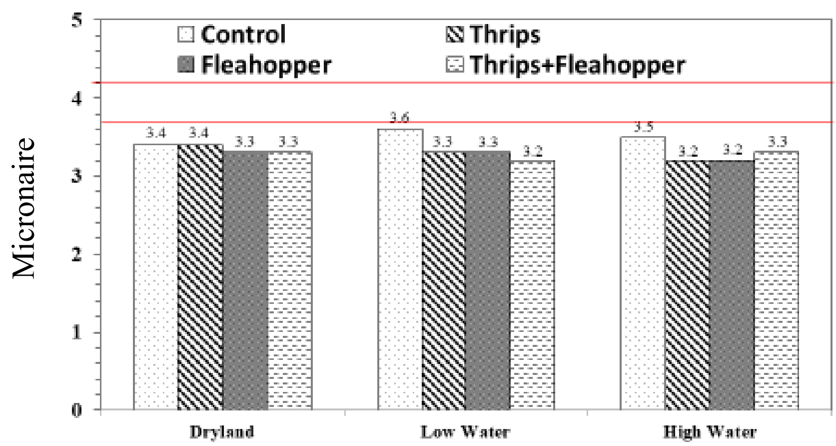

Figure 14. Cotton fiber micronaire (units) values influenced by thrips and fleahopper infestations three irrigation water treatments, Lubbock, Texas, 2021.

Table 3. HVI fiber quality parameters influenced by thrips and cotton fleahopper infestation singly as well as sequential infestation of both insects under three irrigation water treatments, Lubbock, Texas, 2021.

Fiber Parameters	**Irrigation Treatment**	**Uninfested Control**	**Thrips**	**Fleahopper**	**Thrips+ Fleahopper**
Micronaire	Dryland	3.4	3.4	3.3	3.3
Fiber length	Dryland	1.1	1.1	1.1	1.1
Uniformity	Dryland	80.2	80.6	80.7	80.7
Strength	Dryland	31.6	32.9	32.7	33.1
Elongation	Dryland	7.2	7.4	7.3	7.3
Micronaire	Low	3.6	3.3	3.3	3.2
Fiber length	Low	1.1	1.1	1.1	1.1
Uniformity	Low	80.4	80.9	80.1	80.4
Strength	Low	31.4	32.5	32.8	31.9
Elongation	Low	7.5	7.4	7.6	7.4
Micronaire	High	3.5	3.5	3.2	3.3
Fiber length	High	1.1	1.1	1.1	1.2
Uniformity	High	81.2	80.3	80.4	81.1
Strength	High	32.8	32.1	31.7	32.6
Elongation	High	7.8	7.6	7.7	7.7

2022 study

The natural thrips colonization was insignificant in 2022 as in previous four years. Manually augmented thrips exerted noticeable injury to the plants in test plots. Cotton fleahoppers exerted significant injury pressure on plants, which caused 19, 17, and 15% square abscission in dryland, supplemental irrigation and full irrigation plots, respectively (top panel; Fig. 15). Cotton fleahopper induced square abortion in thrips-fleahopper sequential augmentation plots was similar to what was observed in plots that were infested with fleahopper alone (bottom panel; Fig. 15).

While cotton fleahopper-induced square losses were similar across irrigation and insect treatments, variations existed amongst treatments on temporal flowering patterns. Uninfested control plots showed greater flower densities than cotton fleahopper and thrips+cotton fleahopper infested plots (Fig. 16). Sequential infestation of thrips and cotton fleahopper dampened the flowering dynamics compared to cotton fleahopper infestation alone. Clearly, cotton fleahopper infested plots delayed peak flowering than the uninfested plots. Flowering dynamics were influenced by irrigation water and insect infestation treatment interactions.

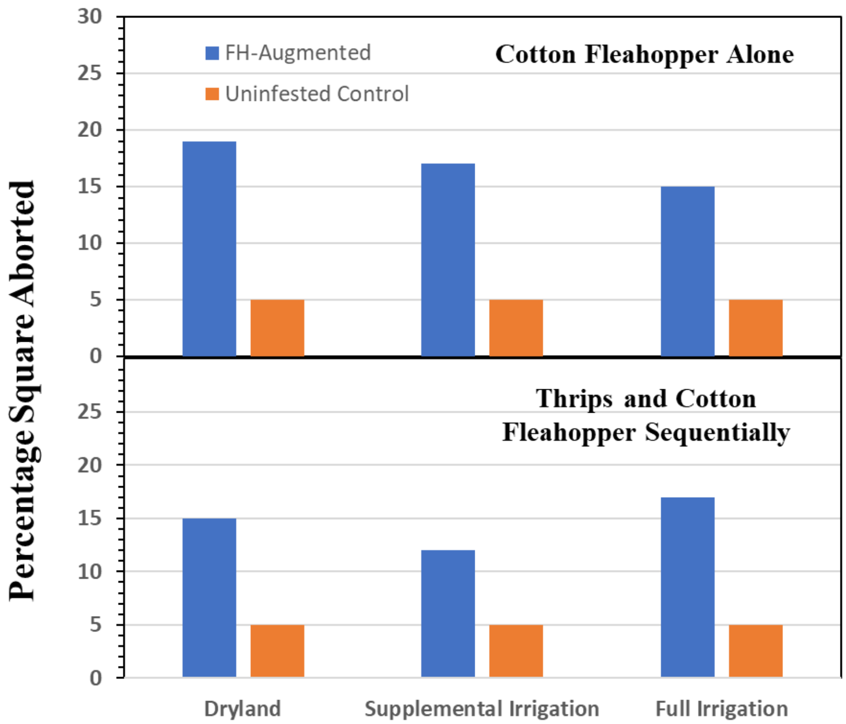

Figure 15. Average percentage square abscission in cotton fleahopper alone versus thrips-cotton fleahopper sequential augmentation plots under dryland, supplemental (low), and full (high) irrigation production conditions, Lubbock, Texas, 2022.

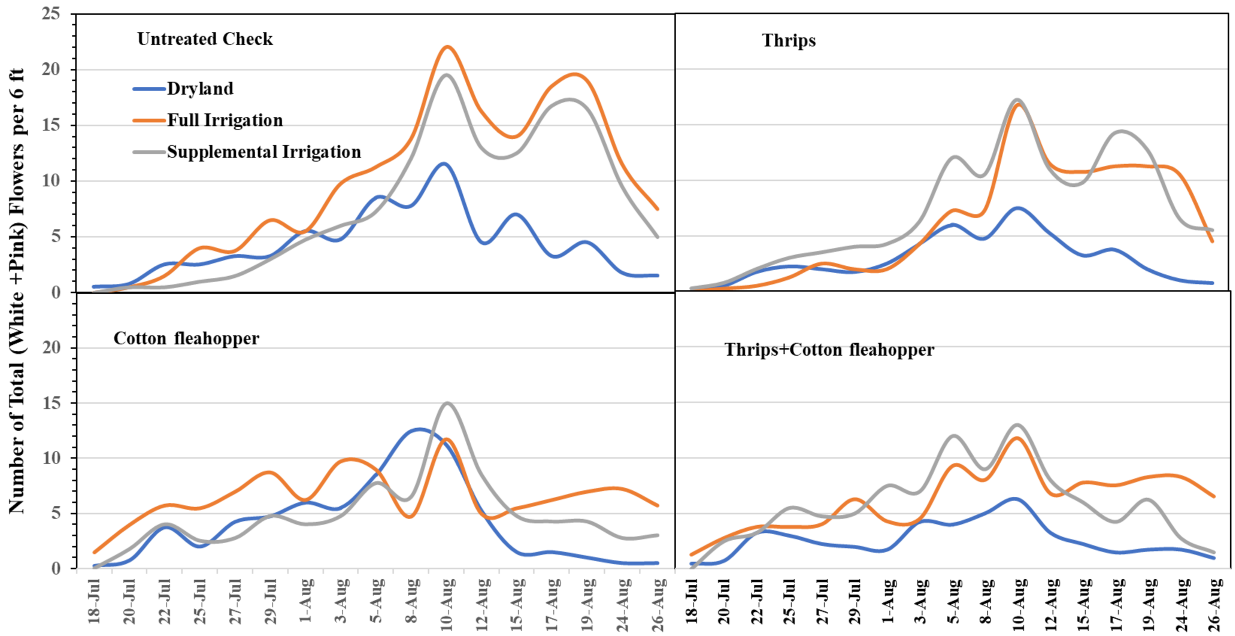

Figure 16. Temporal abundance of total (white and pink) flowers (number of flowers per 6 row-ft per sample date) recorded from insect-release treatment plots under dryland, supplemental (low), and full (high) irrigation production conditions, Lubbock, Texas, 2022.

Averaged over four years, there was a clear trend that sequential infestations of thrips and fleahoppers reduced the lint yield across all irrigation treatments. Thrips reduced yield significantly in dryland and full irrigation, whereas cotton fleahopper was not a significant yield reducer by itself. However, sequential infestations of thrips and cotton fleahopper increased yield loss, but the effect increased with increasing water level. Sequential infestation of thrips and cotton fleahoppers lost ~20% yield in dryland and full irrigation (Fig. 17). Unusually dry weather of 2022 caused higher micronaire values in lint across most treatments (Table 4). Short fiber content increased in thrips augmented treatments compared to uninfested control plots.

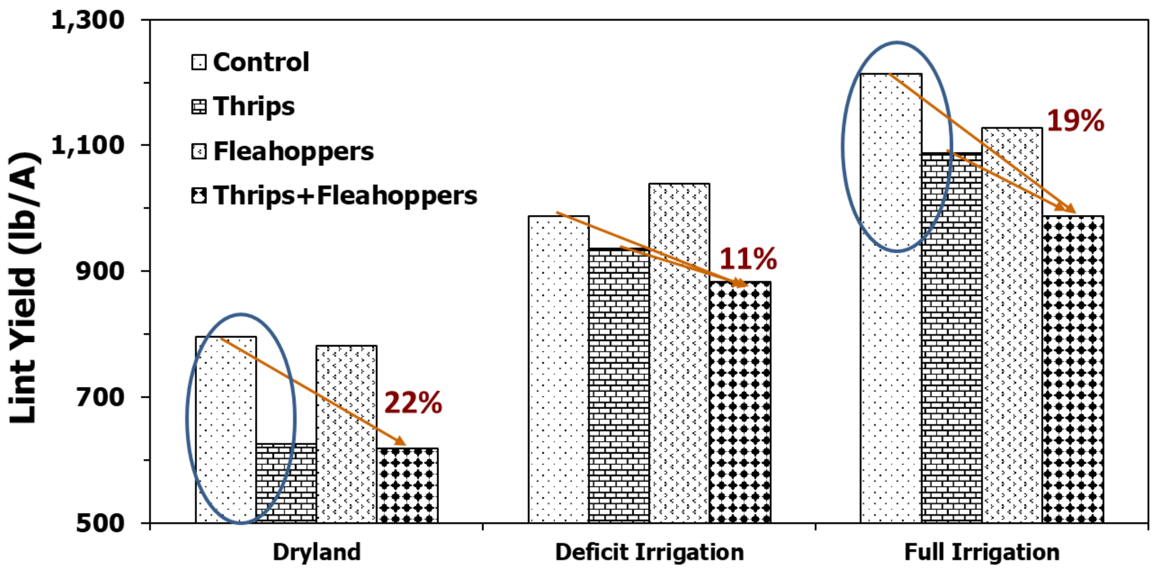

Figure 17. Average cotton lint yield losses due to thrips and cotton fleahopper infestations under three irrigation water treatments, Lubbock, Texas, 2018-2022.

We have begun to develop the structure of the profitability model using these five-year data. This data set will be used to analyze and compare the economics of management of thrips and cotton fleahoppers singly or in sequential combinations under three water-deficit production regimes. A set of economic profitability models will empower cotton producers in production decision-making in their specific production scenarios (insect pest management options in relation to water availability in their production enterprises). Economic decision-making models will be developed based on crop yield response and crop budget analyses. Crop yield response functions will be generated for each of the four insect management treatments within each water-deficit production system. Thrips reduced gross margins across all three water levels. Cotton fleahopper reduced gross returns only under full irrigation ($90/A). Sequential infestation of thrips and cotton fleahopper reduced gross returns by $128, $65, and $182 per acre (Fig. 18).

Cotton yield response to each insect treatment under three water levels will be fitted to calculate the slope (coefficient) of each treatment. The functional form will consider cotton yield and insect exposure (treatment) as fixed effect, and year as random. Insect management treatments within each water level will be ranked based on likelihood ratio test. Although the available data are highly variable and inconsistent between the years, we expect that these data will help us develop the foundation of the model which may be refined and further improved with additional data.

Table 4. HVI fiber quality parameters influenced by thrips and cotton fleahopper infestation singly as well as sequential infestation of both insects under three irrigation water treatments, Lubbock, Texas, 2022.

Fiber Parameters	Irrigation Treatment	Uninfested Control	Thrips	Fleahopper	Thrips+ Fleahopper
Micronaire	Dryland	4.49	4.56	4.37	5.11
Fiber length	Dryland	1.16	1.10	1.13	1.13
Uniformity	Dryland	81.80	80.15	80.90	80.70
Strength	Dryland	28.35	29.38	29.65	31.05
Elongation	Dryland	7.56	6.18	6.98	6.53
SFI	Dryland	9.10	11.75	10.03	10.08
Micronaire	Low	4.96	4.06	4.59	4.58
Fiber length	Low	1.13	1.12	1.15	1.13
Uniformity	Low	81.80	80.30	81.55	81.58
Strength	Low	30.28	28.05	29.30	29.65
Elongation	Low	6.75	7.28	6.90	6.43
SFI	Low	9.18	11.43	9.38	9.95
Micronaire	High	4.53	4.64	5.34	5.27
Fiber length	High	1.18	1.11	1.09	1.13
Uniformity	High	81.60	80.28	81.10	80.45
Strength	High	31.03	29.63	30.30	31.55
Elongation	High	6.63	6.48	6.30	6.13
SFI	High	9.53	10.53	9.78	9.83

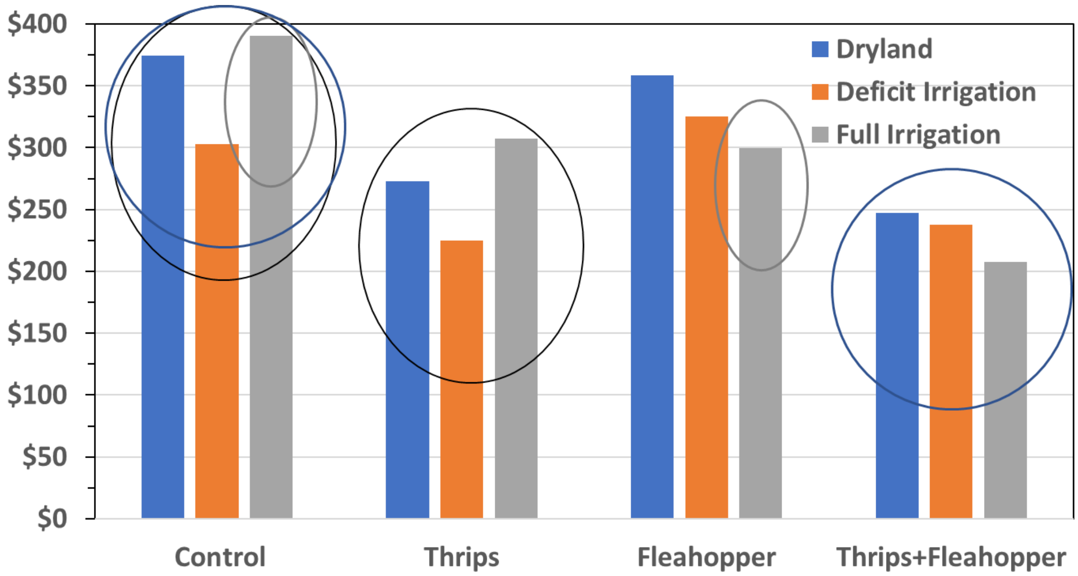

Figure 18. Average gross returns across insect-augmentation treatments under three irrigation water treatments, Lubbock, Texas, 2018-2022.

Acknowledgments

Research funding which facilitated this study came from Cotton Incorporated Texas State Support Committee. Dol Dhakal provided the technical help.