TEXAS A&M AGRILIFE RESEARCH & EXTENSION

COTTON ENTOMOLOGY RESEARCH REPORT 2017

TECHNICAL REPORT 18-4

TEXAS A&M AGRILIFE RESEARCH, CRAIG NESSLER, DIRECTOR
THE TEXAS A&M UNIVERSITY SYSTEM, COLLEGE STATION, TEXAS

COTTON ENTOMOLOGY PROGRAM

RESEARCH ACTIVITY ANNUAL REPORT

2017

SUBMITTED TO:

PLAINS COTTON IMPROVEMENT COMMITTEE
PLAINS COTTON GROWERS, INC.

JAROY MOORE, RESIDENT 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
Lubbock, Texas 79403
Phone: (806) 746-6101
Fax: (806) 746-6528
Email: m-parajulee@tamu.edu

PARTICIPANTS

ABDUL HAKEEM, Texas A&M AgriLife Research-Lubbock

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

CHARLES ALLEN, Texas A&M AgriLife Extension Service- San Angelo

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

DANNY CARMICHAEL, Texas A&M AgriLife Research-Lamesa

DANNY MEASON, Texas A&M AgriLife Research-Lubbock

FRED MUSSER, Mississippi State University, Mississippi State

GLEN RITCHIE, Texas Tech University

JIM BORDOVSKY, Texas A&M AgriLife Research-Lubbock

JIM NECHOLS, Kansas State University, Manhattan

JOHN RUBERSON, Kansas State University, Manhattan

JULIETTE JORDAN, Texas Tech University

KATIE LEWIS, Texas A&M AgriLife Research-Lubbock

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

MEGHA N. PARAJULEE, Texas A&M AgriLife Research-Lubbock

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

ROBERT BOWLING, Texas A&M AgriLife Extension Service- Corpus Christi

SARAH ZUKOFF, Kansas State University, Garden City

STANLEY C. CARROLL, Texas A&M AgriLife Research-Lubbock

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

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

TAHAMMAL HUSSAIN, University of Agriculture, Faisalabad, Pakistan

TOMMY DOEDERLEIN, Texas A&M AgriLife Extension Service-Lamesa

WAYNE KEELING, 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. 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 14 years. In 2015, all 11 West Texas zones (Southern Rolling Plains, El Paso/Trans Pecos, St. Lawrence, Permian Basin, Rolling Plains Central, Western High Plains, Southern High Plains/Caprock, Northern Rolling Plains, Northern High Plains, Northwest Plains, and Panhandle) have been declared boll weevil eradicated and is managed as a single zone called West Texas Maintenance Area (WTMA). The team effort of PCG, Texas A&M AgriLife Research and AgriLife Extension Service over several decades has resulted in a comprehensive understanding of boll weevil ecology and behavior.

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 17 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 a 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. 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, 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.

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.

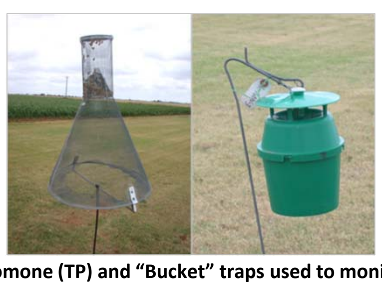
EFFECT OF NITROGEN FERTILITY ON COTTON CROP RESPONSE TO INSECT DAMAGE

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 affect 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 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, TOBACCO BUDWORM, AND BEET ARMYWORM MOTHS IN THE TEXAS HIGH PLAINS

A long-term study has been conducted in the Texas High Plains to investigate the year-around weekly moth flight activity patterns of bollworms, tobacco budworms, and beet armyworms. These three species are important cotton pests in the High Plains. The regional adoption of cotton and corn cultivars incorporating *Bt* technology has been instrumental in reducing the current threat of these lepidopteran pests, yet diminishing underground water availability for irrigation is necessitating lower crop inputs, such as transgenic seed costs, for our increasing dryland crop production acreage, increasing the importance of these pests.



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

STATEWIDE SURVEY OF BOLLWORM MOTHS FOR POSSIBLE OLD WORLD BOLLWORM DETECTION IN TEXAS

The objective of this study is to conduct a statewide monitoring of *Helicoverpa armigera* in Texas which will be used to inform growers and consultants and serve as the foundation for the development of management strategies. Plastic bucket traps and pheromone lures will be used to collect moths; moths will be dissected to distinguish Old World and New World bollworm based on genital characteristics.

DEVELOPMENT OF ECONOMIC THRESHOLD AND MANAGEMENT RECOMMENDATIONS FOR *LYGUS* BUG

Texas A&M AgriLife **Cotton Entomology Program** has been providing a unique leadership in *Lygus* research across the United States cottonbelt since 2002. We have quantified the compensation ability of cotton to *Lygus*-induced fruit loss and the recommendation has been made to our producers that pesticide applications prior to 30% pre-flower and 25% early flower fruit shed may not be necessary. We also have developed a late-season insecticide termination guideline for Texas High Plains cotton growers, according to which, insecticide intervention for *Lygus* control may not be warranted when harvestable bolls accumulate ≥350 heat units or the boll is ≥3 cm in diameter after crop cut-out. Current effort concentrates on developing economic threshold-based management recommendations for *Lygus* in Texas High Plains cotton, thereby aiming to minimize economic losses to producers. Continuing studies will examine the effect of *Lygus* on drought-stressed and limited irrigation cotton.

***Lygus* adults and nymphs cause damage to squares, flowers, and bolls**

THRIPS MANAGEMENT IN TEXAS HIGH PLAINS COTTON: INSECTICIDE PRODUCT EVALUATION

Multi-year statewide studies are being conducted at several Texas locations to represent cotton fields surrounded by variable vegetation/crop complexes and thrips population pressure in cotton. The study objectives are to: 1) evaluate the foliar insecticide application frequency in managing thrips in seedling cotton, and 2) evaluate the efficacy, residual performance, and economic competitiveness of selected products in thrips management. Insecticides, including seed treatment (thiamethoxam [Cruiser®] and imidacloprid [Aeris®]) and foliar (Orthene®, Bidrin®, and Vydate®) treatments are evaluated for their efficacy and cost effectiveness in managing thrips populations in cotton relative to an untreated control. Detailed in-season plant growth parameters are also measured.

Field evaluation of thrips insecticide products

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

M.N. Parajulee, A. Hakeem, S.C. Carroll, and J.P. Bordovsky

Objective: The objective was to evaluate the effect of artificial injury to cotton squares mimicking acute cotton fleahopper damage under variable nitrogen application rates on cotton fiber yield and quality.

Methodology: A high-yielding cotton cultivar, FiberMax® 1900GTL, was planted at a targeted rate of 52,000 seeds/acre on May 4, 2017. The experiment was laid out in a split-split-plot randomized block design with five nitrogen fertility rate treatments applied for 16 years as main plots (16-row plots), split into two 8-row sub-plots: 1) nitrogen applied (N_a), and 2) nitrogen not applied (N_{na}) during 2017, and two artificial cotton square injury treatments mimicking acute cotton fleahopper infestation as sub-sub-plots with four replications. The five main-plot treatments included pre-bloom side-dress applications of augmented N fertilizer rates of 0, 50, 100, 150, and 200 lb N/acre using a soil applicator injection rig on July 3, 2017. 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 July 20, 2017. Within each sub-plot, two 8-ft. sections of uniform cotton were flagged in the middle two rows, each receiving hand removal of 100% cotton squares three weeks into squaring or control (no square removal). Five plants were removed to determine biomass. Treatment plots were harvested for lint yield and fiber analysis.

Results: Considerably higher residual soil nitrogen was recorded from plots that received the two highest N rates in preceding 16 years (Fig. 1). Not applying N following 16 years of continuous augmentation of N resulted in lower leaf N in all N rate treatments. However, lint yield was similar across all five N treatments in 2017 when N augmentation was ceased and the crop only experienced the long-term residual N. Lint yield in N augmented treatments increased with higher N rates, but it maximized at 100 N lb/A and then declined. It was unclear why the yield was significantly reduced at 150 lb/acre treatment. Numerically higher lint yield was observed in the 100 and 150 lb/acre nitrogen treatments, however, no significant differences in lint yield were observed between N_a and N_{na}.

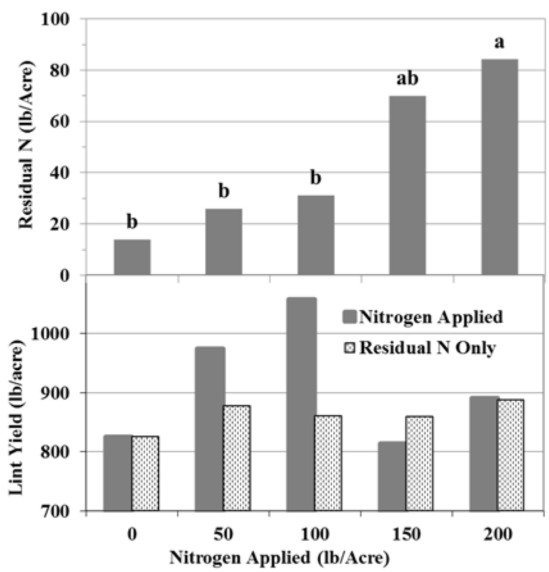


Fig. 1. Residual N (top) after the 16-year augmentation of five N rates and lint yield (bottom) on N_a vs. N_{na}.

High residual soil nitrogen has resulted in higher leaf nitrogen levels, yet at the same time, higher residual soil nitrogen reduced lint yield as plants grow longer, producing more bolls which shed later due to physiological stress. This year we have not observed reduced lint yields from plots in which N was not applied, which indicates the presence of enough residual nitrogen in the soil.

TITLE:

Cotton yield response to cotton fleahopper infestations as influenced by irrigation level and cultivar treatments, Lamesa, TX, 2017.

AUTHORS:

Megha Parajulee – Professor, Faculty Fellow, and Regents Fellow
Abdul Hakeem – Postdoctoral Research Associate
Stanley Carroll – Research Scientist
Wayne Keeling - Professor

MATERIALS AND METHODS:

Plot Size: 4 rows by 300 feet, 3 replications

Planting date: May 10

Fertilizer pre-plant: 42-40-0
Fertilizer in-season: Low water – 64-0-0; High water – 128-0-0

Cultivars: FiberMax 1911 GLT and Deltapine 1646 B2XF

Irrigation:

	Low	High
Preplant	3.4”	3.4”
In Season	3.9”	7.5”
Total	7.3”	10.9”

Cotton fleahopper: Three treatments [*Control* (zero cotton fleahoppers), *Cotton fleahopper augmented* (5 bugs per plant), and *Manual removal* (100% squares removed manually three weeks into squaring]

Herbicides: 2,4-D 1 qt/A – March 2
Roundup PowerMax 1 qt/A – April 10, cover termination
Prowl 3 pt/A – April 27
Roundup PowerMax 1 qt/A – June 15
Roundup PowerMax 1qt/A –August 3

Insect release date: July 1, 2017 at fleahopper susceptible stage

Plant mapping date: July 15, 2017 (in-season); October 23, 2017 (pre-harvest)

Harvest date: October 23 (hand-harvested)

Comparative effect of cotton fleahopper feeding injury versus manually removed early stage fruits on resulting cotton lint yield was evaluated on two cotton cultivars, FM 1911 GLT and DP 1646 B2XF, as influenced by irrigation water level. Two seasonal irrigation levels, *High* (10.9 inches) and *Low* (7.3 inches) were evaluated under a center pivot irrigation system. Laboratory-reared cotton fleahopper nymphs were released onto cotton terminals (n=7 plants per experimental unit. Experimental design consisted of three square abscission treatments (*cotton fleahopper augmentation, manual removal of squares,* and *control*), two water levels (*high* vs. *low*), and two cultivars (*FM 1911 GLT* and *DP 1646 B2XF*), replicated three times and deployed in a randomized complete block design (total 36 plots). Square abscission treatments, 1) *control* (zero fleahopper augmentation), 2) *manual removal* (removal of 100% squares from the plant, and 3) *cotton fleahopper augmentation* (five fleahoppers augmented per plant), were deployed on July 1, 2017, in order to mimic a natural early-season acute infestation of cotton fleahoppers. A single release of cotton fleahoppers and manual removal of fruits were timed to simulate an acute infestation of cotton fleahoppers while cotton was highly vulnerable to fleahopper injury (2-3 weeks into cotton squaring). Augmented cotton fleahoppers were allowed to feed for 10 days and insecticides were sprayed in all experimental plots. Damage inflicted by fleahopper augmentation was assessed on July 15, 2017 and test plots were harvested on October 23, 2017.

RESULTS AND DISCUSSION:

Cotton cultivar DP 1646 B2XF appeared to be more sensitive to cotton fleahopper injury compared to FM 1911 GLT (Fig. 1). However, the injury effect of cotton fleahopper was more pronounced under low irrigation compared with that in high irrigation condition. Control plots had no square loss because the experimental field did not have naturally occurring cotton fleahoppers. Averaged across cultivars, cotton fleahopper induced crop damage, as measured by cotton square loss, did not vary between the two water levels (32.6% average square loss). Cotton fleahopper augmentation inflicted 27.2% and 40.4% square loss in DP 1646 B2XF and FM 1911 GLT under low water regime, whereas 29.2% and 36.1% squares were lost under high water regime, respectively (Fig. 1), and such pre-flower cotton square loss is considered a moderate level of insect-induced early fruit loss for Texas High Plains cotton.

Lint yield was not significantly affected by square abscission treatments under low water regime (Fig. 2), whereas control plots had significantly higher lint yield followed by manual removal plots, and the lowest lint yield was recorded on the fleahopper-augmented plots under high water regime (Fig. 2). While the overall lint yield was significantly lower in low water plots compared to that in high water plots, as expected, the lack of fleahopper impact on deficit-irrigated cotton is noted. It is suggested that the fruit carrying capacity of the plants under low water regime was maximized at around 800 lb per acre for the amount of water applied and the fleahopper-induced square abscission maintained the fruit load via pruning of extraneous fruits.

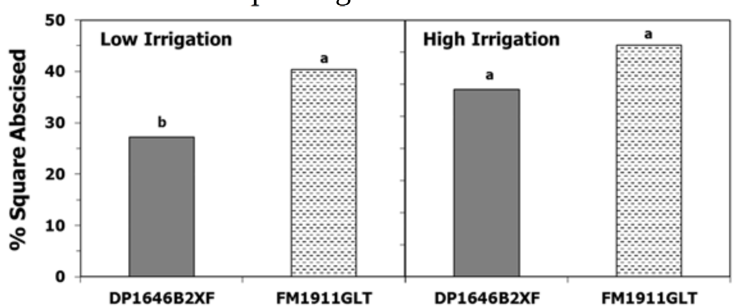


Figure 1. Average square loss following an acute infestation of cotton fleahoppers, achieved by augmenting 5 bugs per plant during the second week of squaring, under low and high irrigation regimes on cotton, Lamesa, Texas, 2017.

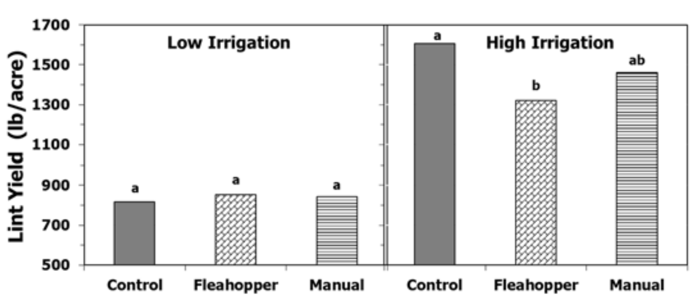


Figure 2. Average lint yield following an acute infestation of fleahoppers and manual removal of 100% squares prior to first flower under high and low irrigation regimes, Lamesa, Texas, 2017.

Effect of *Lygus* on Drought-Stressed Cotton

Cotton Incorporated Core Program
Project Number: 16-354

PROJECT SUMMARY

Western tarnished plant bug, *Lygus hesperus,* is the primary *Lygus* species inhabiting cotton and several other hosts in the Texas High Plains. Our previous studies have documented that several non-cotton hosts including alfalfa, sunflower, corn, grain sorghum, as well as weedy habitats along roadside bar-ditches and turnrows could impact *Lygus* severity in adjacent cotton. Our previous projects, supported by the Cotton Incorporated State Support Program, have generated significant information on the damage potential of adult and immature *Lygus* on maturing cotton bolls. A three-year field study has quantified the boll age (measured in terms of heat units from flowering) that is safe from *Lygus* damage. Boll damage assessment based on heat unit-delineated maturity provided a boll-safe cutoff value of 350 heat units (~2-3 weeks from flowering), although *Lygus* adults and nymphs both cause external lesions on bolls throughout boll development and may give farmers a false impression of *Lygus* damage. A 4-year TSSC project (2012-2015) developed economic threshold-based management recommendations for *Lygus* in Texas High Plains cotton, which is expected to recommend a boll management threshold for early versus late season *Lygus* infestations.

While the Texas High Plains is fortunate to experience insignificant *Lygus* pressure in cotton during the recent years, the research on *Lygus* feeding behavior as it relates to low-input production systems in the Texas High Plains needs to continue. In particular, the characteristic low annual rainfall and decreasing irrigation water availability in the region has resulted in increased dryland cotton acreage. This project examined the feeding behavior and plant response to *Lygus* injury in relation to drought conditions. In 2016, drought-stress treatments included two irrigation levels (full irrigation versus dryland), each nested with two cotton cultivars (early maturing DP 1518 versus full-season DP 1044). Each irrigation x cotton maturity combination received two *Lygus* infestation levels [untreated control versus 2X threshold (high infestation)], each with four replications, resulting in a total of 32 plots. In 2017, only DP 1518 was evaluated.

In 2016, effect of drought-stress on *Lygus*-induced injury was more pronounced in DP 1518 (38.8% lint loss) compared to that in DP 1044 (28.2%), suggesting that DP 1518 may be more susceptible to *Lygus* injury under dryland or water-stressed conditions. Irrigated plots had significantly lower lint loss in both cotton cultivars due to *Lygus* feeding compared with that in dryland plots (14.1% in DP 1518 and 9.3% in DP 1044). In 2017, *Lygus*-induced injury reduced 41% lint loss in dryland versus 29.8% in irrigated cotton. Our 2-year study indicated that the impact of *Lygus* injury was more pronounced under dryland conditions. This study is planned to be replicated in 2018.

Effect of *Lygus* on Drought-Stressed Cotton

INTRODUCTION

Western tarnished plant bug (WTPB), *Lygus hesperus*, is the primary *Lygus* species inhabiting cotton and several other crop and weed hosts in the Texas High Plains. Previous research indicates that WTPB is a pest of late-season cotton in the Texas High Plains. Regional survey work suggests that WTPB generally do not move from roadside weed habitats to cotton until late during the season as bolls mature, at which time roadside weeds decrease in prevalence or suitability. However, WTPB can be a significant economic pest of squaring and/or flowering cotton if they are forced to move into cotton in the absence of roadside weed habitats due to drought.

Due to utilization of underground water in excess of its recharge capacity and characteristic low rainfall in this semi-arid region, the Texas Southern High Plains has been facing some significant drought conditions in recent years. This has resulted in many of our cotton acreages going to dryland or limited-irrigation production. The shift in cotton production system from 60:40% irrigated:dryland to 40:60% in just the last 10-15 years has altered our input resources, cultivars, and management practices. It is generally expected that the drought-stressed plants would be significantly more impacted by insect injury than fully irrigated crops, but the drought-stressed plants would also likely have lower fruit load thresholds. However, a plant's ability to compensate for *Lygus*-induced crop damage may be greatly impacted by the drought-stress conditions, with possibly a low infestation rendering proportionately higher damage to the crop.

Cotton plant growth is sensitive to numerous environmental and management input factors, particularly irrigation and nitrogen fertility. Cotton growth responses to various input factors are well-documented and growth models have been developed. However, the specific cotton plant responses to *Lygus* injury under a range of irrigation regimes remain uninvestigated. Plant bugs have a general inclination to attack the stressed plants and cause significant damage. The greater damage on stressed plants compared to healthy plants is partly due to the inability of plants to physiologically react to the injury. Thus, it is expected that the drought-stressed plants would be more vulnerable to *Lygus* injury than unstressed plants. However, the fruit-load threshold of a cotton plant is also dependent on soil moisture availability, among several other input and management factors. There is no information on how *Lygus* feeding behavior will be impacted under various irrigation regimes and how the plants would respond to varying levels of *Lygus*-induced injury under drought conditions. Similarly, cotton cultivars respond differently to various moisture stress conditions and the interactive effect of *Lygus* injury, phenological attributes of cotton cultivar, and drought conditions are unknown. The overall goal of this study was to characterize the effect of drought conditions on *Lygus* infestation/feeding behavior and plant response to *Lygus* injury.

METHODOLOGY

A four-year study was initiated in 2016 in a multi-factor split-plot randomized block design with four replications (blocks). Drought-stress parameters included two irrigation levels (full irrigation versus dryland) that served as main plot factors, whereas two cotton cultivars (early maturing versus full-season) were used as subplot factors to create an interaction of cultivar maturity and drought-stress situations to mimic the Texas High Plains (THP) scenario during dry summers. The full irrigation water level was created via 100% replenishment of evapotranspiration (ET) requirement for THP, whereas the dryland treatment received no supplemental irrigation. Two cotton cultivars included in the study were DP 1518 (short-season) and DP 1044 (full-season), planted on May 25, 2016 and May 26, 2017. Each irrigation treatment (2) x cotton maturity (cultivar type) treatment (2) received two *Lygus* infestation levels [untreated control, 2X threshold (high infestation)], each with four replications, resulting in a total of 32 plots. In 2017, due to logistic limitations, the study was conducted only on DP 1518.

Lygus density treatments were applied on one 3-ft cotton row section per plot on August 11, 2016 and August 18, 2017. For insect release plots, a single release of *Lygus* adults (5 adult *Lygus* per plant, resulting in 1 bug per plant after 80% field mortality) was timed to simulate the acute infestation of *Lygus* while cotton was at peak flowering/boll development stage. Multi-plant (7 plants) cages were used to contain the released adults (Fig. 1). The control plots were flagged and sprayed with insecticides. Two weeks after the deployment of insect release treatments, all experimental plots were sprayed with insecticide Orthene to ensure that the released insects were removed. Two plants from each treatment were removed on August 30 and processed for *Lygus* damage assessment. Variables including number of fruits aborted and internal/external damage to developing bolls were measured. Pre-harvest plant mapping was conducted and crop was hand-harvested on November 5 (2016) and November 2 (2017) and ginned on a tabletop gin. Hand-harvested yield samples were sent to Cotton Incorporated for fiber quality analysis.

Figure 1. A and B) Multi-plant cages used for *Lygus* release, C) Examination and data collection from the test site.

RESULTS

2016 Study. As expected, higher numbers of internal warts were observed in bolls collected from *Lygus*-infested plants compared to that in control plots (Fig. 2). Lygus appeared to cause greater damage to dryland-grown plants compared to that in full irrigation plots. It is somewhat interesting to note that the dryland plots received greater boll injury while the bolls in dryland plots are expected to possess tougher carpel wall. It is possible that the water-stressed bolls are more sensitive to *Lygus* feeding injury.

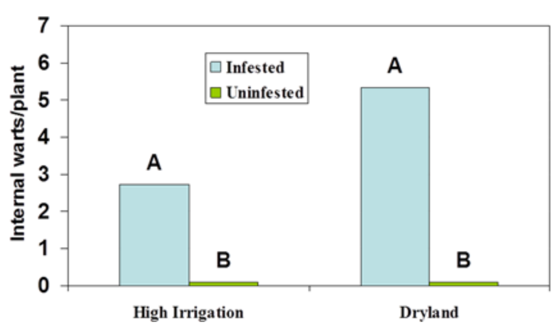


Figure 2. Internal injury warts in developing bolls caused by *Lygus* feeding on plants grown under full irrigation versus dryland, Lubbock TX, 2016.

Averaged across the water level and cultivar treatments, total boll density on *Lygus*-infested plants was lower (2.27 bolls per plant) compared to that on uninfested control plants (3.2 bolls per plant) two weeks after *Lygus* infestation, suggesting possible abortion of small bolls due to *Lygus* feeding. Within varieties, DP 1518 had slightly more (2.8 bolls per plant) bolls compared to DP 1544 (2.6 bolls per plant), but this difference was not statistically significant.

Averaged across cultivars and irrigation treatments, no significant difference in lint yield was observed between *Lygus*-release treatments and non-release control treatments. However, drought-stress induced significantly greater impact of *Lygus* injury on cotton lint yield. *Lygus* injury caused 34.83% lint yield loss in dryland cotton compared to only 11.3% loss in irrigated cotton (Fig. 3), suggesting a reduced *Lygus* injury sensitivity on full irrigated cotton compared to that in water-stressed production situation.

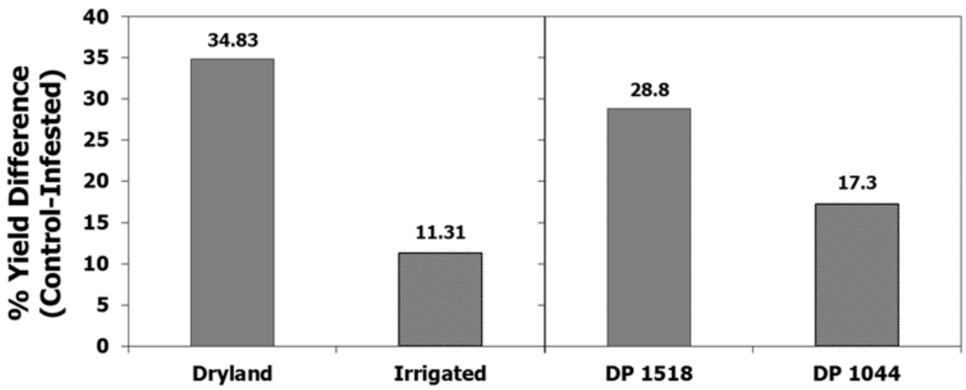


Figure 3. Effect of *Lygus* bugs on lint yield of cotton under dryland and irrigated production conditions and between the two cultivars, Lubbock, TX, 2016.

Lygus injury sensitivity varied between cultivars. While no significant difference in total lint yield was observed between the two cotton cultivars evaluated, *Lygus*-induced lint yield reduction was significantly greater (28.8%) in DP 1518 compared to 17.3% in DP 1044 (Fig. 3).

Effect of drought-stress was more pronounced in DP 1518 (38.8% lint loss) compared to that in DP 1044 (28.2%) (Fig. 4), suggesting that DP 1518 may be more susceptible to *Lygus* injury under dryland or water-stressed conditions. Irrigated plots had significantly lower lint loss in both cotton cultivars due to *Lygus* feeding compared with that in dryland plots (Fig. 4). Our preliminary results indicated that DP 1044 appeared to show lower sensitivity to *Lygus* injury under both dryland and irrigated conditions, but the impact was more pronounced under dryland condition.

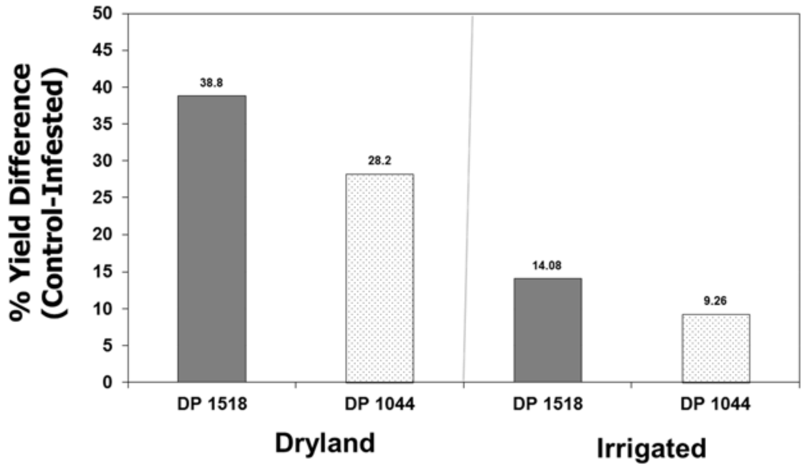


Figure 4. Percentage yield losses due to *Lygus* infestation under dryland versus irrigated production conditions, Lubbock, Texas, 2016.

2017 Study. *Lygus* augmentation exerted significant injury to the maturing bolls in both dryland and irrigated cotton (Fig. 5). There was a slight increase in the number of external lesions, internal boll injury warts, and damaged seeds in irrigated cotton compared to that in dryland cotton, but the trend was similar between the two irrigation treatments. Even though the Lygus injury caused lower amount of visible damage in dryland cotton compared to that in fully irrigated cotton (Fig. 5), drought-stress may render greater boll vulnerability to Lygus injury for continuing boll growth, lint development, and fiber quality.

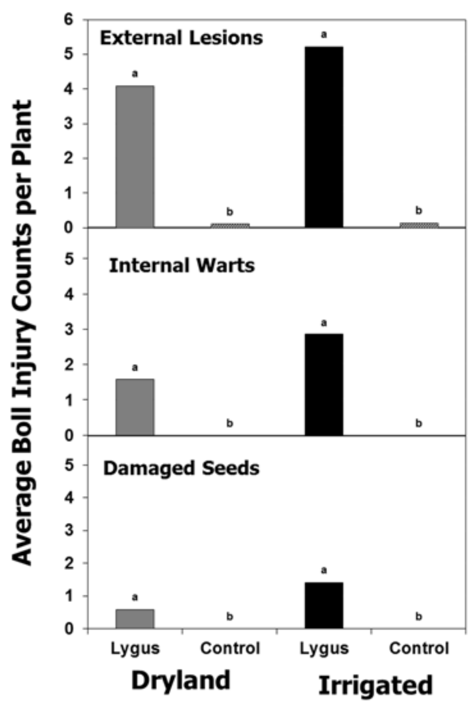


Figure 5. External lesions, internal injury warts, and damaged seeds in developing bolls caused by *Lygus* feeding on plants grown under full irrigation versus dryland, Lubbock TX, 2017.

Lygus augmentation significantly reduced lint yield in both fully irrigated and dryland conditions. As expected, dryland plots produced lower lint yield compared to that in irrigated plots (Fig. 6). Within dryland, un-augmented control plots produced 1,292 lb per acre lint compared to 762 lbs per acre when *Lygus* bugs were augmented and injury was inflicted to the maturing crop. Similar relationship was observed under full irrigated crop production system, with 1,974 lbs per acre lint yield in control plots and 1,386 lbs per acre in *Lygus*-augmented plots (Fig. 6). Irrigated plots had significantly lower lint loss (29.8%) due to *Lygus* feeding compared with that in dryland plots (41.1%) (Fig. 7).

In both 2016 and 2017, *Lygus* injury impact was more pronounced under dryland condition compared to that under full irrigation production. The study is planned to replicate in 2018.

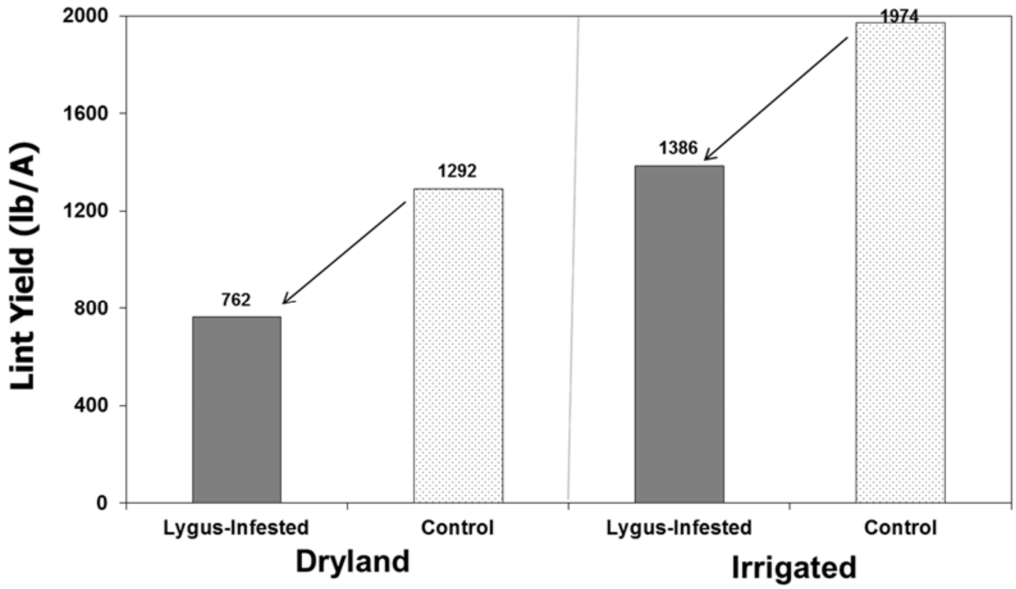


Figure 6. Cotton lint yield losses due to *Lygus* infestation under dryland versus irrigated production conditions, Lubbock, Texas, 2017.

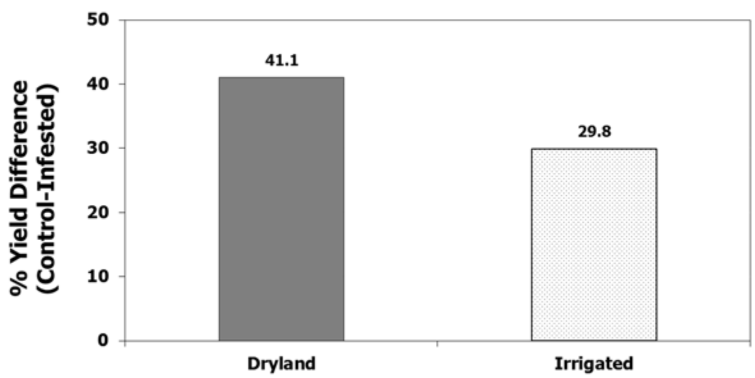


Figure 7. Percent lint yield losses due to *Lygus* infestation under dryland versus irrigated production conditions, Lubbock, Texas, 2017.

Acknowledgments

Research funding which facilitated this study came from Cotton Incorporated Core program.

Monitoring the Old World Bollworm, *Helicoverpa armigera*, in Texas toward Developing Potential Management Strategies

Cotton Incorporated Texas State Support Program
Project Number: 16-272TX

Project Summary

A four-year study was initiated in 2015 in the Texas High Plains and South Texas to investigate the seasonal moth flight activity patterns of *Helicoverp*a spp. and to possibly detect the presence of the 'Old World' bollworm (OWB, *H. armigera*), if it has already been introduced into the Texas bollworm population. The primary objectives of the study were to: 1) Investigate the effectiveness of species-specific pheromone lures obtained from two vendors, and 2) Determine the efficiency of two different trap designs in capturing *Helicoverpa* spp. moths. Trap type x pheromone lure combination treatments were deployed in mid- to late July each year, followed by all traps being monitored and the captured moths counted approximately weekly through mid-November. All traps were re-baited with fresh lures approximately every two weeks. In 2016, sub-samples of up to 25 moths per trap per sample date (total of 1500 moths) were dissected to determine if the Texas High Plains moth populations contained any *H. armigera*. In 2017, thirty-eight samples (1-28 moths per sample) were sent to USDA Center for Plant Health Science and Technology, Fort Collins, CO for molecular diagnosis of OWB specimens. Our current hypothesis is that OWB invasion has not occurred in Texas. In the absence of *H. armigera*, it is therefore, impossible to determine which lure type and/or lure vendor has the best pheromone lure formulation for attracting *H. armigera*. Among the five selected experimental treatments, the Texas Traps baited with Trécé™ *H. armigera* lure captured the highest number of *Helicoverpa* spp. moths during all three years of the study, 2015, 2016, and 2016. The *H. armigera* baited traps with the USDA Cooperative Agricultural Pest Survey (CAPS) lures captured significantly fewer moths compared to that in 2015, but caught an equal or greater number of tobacco budworm moths [*Heliothis virescens* (F.)]. The Trécé™ (*H. zea* and *H. armigera*) lure baited traps did not attract tobacco budworm moths, yet both Trécé™ species-specific lures captured numerous *H. zea* specimens. Improvement in the CAPS lure since 2016 has discriminated *Helicoverpa* moth species significantly and the moth capture by CAPS lure in Texas has been greatly reduced, indicating the greater sensitivity of the USDA lure in possible monitoring of OWB moths. On the other hand, Trécé™ *H. armigera* lure is totally ineffective in discriminating the *Helicoverpa* moth species. Sample dissections of 2016 resulted in no positive identification of OWB samples from Texas populations. Similarly, the molecular examination of 2017 samples also resulted in no positive identification of OWB; hence, we do not believe that the *H. armigera* has been introduced to Texas at this time. We plan to conduct this study one more in 2018.

Introduction

The Old World bollworm (OWB), *Helicoverpa armigera*, is a polyphagous pest, feeding on a wide range of crop and non-crop plant hosts. Its global distribution spans Europe, Asia, Africa, Oceania, and South America. During 2014, *H. armigera* was detected in Puerto Rico and Costa Rica, and then on 17 June 2015, one male moth was collected in a pheromone trap in Bradenton, FL. It is anticipated that this pest will invade the southern U.S. in the very near term and some entomologists have speculated that the invasion has already occurred. Ecological niche modeling indicates that the majority of the U.S. is a suitable habitat for the permanent establishment of reproductive OWB populations. Therefore, the current OWB issue in Texas is a rigorous anticipatory survey.

This continuing Texas High Plains study is being conducted to investigate the seasonal moth flight activity patterns of *Helicoverpa* spp. captured on two different trap designs (Fig. 1) and pheromone lures, obtained from two sources, specifically designed to trap *H. zea* or *H. armigera*. It should be noted that *H. zea* moths commonly respond to *H. armigera* pheromone baited traps and the two species are difficult to distinguish from each other without genetic testing or dissecting the adult males.

The study objectives were to: 1) Investigate the effectiveness of *H. armiger*a and *H. zea* pheromone lures obtained from two sources [Trécé™, Inc. (both species); USDA CAPS (*H. armigera* lures only)], 2) Determine the efficiency of two different trap designs ('Texas Trap' vs. green 'Bucket Trap') in capturing *Helicoverpa* spp. moths, and 3) Perform dissections of seasonal male adult sub-samples of *Helicoverpa* spp. captured on *H. armigera* pheromone baited traps in order to possibly detect Old World bollworm sightings in Texas bollworm moth populations.

Materials and Methods

Survey area for the study included four trapping sites situated in a west-to-east orientation along Texas FM1294 in northern Lubbock County, TX. Five selected experimental treatments included: 1) 'Texas Trap' baited with Trécé™ *H. zea* lure, 2) 'Texas Trap' with Trécé™ *H. armigera* lure, 3) 'Bucket Trap' (green) with Trécé™ *H. zea* lure, 4) 'Bucket Trap' (green) with Trécé™ *H. armigera* lure, and 5) 'Bucket Trap' (green) with USDA CAPS *H. armigera* pheromone lure. Each treatment was represented at each trapping site, including five treatments and four sites (replications) deployed in a randomized block design. Bucket trap with USDA CAPS *H. armigera* pheromone lure was also used to trap moths in Hidalgo Co. to represent South Texas.

Trapping (surveying) periods for all study years included typically deploying the traps during mid- to late July with monitoring extending until mid-November annually. Plans include an identical test to continue in 2018. Traps were inspected weekly and re-baited at two-week intervals. All captured moths were counted, placed into Zip-Loc™ bags, and then samples were placed into a freezer for species identification dissections at a later date (2016) or sent to USDA Lab in Fort Collins, CO for molecular identification (2017).

Figure 1. Two trap designs, 'Texas Trap' (A) and green 'Bucket Trap' (B), deployed at four Lubbock County sites, 2015-2017.

Results and Discussion

<u>'Texas Trap' with Two Associated Pheromone Lure Treatments</u>

The Trécé™ *H. armigera* and Trécé™ *H. zea* lure baited Texas traps yielded 2015 seasonal weekly captures of 119 and 83 bollworm moths per trap, respectively; while during 2016, similar seasonal weekly moth capture averages of 110 and 80 were observed (Figs. 2 and 3). Moth captures in 2017 was higher than that in the previous two years, with 234 and 177 moths per trap per week for *H. armigera* and *H. zea* lures, respectively. Overall, it should be noted that among the five study treatments, the Texas Traps baited with Trécé™ *H. armigera* lure captured the highest number of *Helicoverpa* spp. moths during all three years of the study (Figs. 2, 3 and 4). Because *H. zea* cross-responds to *H. armigera* lure and the Trécé™ *H. armigera* lure is not sufficinetly sensitive to species specificity, it appears that the Trécé™ lure that is designed for *H. armigera* is as much or more attractive to *H. zea* (Figs. 2, 3, and 4). Therefore, the Trécé™ *H. armigera* lure is not a viable monitoring tool in OWB survey.

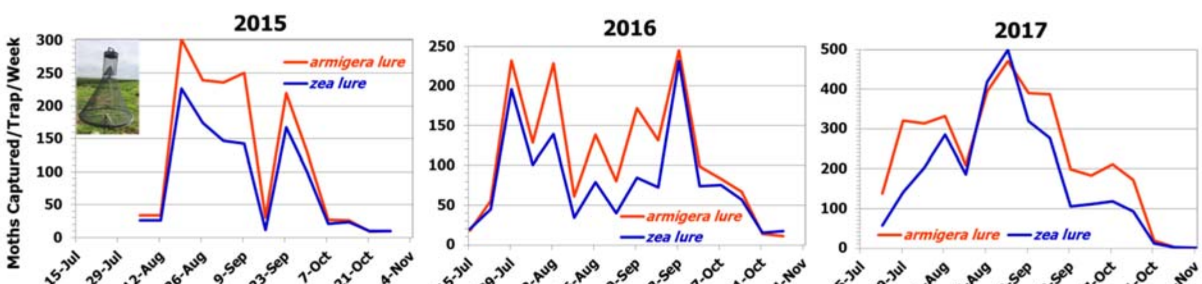


Figure 2. Texas Traps [also referred to as Texas Pheromone Trap, TP Trap or Hartstack Trap (Hartstack et al. 1979)]: Weekly *Helicoverpa* spp. male moth captures during 2015, 2016, and 2017 on 'Texas Traps' baited with *H. zea* or *H. armigera* Trécé™ pheromone lures.

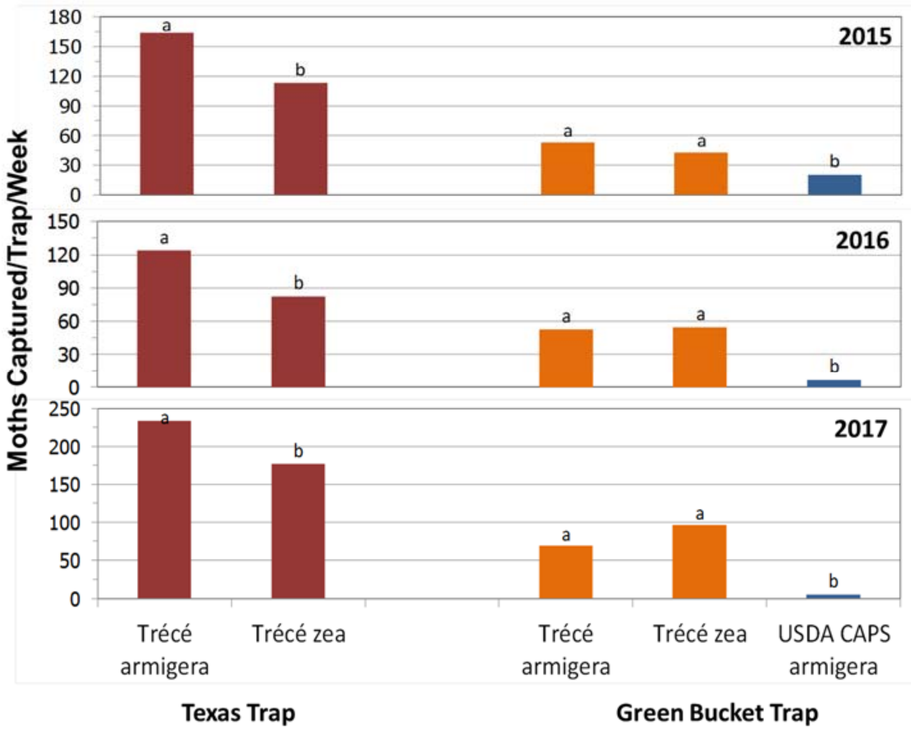


Figure 3. Seasonal mean number of *Helicoverpa* spp. male moths captured per week per trap on Texas Traps (red bars) baited with Trécé™ *H. armigera* and *H. zea* pheromone lures. Likewise, the two orange bars indicate weekly means for green Bucket Traps baited with Trécé™ *H. armigera* and *H. zea* lures. The blue bar illustrates the data for green Bucket Traps baited with the USDA CAPS *H. armigera* lures. Seasonal means within each trap type indicated by different lowercase letters indicate statistical difference between these means.

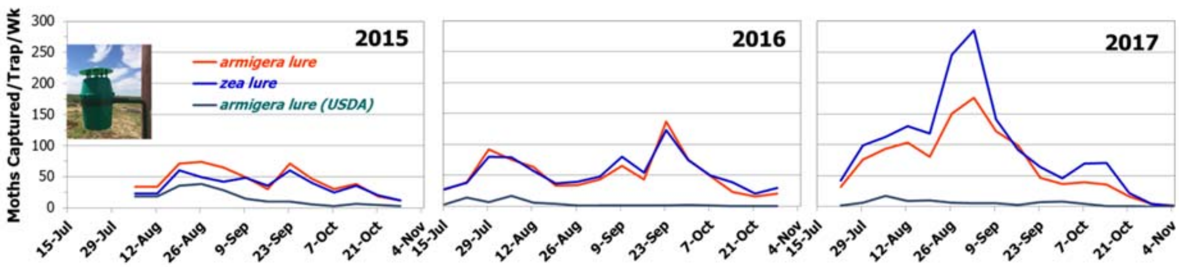


Figure 4. Green 'Bucket Traps': Weekly *Helicoverpa* spp. male moth captures during 2015, 2016, and 2017. Traps were baited with *H. zea* or *H. armigera* Trécé™ pheromone lures, and *H. armigera* USDA CAPS lure.

During 2016, a slightly different numerical trend was observed in which the Trécé™ *H. zea* lure baited traps captured a seasonal mean of 55 moths per trap, whereas the Trécé™ *H. armigera* lure captured slightly lower moth numbers (although not statistically different) at 52 moths per trap (Fig. 3). Trap captures in 2017 were significantly higher than that in 2016, with 96 and 69 moths captured in Trécé™ *H. zea* lure and *H. armigera* lure baited traps, respectively.

What should be noted is that the moth captures on the USDA CAPS baited green bucket traps did not reflect the same moth trap response activity patterns of the other four treatments which utilized lures obtained from Trécé™, Inc. Figures 3 and 4 clearly illustrate that the moth numbers were much lower and only the early season peak trap responses were slightly reflected by USDA CAPS lure as compared to the other pheromone lure treatments. While *H. armigera* lure is expected to cross-capture *H. zea*, USDA CAPS lures were designed to be more sensitive toward *H. armigera* compared to commercially available *H. armigera* lure. At the present time, *H. armigera* does not appear to be in the Texas High Plains bollworm population (see below in *Identification* section), therefore it is difficult to determine which lure type and/or lure vendor has the best pheromone lure formulation for attracting *H. armigera*. Nevertheless, USDA CAPS lure seems to discriminate *H. zea* moths significantly as shown by drastically lower moth captures in CAPS lure baited traps versus Trécé™ OWB lure.

During 2016, the traps baited with the USDA CAPS lures were observed to also capture tobacco budworm [*Heliothis virescens* (F.)] moths, while the Trécé™ (*H. zea* and *H. armigera*) lure baited traps did not attract tobacco budworm moths. In fact, traps baited with CAPS lure captured significantly greater abundance of tobacco budworm moths than *Helicoverpa* spp. For instance, during the 11-week trapping period of 18 August to 4 November, the four USDA CAPS lure baited traps captured a total of 680 tobacco budworm moths, while during the same time period these traps captured only 232 *Helicoverpa* spp. moths. In 2017, CAPS lure showed similar trend as in 2016, but it captured 347 total moths in 38 samples.

Dissections to Determine *Helicoverpa* spp. Identifications

A total of 1,500 moths from Trécé™ and USDA CAPS *H. armigera* lure baited traps in the Texas High Plains were dissected in 2016. These dissections resulted in no positive identification of OWB in the Texas High Plains moth populations. All dissected male moths appeared to be *H. zea* specimens. Approximately 500 moths per year were dissected from Hidalgo Co. in 2016 and 2017 and no positive OWB samples were detected in that region either. Thirty-eight samples including 347 specimens from 2017 survey in the Texas High Plains were sent to USDA Center for Plant Health Science and Technology, Fort Collins, CO for molecular diagnosis of OWB specimens and their molecular examination also resulted in no positive identification for OWB. We plan to repeat this survey in 2018 as final year of this study.

Acknowledgments

Research funding which facilitated this ongoing study came from Cotton Incorporated State Support Committee and Plains Cotton Growers, Inc. USDA CAPS lures were provided by USDA APHIS PPQ. Stanley Carroll provided the technical assistance.

References

Hartstack, A.W., J.A. Witz, and D.R. Buck. 1979. Moth traps for the tobacco budworm. J. Econ. Entomol. 72: 519-522.

U.S. Department of Agriculture, Animal Plant Health Inspection Service, Plant Protection and Quarantine. 2014. New Pest Response Guidelines: *Helicoverpa armigera* (Hübner) (Old World Bollworm). Washington, D.C.: Government Printing Office. http://www.aphis.usda.gov/import_export/plants/manuals/online_manuals.shtml

Seasonal abundance patterns of bollworm, tobacco budworm, and beet armyworm moths in the Texas High Plains

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

INTRODUCTION

A long-term study (16 years and continuing) has been conducted in the southern Texas High Plains (THP) region to investigate the year-around weekly moth flight activity patterns of cotton bollworm, *Helicoverpa zea* (Boddie), tobacco budworm, *Heliothis virescens* (F.), and beet armyworm, *Spodoptera exigua* (Hübner).

These three species are important cotton pests in the southern Texas High Plains, which is recognized as the most intensive cotton growing region of the world (Fig. 1). In this region, the bollworm is classified as an important economic pest while the tobacco budworm and beet armyworm are classified as occasional pests.

The regional adoption of cotton and corn crop cultivars incorporating *Bt* technology has been instrumental in reducing the current threat of these lepidopteran pests yet diminishing underground water availability for irrigation is necessitating vigilant economic cost/benefit evaluations of high-cost crop inputs, such as genetically modified seeds, for our increasing dryland/limited irrigation crop production acreage.

MATERIALS & METHODS

Study Duration: March 2002 to Present (continuing); **Study Sites:** Lubbock County, Texas

Pest Species Monitored: Cotton bollworm, tobacco budworm, and beet armyworm

Survey Protocol: Nine pheromone traps [3 lepidopteran species monitored X 3 study sites] were placed in Lubbock County representing the approximate center of the southern Texas High Plains. The three sites were selected and one trap for each pest species was placed, then baited and monitored weekly (growing season) to twice monthly (non-crop months) throughout the year. Trap types included: 1) Texas pheromone trap (Hartstack et al. 1979) for bollworms and tobacco budworms, and 2) Bucket traps (green) for beet armyworms. The three species-specific pheromone lure types were secured from a single source (Trece®, Inc., Adair, OK). Bollworm and tobacco budworm pheromone lures were replaced approximately every two weeks, while *beet armyworm* pheromones were replaced monthly. GPS coordinates for each of the three selected Lubbock County trapping sites were recorded along with the weekly/bimonthly trap captures.

RESULTS & DISCUSSION

Seasonal abundance and flight patterns of cotton bollworm, tobacco budworm, and beet armyworm moths were determined based upon captures in pheromone traps monitored all months of the year (Parajulee et al. 1998, 2004). For each species, the ongoing trapping study has been sub-divided into four successive periods, including: 1) 2002-2005, 2006-2009, 2010-2013, and 2014-2017, roughly representing boll weevil eradicated and beginning of *Bt* cotton adoption in THP, low *Bt* cotton acreage (<50%), majority *Bt* cotton (70%), and the most recent 4-year period, respectively.

Cotton Bollworm. The cumulative annual number of bollworm moths captured per trap averaged 10,618, 7,970, 4,071 and 3689 for 2002-2005, 2006-2009, 2010-2013, and 2014-2017, respectively. The observed trend suggests a decreasing, yet high bollworm numbers during years 2002 to 2009, followed by a leveling-off of numbers beginning in 2010 to the present. Fig. 3 (top-left panel) clearly illustrates this trend of decreasing trap captures during the first 8 years, followed by lower, yet relatively level, overall annual bollworm total captures (per trap) from 2010 to 2017. Interestingly, although bollworm numbers decreased over time, the seasonal flight profiles remained quite similar over the four periods.

Tobacco Budworm. The cumulative annual number of tobacco budworm moths captured per trap averaged 953, 87, 209 and 247 for 2002-2005, 2006-2009, 2010-2013, and 2014-2017, respectively. Higher numbers of tobacco budworm moths were trapped during the early 2002-2005 period and then numbers decreased and have remained fairly low in the past 12 years with the exception periods for peak flight from late August through September (Fig. 1, top-right). Although the number of trapped budworm moths varied between the four defined periods, the overall flight activity patterns had somewhat similar profiles with activity starting in late April, peak activity during early August to early October and most trap response ending by late October.

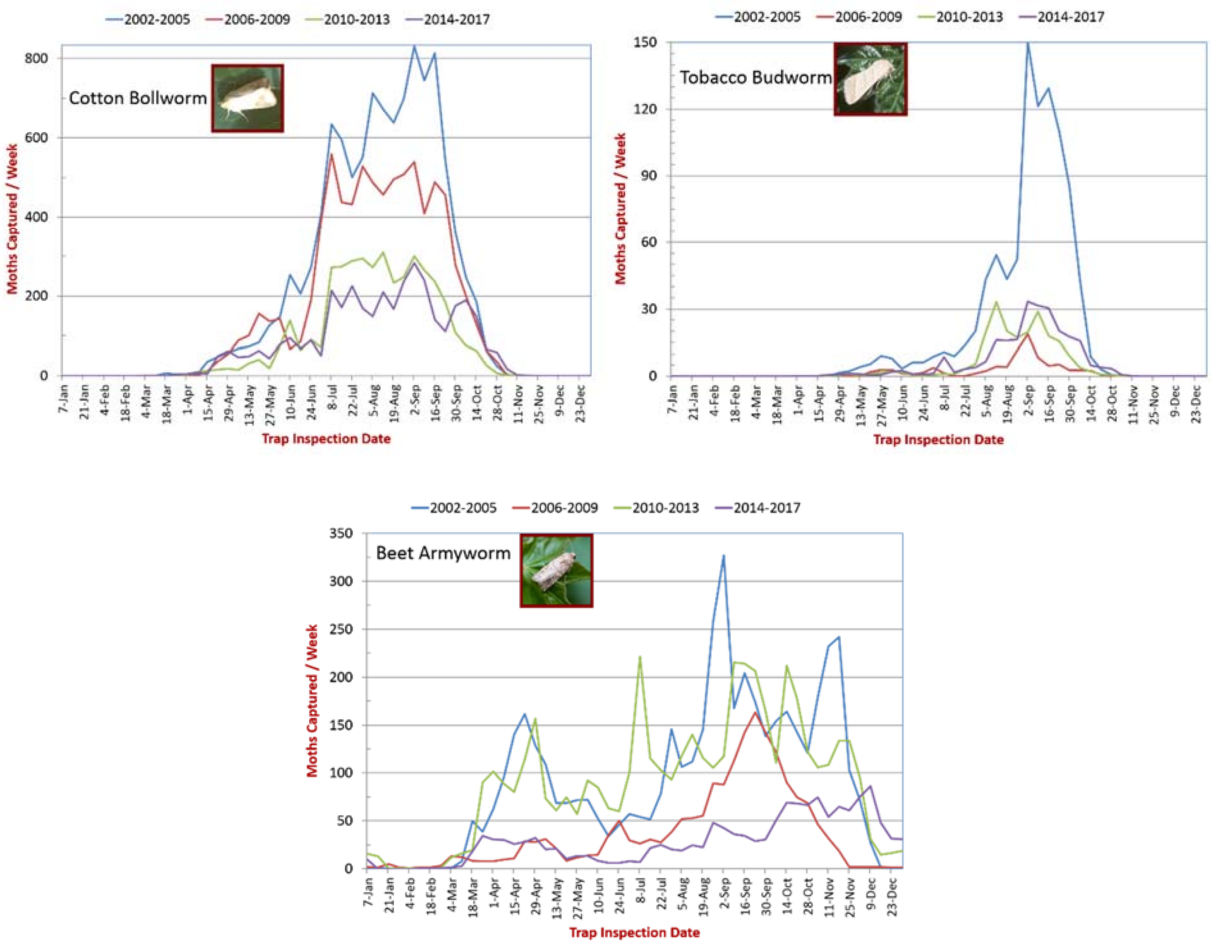


Figure 1. Number of bollworm (top-left), tobacco budworm (top-right), and beet armyworm (bottom-center) moths captured per week, averaged across four selected consecutive-year groupings spanning the 16-year study, Lubbock County, TX, 2002-2017.

Beet Armyworm. The cumulative annual number of beet armyworm moths captured per trap averaged 4,651, 1,790, 4,593, and 1090 for 2002-2005, 2006-2009, 2010-2013, and 2014-2017, respectively. Although beet armyworm moths were often captured during all months of the year, they were primarily active during the period of mid-March to early December (Fig. 1, bottom-center panel). Unlike decreasing bollworm and tobacco budworm numbers since the beginning of the study, no obvious population trends are evident. For example, high cumulative trapped beet armyworm numbers were observed during two separate periods of 2002-2005 and 2010-2013. The lowest numbers have been observed during the most recent years (2014-2017).

Influence of annual rainfall on moth abundance and flight profiles. Within the 16-yr study period, cumulative annual rainfall ranged from 5.7-in. to 33.3-in. The two years with the lowest rainfall were 2003 (8.8-in.) and 2011 (5.7-in.), while the two highest rainfall years were 2004 (33.3-in.) and 2015 (29.5-in.). For each pest species, the seasonal abundance and flight profiles are plotted for the two highest and two lowest rainfall years (Fig. 2).

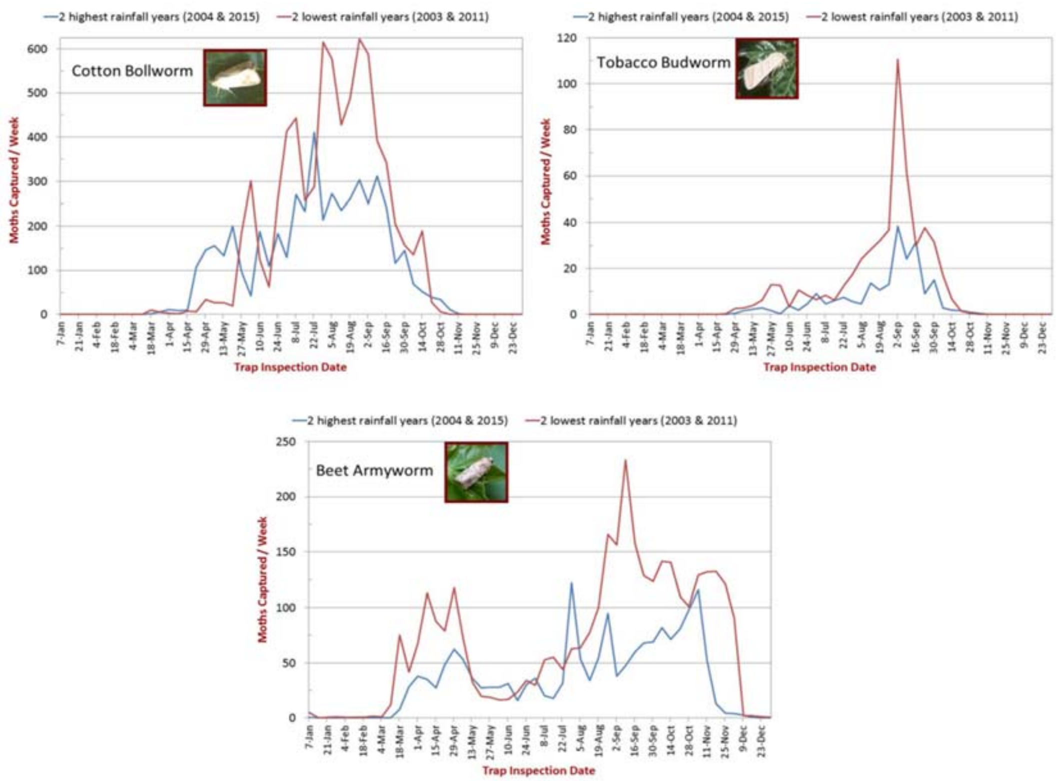


Figure 2. Cotton bollworm (top-left), tobacco budworm (top-right), and beet armyworm (bottom-center) moth seasonal flight profiles averaged for: 1) Two study years with the highest rainfall (2004 & 2015), and 2) Two lowest rainfall years (2003 & 2011). Lubbock County, 2002-2017.

*Cotton Bollworm***.** The overall timing of the flight profiles were similar between high and low rainfall years, except in regard to the magnitude of the peak numbers of moths captured (Fig. 2, top-left panel). The highest cumulative number captured per trap per year was 7,254 for the low rainfall years, while the numbers in highest rainfall years declined by 31.0% to 5,005 moths.

*Tobacco Budworm***.** Again, the overall timing of the flight profiles was similar between high and low rainfall years, but more budworm moths were captured during the low rainfall years (Fig. 2, top-right panel). The highest cumulative number captured per trap per year was 533 for the low rainfall years, while the cumulative number in the highest rainfall years declined by 58.5% to 221 moths.

*Beet Armyworm***.** During the low rainfall years, the beet armyworm flight profiles started earlier and also extended later into the early winter period as compared to the flight active periods observed during the high rainfall years (Fig. 2, bottom-center panel). The highest cumulative number of beet armyworm moths captured per trap per year was 3,398 for the low rainfall years, while the numbers in highest rainfall years declined by 47.8% to 1,773 moths.

ACKNOWLEDGMENTS

Funding for this study was provided by Texas A&M AgriLife Research Hatch Project 8810. We acknowledge and thank Bill and Donna Lingren (Trece™, Inc.) for their support of this long-term trapping study.

REFERENCES

Hartstack, A. W., Jr., J. A. Witz, and D. R. Buck. 1979. Moth traps for the tobacco budworm. J. Econ. Entomol. 72: 519-522.

Parajulee, M.N., J.E. Slosser, and E.P. Boring. 1998. Seasonal activity of *Helicoverpa zea* and *Heliothis virescens* (Lepidoptera: Noctuidae) detected by pheromone traps in the Rolling Plains of Texas. Environ. Entomol. 27:1203-1219.

Parajulee, M.N., D.R. Rummel, M.D. Arnold, and S.C. Carroll. 2004. Long-term seasonal abundance of *Helicoverpa zea* and *Heliothis virescens* (Lepidoptera: Noctuidae) moths in the Texas High Plains. J. Econ. Entomol. 97:668-677.

Efficacy of Insecticide Seed Treatments to Thrips on Cotton and Fleahopper Response to Selected Cotton Varieties in Texas

Robert Bowling, Michael J. Brewer, Megha N. Parajulee, Suhas Vyavhare, Greg Sword, Charles Allen, Blayne Reed, Kerry Siders, Brad Easterling, Tommy Doederlein, Stephen Biles, Danielle Sekula-Ortiz, and Jane Pierce

Performing Institution: Texas A&M AgriLife Extension; Texas A&M AgriLife Research

In Texas, achieving cotton production goals often is dependent on managing pre-flowering insect pests such as thrips, cotton aphid, whiteflies, and fleahoppers and stink bugs later in the season. Thrips feeding in the terminal bud of cotton cause leaves to have a crinkled, tattered appearance as they expand and heavily damaged foliage often is stunted and curls upward at the margins. Another characteristic of thrips damage is a silvery appearance of leaves at the feeding sites.

Early-season pest management in cotton was primarily achieved with an in-furrow treatment of aldacarb (Temik®). In 2010 the Environmental Protection agency and Bayer CropScience reached an agreement to terminate production and use of aldicarb in the United States (EPA Newsroom, 2010). Consequently, achieving cotton production goals has required adoption of alternative practices for early-season pest management. Neonicotinoid insecticide seed treatments have become the primary solution to managing early-season pests of cotton in Texas. Thiamethoxam and imidacloprid are two common systemic insecticide seed treatments applied to commercial cotton seed. They are relied on to provide protection from early-season cotton pests in Texas. Although the two insecticides belong to the same insecticide group, their physical and chemical properties vary and they may exhibit differential mortality among target pests, especially under extreme variations in Texas cotton production regions.

Introduction of new management strategies, such as new insecticides in a cropping system, may lead to secondary pest outbreaks. The twospotted spider mite, *Tetranychus urticae*, is a sporadic, yet, potentially serious pest to cotton production in Texas. Although it is generally considered a late-season pest of cotton, increasing frequency of mite infestations on seedling cotton has been reported where neonicotinoid seed treatments have replaced furrow applied aldacarb (Sclar et al. 1998, Beers et al. 2005). Troxclair (2007) and Smith et al. (2013) reported cotton with thiamethoxam and imidacloprid seed treatments had a higher percentage of plants with twospotted spider mites than those treated with aldicarb or untreated cotton. Smith et al. (2013) noted that a larger mite density on neonicotinoid treated cotton was the result of deleterious effects to predators with no effect on mites.

Cotton fleahopper, *Pseudatomoscelis seriatus* (Reuter) (Hemiptera: Miridae), is another key insect pest of cotton with induced yield loss estimates of 0.4% over the past decade and was the leading cause of yield loss due to insect damage in Texas during 2012-2013 (Williams 2011). The cotton fleahopper can cause excessive loss of cotton squares resulting in reduced yield and harvest delays (McLoud et al. 2015). Damage to individual fields may vary from none to extremely high square loss when heavy populations develop and are left uncontrolled. The reason for variability in losses caused by the cotton fleahopper is not understood but may, in part, be associated with cultivar differences (Holtzer and Sterling 1980, Barman et al. 2012). Understanding cotton fleahopper response to cotton varieties will allow better management strategies for managing this pest on cotton.

The objectives of the current research were to determine the efficacy of neonicotinoid insecticide seed treatments to manage thrips on seedling cotton to evaluate cotton fleahopper populations on selected cotton varieties to determine if colonization differs among varieties with unique genetic backgrounds and determine if fleahopper damage differs among varieties and if this damage influences yield.

Materials and Methods

Thrips study. Cotton seeds treated with two different neonicotinoid insecticides (imidacloprid and thiamethoxam) were used to evaluate their efficacy against thrips on seedling cotton at multiple TX locations. Seeds of FM1900GLT, a widely-adapted cotton variety, was separately treated with imidacloprid and thiamethoxam. An additional seed treatment, including the check with no insecticide seed treatment, consisted of a base fungicide for protection against fungal pathogens. Five cotton producing regions were selected for the placement of seed treatment trials including the Texas High Plains (3), Rolling Plains (1), Blacklands (1), Lower Rio Grande Valley (1), and Coastal Bend (2) regions. In each region, 1-3 locations were chosen to conduct the seed treatment trials. Site selection were based on the historical early-season population pressure and experience of the local collaborator. A trial consisted of three different treatments (two insecticide seed treatments and one untreated control), replicated four times. Planting dates were adjusted per recommendations for respective production regions. After planting and seedling emergence, thrips counts were made and several plant parameters were recorded. A washing method (Burris et al., 1989) was used to determine thrips populations instead of a visual sampling method to reduce the sampling variability. Plant samples were collected at four different time period/growth periods; cotyledon, 2-leaf, 3-leaf, and 4-leaf stages. For each sampling date and experimental plot, 10 randomly selected cotton seedlings of each respective growth stage, were cut above the soil and preserved in a quart size glass jar, half-filled with 75% ethanol. The samples were brought to the laboratory and processed to extract the thrips (both adults and immatures) for each sampling date. Adult and nymph counts were recorded separately for each plot and at each location. Later in the season, delays in plant maturity were assessed by counting nodes above white flower (NAWF). Yield data were obtained from the successful test sites.

Fleahopper Evaluations: Four cotton varieties, Stoneville ST4946 (Bayer), DeltaPine DP1219 (Monsanto), Phytogen Phy333 and Phytogen PHY444 (Dow), were planted at multiple TX locations and one site in New Mexico. Varieties DP1219 and Phy444 are smooth-leaf and

ST4946 and PHY33 are hairy-leaf varieties. Cotton fleahoppers were sampled weekly beginning at pinhead square to 1/3 grown squares using the beat bucket technique. Samples were taken from the middle two rows of four row plots by folding over 2-5 plants per sub-sample into a 5 gallon bucket, beating the plants onto the side of the bucket, and immediately counting the cotton fleahoppers. This procedure was continued moving up the middle of the 2 center rows alternating rows with each sub-sample until a total of 25 plants per plot were sampled. Cotton fleahopper counts were divided into adults and nymphs. Sampling for cotton fleahopper was discontinued after the first or second week of bloom.

Corpus Christi: One week following first bloom, cotton fleahopper injury was evaluated on each of 6 plants in one of the center two rows within each plot using PMAP. Fruiting structures match-head size and larger and abscission sites were counted on each branch and first three positions from each of the 6 plants to determine percent fruit retention. Twenty plants, ten each from rows 1 and 4, were removed from the field and bolls on each branch and first three positions to determine retention at harvest. The center two rows were harvested for yield. Cotton fleahopper counts were analyzed by date (Corpus Christi only) and variety using SAS 9.4 (SAS Institute 2013) (Corpus Christi) or ARM. In-season and harvest retention data for positions 1 and 2 combing branches 7 through 12 and yield were analyzed with SAS9.4.

Results

Thrips study: Thrips densities were low throughout the study locations in 2016. Many thrips study sites were abandoned due to crop stand failure (severe rain or hailstorms) or due to the lack of thrips existence in test plots. Thrips failed to recolonize after the rain events in many locations where thrips densities were beginning to colonize prior to the rain. In general, neonicotinoid seed treatments (imidacloprid and thiamethoxam) are expected to significantly reduce thrips populations compared to that in untreated control plots, but the lack of thrips activity failed to detect that phenomenon in our tests sites (Fig. 1). For example, only Victoria site had any meaningful number of thrips where adult thrips densities were lower in neonicotinoid treatment plots than on control plots on May 24 sampling date, but the numbers declined to below economic thresholds after that date.

Insecticide treatments significantly increased leaf area compared with that in control plots at Halfway (Texas High Plains) location for both 2015 and 2016 (Fig. 2). In 2016, thrips were not detected at the Halfway test location. Nevertheless, cotton vigor, measured in terms of total leaf area, was significantly higher in the two neonicotinoid seed treatment applied plots compared to control plots, suggesting that the seed-applied insecticide treatments may have some agronomic benefit to seedling growth even in the absence of thrips injury. More detailed study is planned for 2017 to examine the effect of these seed treatments on seedling root health. Lint yield did not vary across treatments at any of the test sites in 2016.

In 2017, thrips densities were above threshold at Lubbock location, whereas most sites were either lost due to weather events or had low thrips densities. At the Lubbock site, both neonicotinoid seed treatment options kept the thrips numbers below treatment thresholds up to three weeks, but the overspray of the seed-treated seedling cotton was not necessary even at high thrips densities (Fig. 3). Nevertheless, lint yield did not vary across treatments.

Cotton Fleahopper Assessments: Cotton fleahopper nymphs ($F_{3,53}$=0.14; P=0.9358), adults ($F_{3,53}$=0.14; P=0.9358), and the combination of the two stages ($F_{3,53}$=0.14; P=0.9358) showed no preference for smooth-leaf or hairy-leaf varieties at Corpus Christi (Table 1). Results from Victoria and Swisher counties in TX and the location in NM were similar (Fig. 3). Cotton fleahopper nymphs ($F_{1,53}$=33.52; P<0.0001), adults ($F_{1,53}$=13.24; P<0.0001), and the combination of the two stages ($F_{1,53}$=18.97; P<0.0001) differed by assessment date (Table 2).

Boll Retention and Yield: In-season plant mapping revealed differences among cotton varieties in boll retention on branches 7 through 12 for first ($F_{3,9}$=9.86; P=0.0033) and second ($F_{3,9}$=95.87; P=0.0168) position sites (Table 3). The number of first position bolls differed among cotton varieties at harvest (($F_{3,9}$=13.31; P=0.0012) but boll retention differences were not observed second position sites ($F_{3,9}$=1.66; P=0.2434) (Table 3). Yield differences occurred among cotton varieties at the location in Corpus Christi ($F_{3,9}$=18.22; P=0.0004).

Discussion

The seed treatments improved the seedling vigor even in the absence of thrips infestation compared to that in plots with no seed treatments in both years (2016 and 2017). Therefore, we plan to investigate the seedling health in relation to root growth behavior as influenced by seed treatment in 2018. While thrips-inflicted injury to seedling cotton was significant in 2017, plants fully compensated the crop growth and there was no yield penalty due to thrips damage. Nevertheless, we plan to examine if the thrips injury resulted in fiber immaturity.

Cotton fleahoppers showed no preference for hairy-leaf or smooth-leaf cotton varieties in all TX locations. This contrasts with previous research reporting cotton fleahopper was usually more abundant on pubescent cotton varieties (Schuster and Frazier 1977). These results suggest that hairy leaf varieties are not only suitable for adult cotton fleahopper but nymphs are capable of feeding and surviving on cotton with dense pubescence.

In-season and harvest assessments showed that cotton varieties classified as ‘hairy leaf’ had greater first position boll retention on branches 7 through 12 when compared with smooth leaf varieties at the Corpus Christi location. First position bolls on these branches are most vulnerable to damage by cotton fleahopper. One explanation is that hairy leaf varieties in this trial may have restricted nymphs moving from leaves to terminals where they could feed on pin-head and match-head squares. The smooth-leaf varieties in this trial would allow nymphs easy access to the terminals where they could feed and damage developing squares.

Hairy-leaf cotton varieties ST4946 and PHY333 out-yielded DP1219, one of the smooth-leaf cotton varieties in this trial. Phy333 provided significantly more lint when compared with PHY444, a smooth-leaf variety. Although lint produced by ST4946 was not statistically different from that produced by PHY444, there was a numerical advantage in lint production by the hairy-leaf cotton. The ability of the two hairy-leaf cotton varieties to retain more first position bolls than the smooth leaf varieties on branches 7–12 corresponds well with the yield advantages offered by these products. Their boll retention advantage over the smooth-leaf varieties on branches 7-12 also suggests they may interfere with cotton fleahopper nymph movement from leaves to developing squares.

Results of the 2016 research are intriguing and warrant further investigation into the possibility of hairy-leaf cotton varieties limiting cotton fleahopper damage to developing squares. In 2017 we propose to increase the number of cotton varieties evaluated to between 8 and 10 with the majority of entries hairy-leaf varieties. We also intend to double plot size from 4 to 8-rows with four rows not-treated and four rows treated with an insecticide to provide a ‘cotton fleahopper free’ sub-plot for boll retention comparisons. We also will simplify boll retention evaluations by counting only first position sites.

References

Barman A., M. Parajulee, C. Sansone, and R. Medina. 2012. Host Preference of Cotton Fleahopper, *Pseudatomoscelis seriatus* (Reuter) is not Labile to Geographic Origin and Prior Experience. Environ. Entomol. 41(1): 125-132.

Burris E., K. J. Ratchford, A. M. Pavloff, D. J. Boquet, B. R. Williams, and R. L. Rogers. 1989. Thrips on seedling cotton: Related problems and control. *Louisiana Agricultural Experiment Station Bulletin* 811. LSU AgCenter, Baton Rouge, LA.

Beers, E. H., J. F. Brunner, J. E. Dunley, M. Doerr, and K. Granger. 2005. Role of neonicotinyl insecticides in Washington apple integrated pest management. Part II. Nontarget effects on integrated mite control. *J. Insect Sci. 5*: 16.

EPA Newsroom. 2010. Bayer Agrees to Terminate All Uses of Aldacarb. 1 pp. http://yosemite.epa.gov/opa/admpress.nsf/e51aa292bac25b0b85257359003d925f/29f9dddede97caa88525778200590c93!OpenDocument.

Holtzer, T.O., and W.L. Sterling. 1980. Ovipositional preference of the cotton fleahopper, *Pseudatomoscelis seriatus*, and distribution of eggs among host plant species. Environ. Entomol. 9:236–240.

McLoud, A. M., S. Hague, A. Knutson, C. W. Smith, and M. J. Brewer. 2015. Cotton square morphology offers new insights into host plant resistance to cotton fleahopper (Hemiptera: Miridae) in upland cotton. J. Econ. Entomol. doi: 10.1093/jee/tov275.

Sclar, D. C., D. Gerace, and W. S. Cranshaw. 1998. Observations of population increase and injury by spider mites (Acari: Tetranychidae) on ornamental plants treated with imidacloprid. *J. Econ. Entomol. 91*: 250-255.

Smith, J. F., A. L. Catchot, F. R. Musser , and J. Gore. 2013. Effects of aldicarb and neonicotinoid seed treatments on twospotted spider mite on cotton. *J. Econ. Entomol.106:* 807-815.

Troxclair, N. 2007. Field evaluation of cotton seed treatments and a granular soil insecticide in controlling spider mites and other early-season cotton pests in Texas. *Integrated Control of Plant-Feeding Mites IOBC/WPRS Bull. 30*: 117-D122.

SAS Institute. 2013. Base SASVR 9.4 procedures guide. SAS Institute Cary, NC.

Williams, M. R. 2011. Cotton insect loss estimates. Depart-ment of Biochemistry, Molecular Biology, Entomology and Plant Pathology, Mississippi State University. (http://www.entomology.msstate.edu/resources/cottoncrop.asp) (accessed 21 January 2017)

Table 1: Mean number of cotton fleahopper nymphs, adults, and a combination of developmental stages on 100 plants of four cotton varieties with different trichome densities.

Variety	Mean (±SE) number of cotton fleahopper by developmental stage		
	Nymphs	Adults	Total
ST4946	9.0 ± 1.9 a	3.0 ± 0.6 a	9.0 ± 1.1 a
DP1219	7.0 ± 1.5 a	5.0 ± 1.1 a	1.0 ± 0.4 a
PHY333	8.0 ± 1.6 a	5.0 ± 1.0 a	21.0 ± 1.8 a
PHY444	8.0 ± 1.9 a	3.0 ± 0.7 a	15 ± 1.1 a

Means not followed by the same letter are significantly different (Tukey's LSD, P<0.05). Standard error of the mean is represented by SE.

Table 2: Mean number of cotton fleahopper nymphs, adults, and a combination of developmental stages on different sampling dates.

Date	Mean (±SE) number of cotton fleahopper by developmental stage		
	Nymphs	Adults	Total
5/6/2016	6.0 ± 1.0 c	3.0 ± 1.0 b	9.0 ± 1.1 c
6/1/2016	1.0 ± 0.5 d	1.0 ± 0.3 b	1.0 ± 0.4 d
6/8/2016	15.0 ± 1.6 a	6.0 ± 1.1 a	21.0 ± 1.8 a

6/16/2016	10.0 ± 0.8 b	6.0 ± 0.9 a	15.0 ± 1.1 b

Means not followed by the same letter are significantly different (Tukey's LSD, P<0.05). Standard error of the mean is represented by SE.

Table 3: Mean percent boll retention on 24 plants on each of four cotton varieties with different trichome densities. Percent retention is the total number of bolls on branches 7-12 divided by the total nuber of sites for each of positions one and two one week after flowering and at harvest.

Variety	Mean (±SE) retention (%)			
	In-Season		Harvest	
	Position 1	Position 2	Position 1	Position 2
ST4946	88 ± 4 a	78 ± 4 a	57 ± 3 a	20 ± 1 a
DP1219	68 ± 7 b	63 ± 3 ab	32 ± 6 b	22 ± 2 a
PHY333	87 ± 3 a	72 ± 4 a	63 ± 3 a	27 ± 4 a
PHY444	66 ± 4 b	48 ± 8 b	42 ± 2 b	23 ± 1 a

Means not followed by the same letter are significantly different (Tukey's LSD, P<0.05). Standard error of the mean is represented by SE.

Table 4: Mean yield (lbs/a) of four cotton varieties with different trichome densities.

Variety	Mean (±SE) yield (lbs/a)
ST4946	1008 ± 10 ab
DP1219	744 ± 38 c
PHY333	1173 ± 51 a
PHY444	912 ± 53 b

Means not followed by the same letter are significantly different (Tukey's LSD, P<0.05). Standard error of the mean is represented by SE.

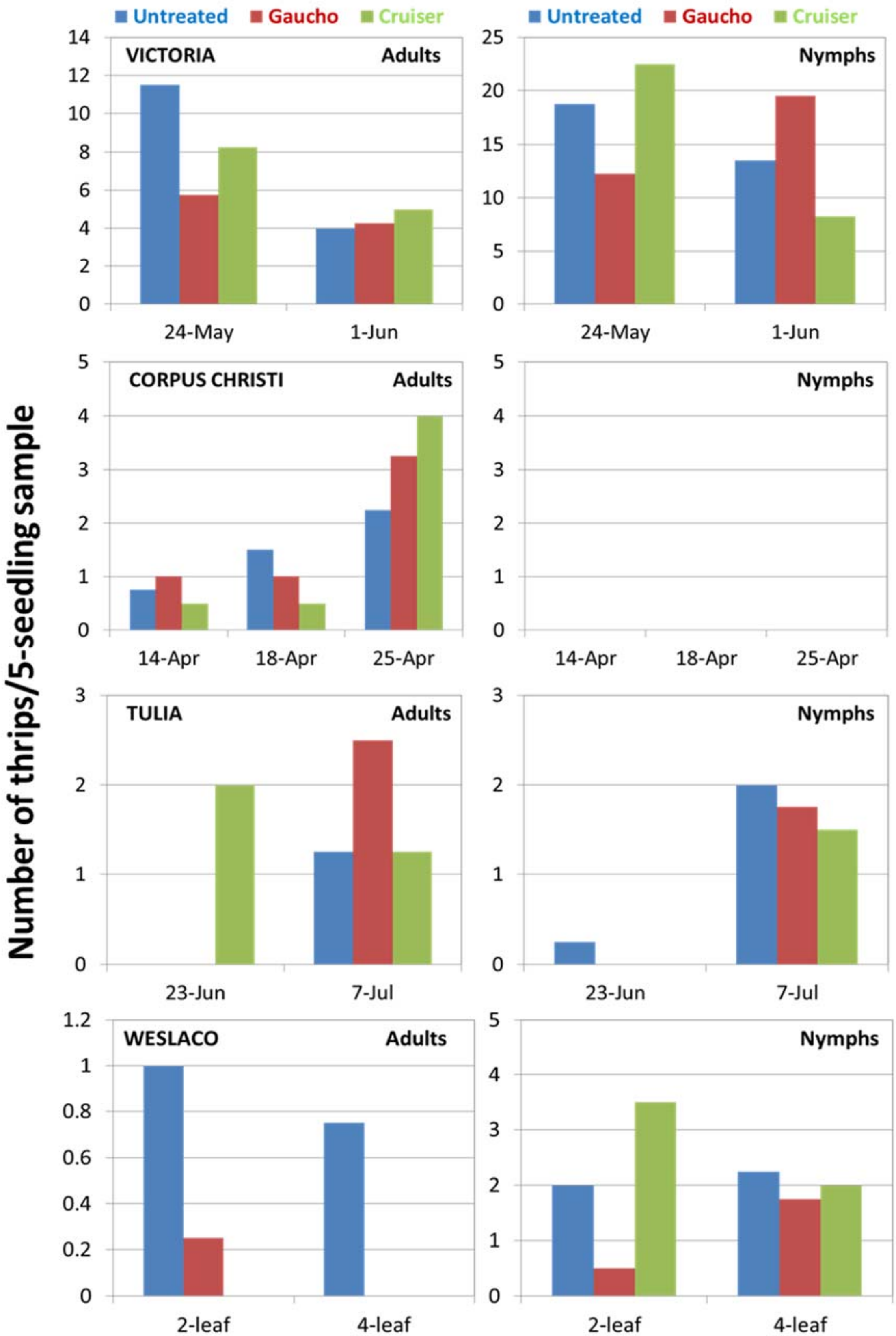


Fig. 1. Number of thrips per 5-seedling sample at various thrips study sites in Texas, 2016.

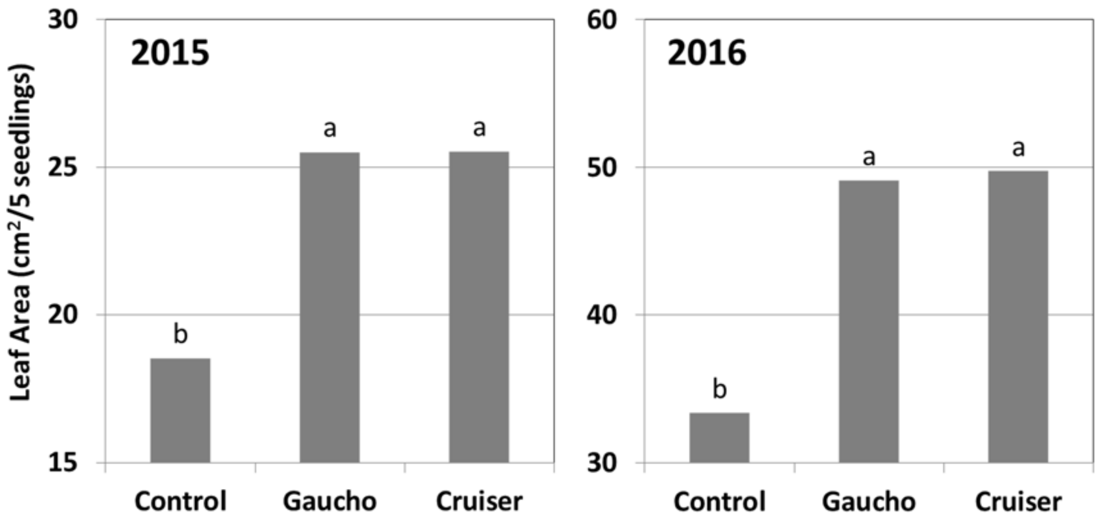


Fig. 2. Seedling vigor, measured in terms of total leaf area per 5-seedling sample, affected by neonicotinoid seed treatments, Halfway (Texas High Plains), Texas, 2015-2016.

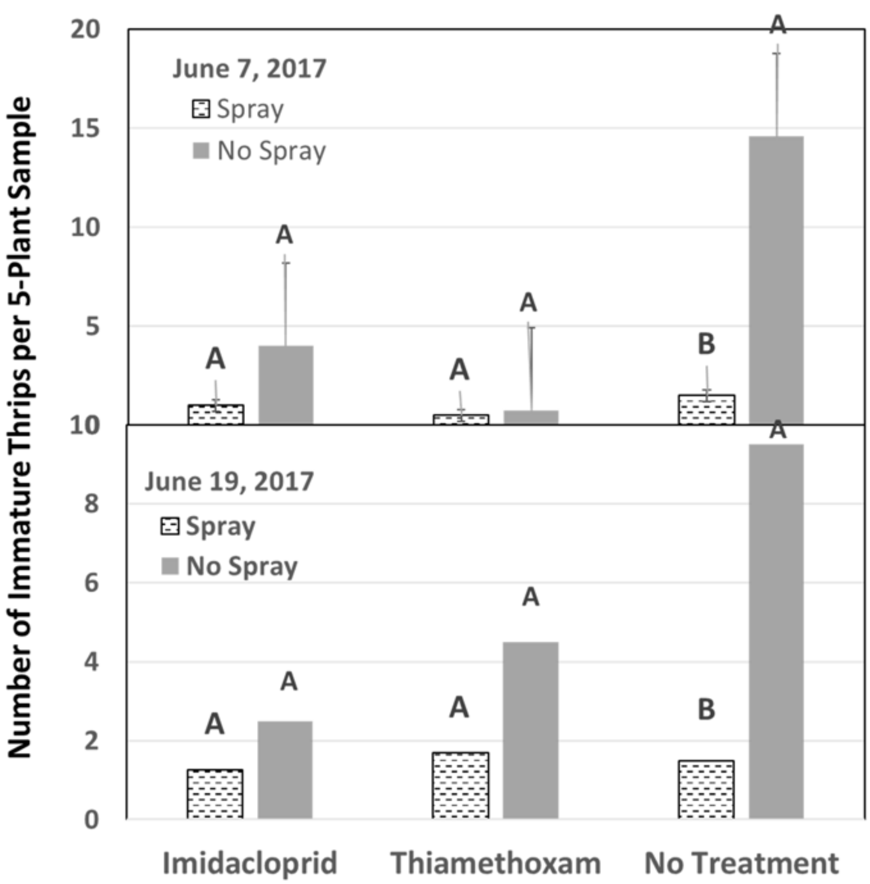


Fig. 3. Number of immature thrips per 5-seedling sample at two sample dates based on absolute sampling and thrips washing technique, Lubbock, Texas, 2017.

IMPACT OF NITROGEN FERTILITY ON COTTON RESPONSE TO COTTON FLEAHOPPER-INDUCED INJURY

M. N. Parajulee
A. Hakeem
Texas A&M AgriLife Research
Lubbock, TX

Abstract

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. A three-year (2014-2016) study evaluated the impact of five nitrogen fertility rates on cotton response to cotton fleahopper-induced injury in the Texas High Plains. The five main-plot treatments included pre-bloom side-dress applications of augmented nitrogen fertilizer rates of 0, 50, 100, 150, and 200 lbs N/acre using a soil applicator injection rig. The sub-plot treatment included two cotton fleahopper augmentation treatments [5 cotton fleahopper nymphs (2014, 2016) or adults (2015) per plant versus no fleahopper augmentation as control] applied to each of the five nitrogen fertility rates two weeks into cotton squaring, the most critical phenological stage of cotton for cotton fleahopper management in the Texas High Plains. The infestations were designed to exert 20-25% square abscission. Cotton fleahopper induced fruit loss resulted in significant crop maturity delay in 2014, as measured by number of unopened bolls (7.7% non-harvestable bolls in the infested plots versus 1.8% in control plots) at harvest. There was no maturity delay penalty in 2015 or 2016 due to an unseasonably warmer fall each year. As expected, lint yield varied with N level regardless of the cotton fleahopper infestation in all three years. In uninfested control plots, lint yield displayed a characteristic staircase effect of nitrogen rate, with lowest lint yield in zero N and highest lint yield in 200 N treatments, with numerical increase in lint yield for each incremental nitrogen application of 50 lb/acre. Combined over all N treatments, the acute infestation of cotton fleahoppers rendered the lint yield reduction from 975 and 910 lb/acre in the uninfested control to 846 and 877 lb/acre in fleahopper augmented treatments in 2014 and 2015, respectively. In both years, cotton lint yield was not significantly affected by ~25% fleahopper-induced square loss three weeks into squaring at both zero N and 200 lb/acre plots, either via insect-induced pruning of undesirable fruit load (zero N) or compensation (200 lb N), whereas lint yield was significantly lower in fleahopper augmented 100 lb/acre plots compared to that in uninfested plots, clearly suggesting that the plant response to cotton fleahopper injury is greatly influenced by nitrogen fertility. In addition, plants fully compensated for manually pruned 100% square removal at the onset of cotton flowering.

Introduction

The cotton fleahopper 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). Both adults and immatures feed on new growth, including small squares. Greater damage is observed on smooth leaf varieties than on hirsute varieties (Knutson et al., 2013), which may extend the susceptible period into early bloom, especially under a high-input production regime. Cotton is affected by cotton fleahopper injury from about the fifth true-leaf through the 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 (Reinhard, 1926). 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 (Chen et al., 2007).

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 (Parajulee et al., 2006, Chen et al., 2007). Cotton plant growth is sensitive to numerous environmental and management input factors, particularly irrigation and nitrogen fertility. 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 under a range of nitrogen fertility remain uninvestigated. This study was designed to evaluate the cotton crop growth parameters and lint yield following cotton fleahopper acute infestations under a range of nitrogen fertility rates.

Materials and Methods

The study was conducted at the Texas A&M AgriLife Research farm near Plainview, Texas. A 5-acre subsurface drip irrigation system has been in place for 16 years and nitrogen fertility treatments have been applied in a randomized block design with five replications since 2002 (Fig. 1). The present study utilized the same experimental set up as for the last 13 years. The field did not receive pre-plant fertility applications.

0	50	200	50	200
100	100	0	100	50
200	150	50	150	0
50	200	100	200	100
150	0	150	0	150

Figure 1. Helms Farm nitrogen study experimental plot layout following a five-treatment x five-replication randomized block design. Annually, each of the 25 plots received one of the five nitrogen augmentation treatments including 0, 50, 100, 150, or 200 lbs N/acre, Hale County, TX.

The experimental field was planted with FiberMax 9063B2R (June 16, 2014), Fibermax 9180 B2F (May 18, 2015), and FM1900GLT (May 27, 2016) at a targeted rate of 54,000 seeds/acre followed by an 'over-the-top' Caparol® 4L (prometryn; 3 pints/acre) application immediately after planting, with post-emergence herbicide applications of RoundUp® @ 32 oz/acre and Warrant® 3 pt/acre for weed management.

Soil residual nitrogen was monitored annually by taking three 24-inch core samples from each plot (Fig. 2). The 0-12 inch portions of each core were combined to form a single, composite soil sample, and likewise, the 12-24 inch portions were combined, resulting in two samples per experimental plot. Samples were sent to Ward Laboratories, Kearny, Nebraska for analysis.

Figure 2. A) Annual pre-season soil sampling of 25 sub-surface drip irrigated cotton plots; B) Annually near the time of first bloom, each plot received the same side-dressed nitrogen application treatment rate; C) Differential cotton plant growth responses are often visually apparent between plots receiving high and low N application rates, Hale County, TX.

Two 10-ft. sections of uniform cotton were flagged in the middle two rows of each 16-row main-plot that served as two insect treatment sub-plots (2014 and 2015) and three 10-ft sections in 2016 to accommodate for manual removal treatment. The sub-plot treatments included two cotton fleahopper augmentation treatments (5 cotton fleahopper nymphs per plant uncaged [2014] or 5 cotton fleahopper adults per plant in multi-plant cages [2015] and manual removal of 100% squares around the onset of cotton flowering stage [2016] versus no fleahopper augmentation or manual removal of squares as control) applied to squaring cotton within these designated row sections to simulate an acute infestation of cotton fleahoppers. This early squaring period is the most critical phenological stage of cotton for cotton fleahopper management in the Texas High Plains (Parajulee et al., 2006).

Cotton fleahoppers were reared in the laboratory from the overwintered eggs laid by reproductive females in woolly croton (Hakeem and Parajulee, 2015). The single release of cotton fleahoppers (nymphs in 2014 and 2016; adults in 2015) mentioned above 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. It was planned so that this arrangement would ensure 20-25% fleahopper-induced square damage on treatment plots. Seven days after cotton fleahopper augmentation, the entire test was sprayed with Orthene 97UP at 12 oz acre. In all three years, the entire test was kept virtually pest-free for the remainder of the crop-season to isolate the effect of cotton fleahopper injury only. Additional data collected included monitoring of plant height, plant biomass, root and shoot lengths, leaf chlorophyll content, leaf nitrogen content, and squaring patterns in all experimental units, starting from the first week of squaring (pre-release data) and approximately weekly thereafter well into the fall crop developmental period (Fig. 3). Final plant mapping and harvesting of test sections were performed after chemically-induced crop termination. Hand-harvested yield samples were obtained from each plot. Fiber samples were analyzed for lint quality parameters at the Cotton Incorporated Fiber Testing Laboratory (North Carolina). Data were analyzed using ANOVA and least significant differences separated the means at α=5%.

Figure 3. A) Blower sampling for arthropods, B) Processing of arthropod samples in the laboratory, C) Measuring leaf chlorophyll, D) Whole-plant sample collection for parameter estimation, E) Measuring leaf area, plant root and shoot biomass, F) cotton harvesting.

Results and Discussion

In all three study years, soil residual N levels were significantly higher in plots that received the two highest application rates of N fertilizer versus plots receiving lower-rate N applications or no N augmentation (Fig. 4). For each year, the highest N augmentation plots (200 lb/acre) had highest average residual N, at least numerically. Plant dry biomass followed the trend of residual N profile with respect to nitrogen-augmentation rates (Figs. 4-5). Measured leaf chlorophyll content varied with nitrogen application level, and leaf chlorophyll contents from cotton in those plots which received 0 lb N/acre or 50 lb N/acre were significantly lower than all others (Fig. 6). Cotton in plots which received the three highest nitrogen application rates (100, 150, and 200 lb N/acre) exhibited relatively consistent leaf chlorophyll readings (Fig. 6). Leaf area and leaf N content followed a similar trend as for leaf chlorophyll readings, indicating that all plant growth parameters were affected by the rates of N augmentation.

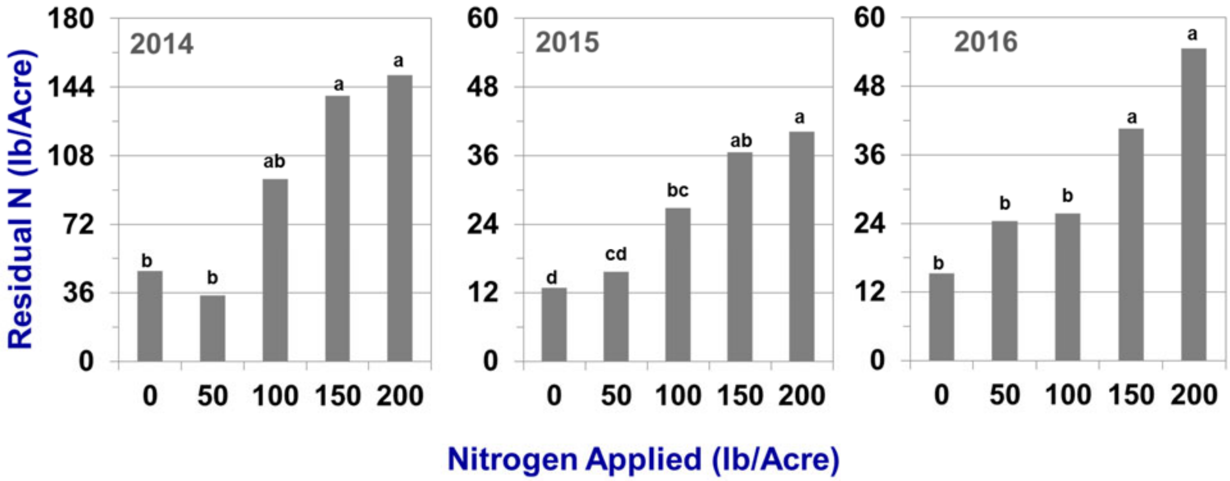


Figure 4. Effect of prior year's N application (0, 50, 100, 150, and 200 lb per acre) on residual N accumulation for the current crop year.

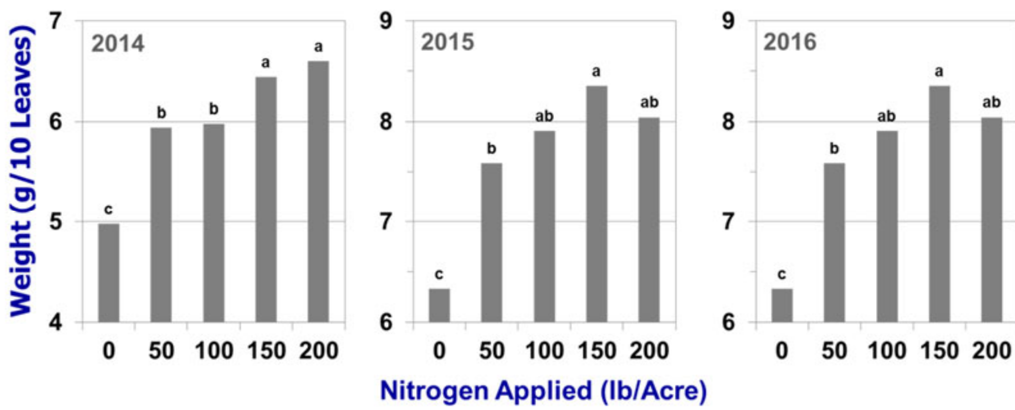


Figure 5. Effect of residual N from the previous crop year on plant dry biomass during the early crop growth period in succeeding years.

Nitrogen fertility level influenced boll maturity. Bolls in zero applied N plots tended to mature significantly earlier than in N augmented plots. Laboratory measurement of boll exocarp penetrability showed that bolls from zero N augmented plots required significantly greater pressure to puncture the exocarp versus that required to do so for bolls from N augmented plots. Variation in soil residual N levels, coupled with variable N application, resulted in phenotypic expression of nitrogen deficiency in cotton across treatment plots, especially between zero N plots and N augmented plots (Fig. 2).

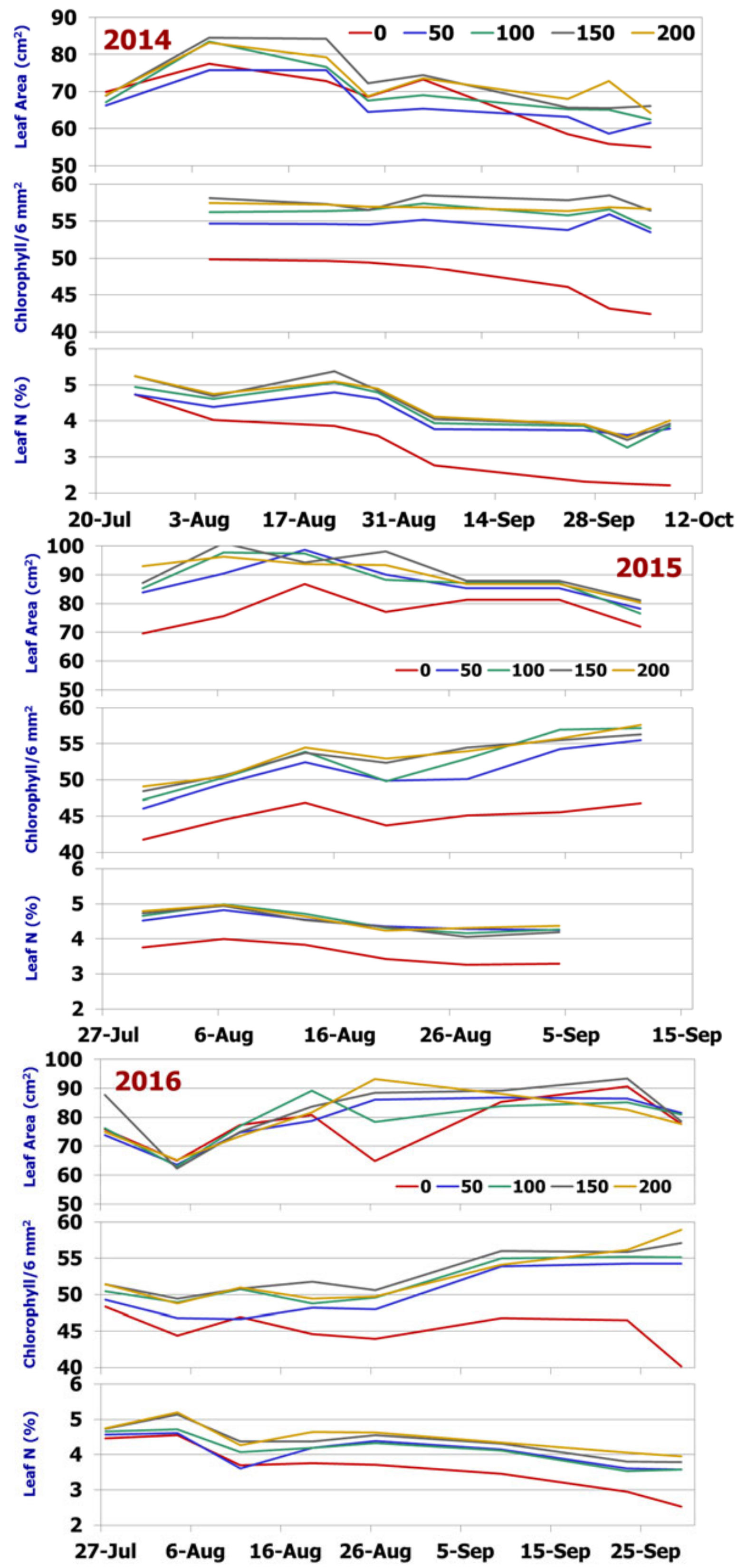


Figure 6. Temporal dynamics of leaf growth (leaf area), chlorophyll concentration, and percentage leaf nitrogen content measured on fifth mainstem leaf as influenced by the variable rates of augmented nitrogen (lb N/acre).

One week of cotton fleahopper infestation resulted in significant square abscission in cotton fleahopper augmented plots, but negligible square abscission (2-4% or less) was observed in uninfested control plots. While total square density did not vary across N treatments, cotton fleahopper-induced square abscission levels varied significantly (14-27%) with N application rates in 2014, but it did not vary across N treatments in 2015 or 2016. In general, higher N rate favored lesser impact of cotton fleahopper injury in 2014. In 2015 and 2016, square abscission rates were similar at ~25% across all N treatments.

As expected, lint yield varied with N level regardless of the cotton fleahopper infestation (Figs. 7-8). In uninfested control plots in 2014, lint yield displayed a characteristic staircase effect of nitrogen application rate, with lowest lint yield (862 lb/acre) in zero N and highest lint yield (1,081 lb/acre) in 200 N treatments, with numerical increase in lint yield for each incremental nitrogen application of 50 lb/acre. In 2015, all N augmented plots had higher lint yield than on zero N plots, but the crop response to variation in N density was not well defined. Combined over all N treatments, the acute infestation of cotton fleahoppers rendered the lint yield reduction from 975 lb/acre and 910 lb/acre in the uninfested control to 846 lb/acre and 877 lb/acre in fleahopper augmented treatments in 2014 and 2015, respectively. In both years, cotton lint yield was not significantly affected by ~25% fleahopper-induced square loss three weeks into squaring at both zero N and 200 lb/acre plots, either via fleahopper-induced pruning of undesirable fruit load (zero N) or compensation (200 lb N). On the other hand, lint yield was significantly lower in fleahopper augmented 100 lb N/acre plots compared to that in uninfested plots, clearly suggesting that the plant response to cotton fleahopper injury is greatly influenced by the availably of nitrogen fertility.

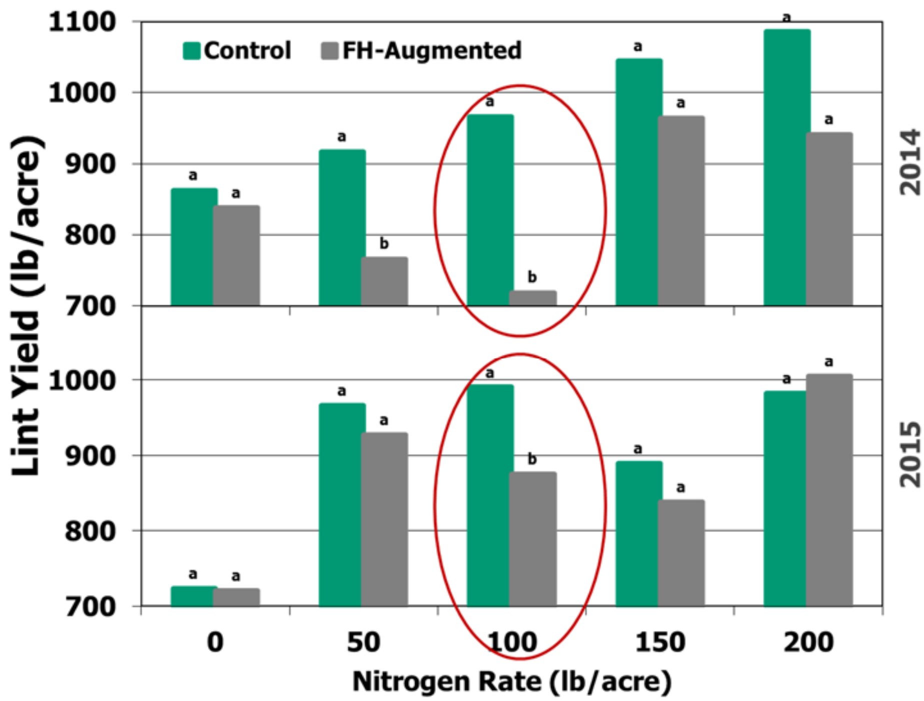


Figure 7. Effect of nitrogen augmentation rates (0, 50, 100, 150, and 200 lb per acre) on cotton lint yield following a single acute infestation of cotton fleahopper versus uninfested control, 2014-2015, Hale County, TX.

In 2016, lint yield was significantly lower in zero-N plots compared to all other N-augmented plots in uninfested control treatment. Manual removal of squares around the onset of first flowering stage of cotton did not negatively impact the final lint yield (Fig. 8). On the other hand, approximately 25% square loss due to cotton fleahopper injury reduced lint yield across all N treatments. A significant reduction was observed at 50 N plots as was the trend in previous years (50 and 100 lb treatments in 2014 and 100 lb treatment in 2015), further validating that the plant response to cotton fleahopper injury is significantly influenced by the availably of nitrogen fertility.

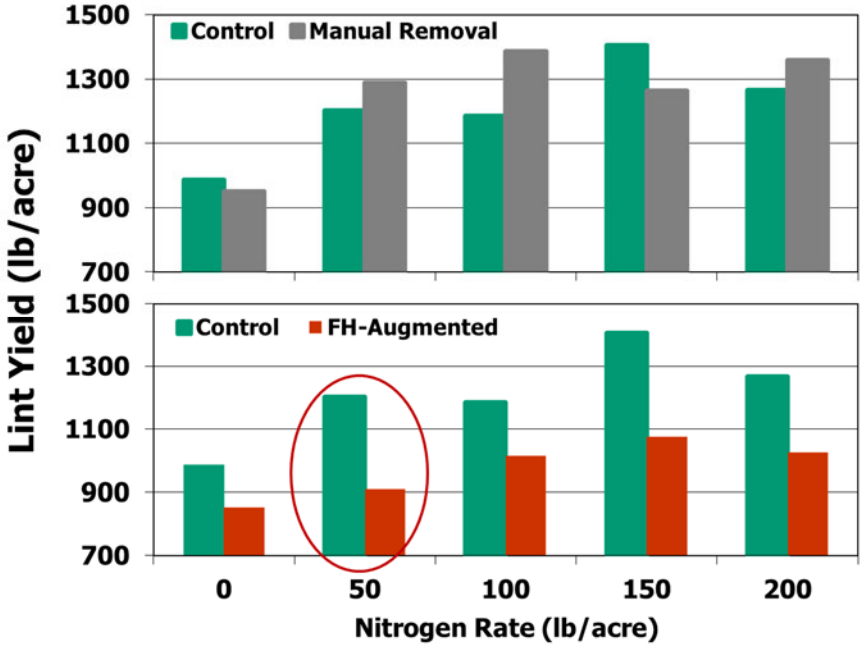


Figure 8. Effect of nitrogen augmentation rates (0, 50, 100, 150, and 200 lb per acre) on cotton lint yield following a manual removal of 100% of the squares up to the pre-flower stage of cotton versus control plants (above) and single acute infestation of cotton fleahopper versus uninfested control (below), 2016, Hale County, TX.

Acknowledgments

Cotton Incorporated Core Program and Plains Cotton Growers, Inc. have provided funding for this long-term nitrogen fertility study. Stanley Carroll, Sean Coyle, and Tahammal Hussain helped with the study.

References

Chen, C., A. K. Barman, and M. N. Parajulee. 2007. Cotton response to early square loss by the cotton fleahopper in the Texas High Plains, pp. 1662-1669. Proceedings, Beltwide Cotton Conf., National Cotton Council, Memphis, TN.

Hakeem, A., and M. N. Parajulee. 2015. Moisture conditions for laboratory rearing of cotton fleahoppers from overwintered eggs laid on woolly croton plants. *Southwestern Entomologist* 40: 455-462.

Knutson, A., K. Mekala, C. W. Smith, and C. Campos. 2013. Tolerance to feeding damage by cotton fleahopper (Hemiptera: Miridae) among genotypes representing adapted germplasm pools of United States upland cotton. J. Econ. Entomol. 106: 1045-1052.

Parajulee, M. N., R. B. Shrestha, and J. F. Leser. 2006. Influence of tillage, planting date, and *Bt* cultivar on seasonal abundance and within-plant distribution patterns of thrips and cotton fleahoppers in cotton. *International Journal of Pest Management* 52: 249-260.

Reinhard, H. J. 1926. The cotton fleahopper. Texas Agric. Exp. Sta. 57-426-12M Bull. 339, Agricultural and Mechanical College of Texas, College Station, TX.

MONITORING BOLLWORMS FOR PYRETHROID RESISTANCE, 2007-2016

Fred R. Musser
Mississippi State University
Mississippi State, MS
Jeremy K. Greene
Clemson University
Blackville, SC
David Kerns
LSU AgCenter
Winnsboro, LA
Scott D. Stewart
The University of Tennessee, WTREC
Jackson, TN
Megha N. Parajulee
Texas A&M AgriLife Research and Extension
Lubbock, TX
Gus M. Lorenz
University of Arkansas
Lonoke, AR
Moneen Jones
University of Missouri
Portageville, MO
D. Ames Herbert
Sally Taylor
Virginia Tech
Suffolk, VA
Phillip M. Roberts
University of Georgia
Tifton, GA
Dominic Reisig
North Carolina State University
Plymouth, NC

Abstract

Bollworms develop on many hosts, with each generation likely to use a different host. Pyrethroid insecticides are applied to control many pests in cotton as well as in other crops. Control of bollworms with pyrethroids has become erratic and is no longer recommended in some states. Bollworm pheromone traps were monitored from May to September in nine or ten states stretching from Virginia to Texas each year from 2007-2016. Trapped healthy male moths were tested for resistance to cypermethrin, a pyrethroid insecticide. Average survival at a rate of 5 µg/vial of cypermethrin during 2016 was 36.1%, higher than ever observed before and more than two times higher than during 2008-2013. All 10 states had survival rates greater than 20% and four states (Arkansas, Georgia, South Carolina, and Virginia) had survival rates exceeding 40%. This spread of resistance to all regions is an indication of insect movement and continued selection for pyrethroid resistance. It also suggests that resistance alleles are becoming fixed in populations and that pyrethroids should no longer be expected to provide adequate control of bollworms consistently in any regions of the southern United States.

Introduction

Bollworm, *Helicoverpa zea*, is a pest in numerous crops where it may be exposed to pyrethroid insecticides. Since it can have 5 or more generations per year in the southern U.S., it has the potential to develop large populations. One to two of these generations occur in cotton, sometimes causing substantial economic loss. Because pyrethroid insecticides are relatively inexpensive, they were traditionally the first choice of growers for foliar control of bollworms. However, control with pyrethroids has become erratic in some regions, so knowledge of the susceptibility of bollworms to pyrethroid insecticides is critical for effective management of this pest.

Monitoring pyrethroid resistance in bollworms has been conducted for numerous years, beginning in 1988 in a few states and then coordinated throughout the cotton belt in 1989-1990 (Rogers et al. 1990). Since then monitoring has continued at various levels every year. Throughout this time the methodology has remained consistent using a method developed by Plapp et al. (1987). Male moths are captured in a pheromone trap and placed in a glass vial that was previously treated with insecticide. Mortality is recorded after 24 h. A concentration of 5 µg cypermethrin / vial has been used with baseline survival generally less than 10% (Martin et al. 1999).

Materials and Methods

Hartstack pheromone traps were placed in various locations in ten states across the cotton belt from VA to TX. Pheromones (Luretape with Zealure, Hercon Environmental) were changed every 2 weeks. Some traps were monitored at least weekly from May until September, but most were monitored over a shorter period when cotton was susceptible to bollworm feeding. Healthy moths caught in these traps were subsequently tested for pyrethroid resistance. Moths were individually placed in 20 ml scintillation vials that had been previously coated with 0 or 5 µg cypermethrin per vial. Vial preparation for all locations except Louisiana was done at Starkville MS and shipped to cooperators as needed throughout the year. Louisiana data are from vials prepared in Louisiana. At all locations, moths were kept in the vials for 24 h and then checked for mortality. Moths were considered dead if they could no longer fly. Reported survival was corrected for control mortality (Abbott 1925).

Results and Discussion

A total of 8047 moths were assayed during 2016. The number of assayed moths per state range from 120 in Missouri to 1815 in Virginia. Average survival to the 5 µg cypermethrin / vial concentration was 36.1% in 2016 (Table 1), which was the highest rate of survival since monitoring began in 2007 and more than twice as high as most years (Fig. 1). The states that had been having the highest survival didn't change much in 2016, but the states that previously had susceptible populations had large increases in survival (Fig. 2), with South Carolina going from 6.4% to 43.3% survival in one year. Arkansas and Texas also saw >15% increases in survival from 2015 to 2016. For the first time since monitoring began, all states had >20% survival. The earliest tests with available data conducted during 1998-2001 did not have more than 20% survival in any state, and even as recently as 2012, this level of survival only occurred in Louisiana and Virginia. The rapid spread of resistance during the last two years suggests that the genetics of resistance have become well established, and any fitness costs associated with resistance are minor enough that these genes have spread throughout the southern United States. As a result, pyrethroid insecticides should not be expected to provide consistent, satisfactory control of bollworm populations in any region. While they may still provide control at times, efficacy will be erratic and often poor. Pyrethroids have already been removed from the list of recommended insecticides for bollworm control in Louisiana and Mississippi (Beuzelin et al. 2016, Catchot et al. 2017) and warnings about control failures due to pyrethroid resistance are included in Arkansas (Studebaker et al. 2017).

Table 1. Bollworm survival (% corrected for control mortality) to 5 µg cypermethrin per vial in 24-h vial tests during 2016.

State	May	June	July	Aug	Sep	Overall	Bollworms tested
AR	13.3	38.1	52.1	41.0		40.6	499
GA		53.1	38.2	55.6	37.3	47.8	1126
LA	30.1	29.2	51.2	28.1	25.4	32.0	1512
MS	9.8	38.6	51.4	34.1	20.6	36.6	1081
MO			20.8			20.8	120
NC				40.1	25.0	31.4	176
SC		37.5	32.3	50.5	45.2	43.3	920
TN				34.4		34.4	438
TX			38.9	25.0	28.0	30.6	360
VA		36.5	39.3	46.2	43.3	43.2	1815
Average	17.7	38.8	40.5	39.4	32.1	36.1	8047

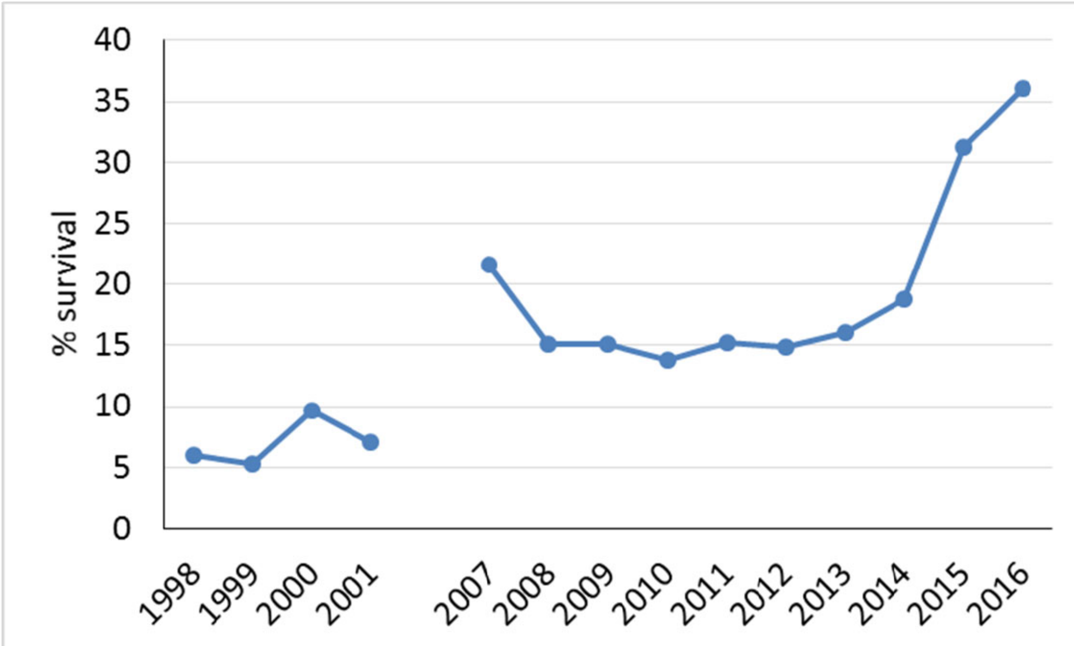


Fig. 1. Beltwide bollworm average survival per year at 5 µg cypermethrin per vial from 1998 – 2016.

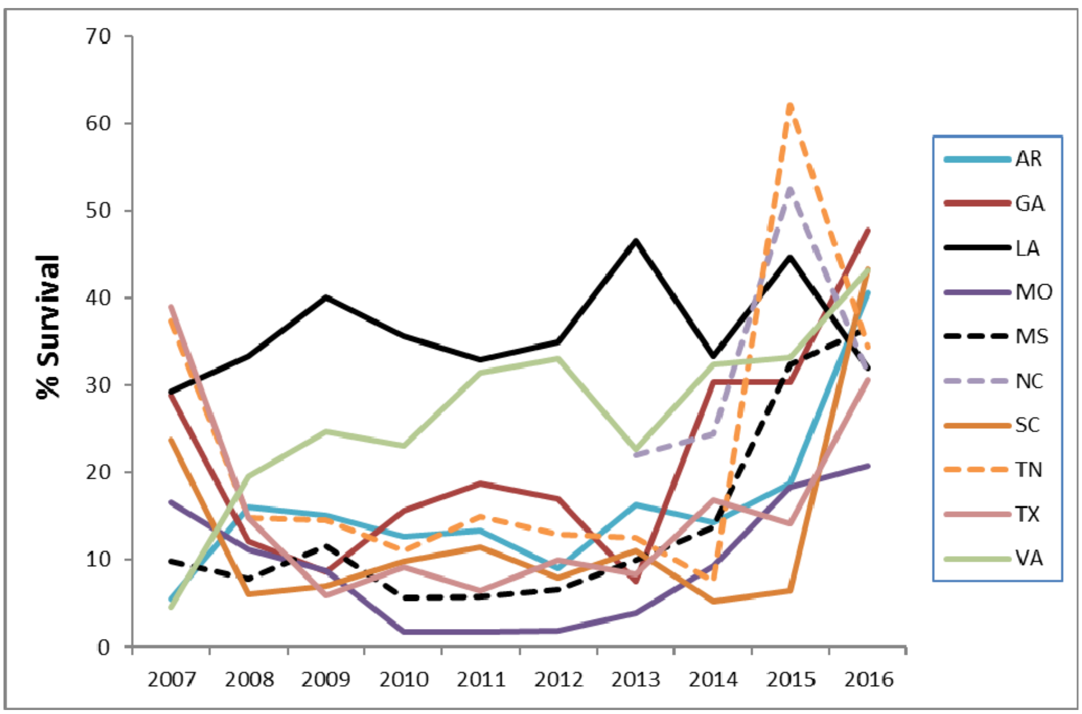


Fig. 2. Average bollworm survival by state per year at 5µg cypermethrin per vial from 2007 – 2015.

Tobacco budworm is considered resistant to pyrethroids when there is substantial survival of the moths at the 10 µg/vial concentration of cypermethrin because only moths that are homozygous for pyrethroid resistance can survive this concentration (Plapp 1987). Recent bollworm testing in Louisiana has had about 25% survival at 10 µg/vial when survival at 5 µg/vial was between 30 and 45%. This relationship of survival rates at these concentrations is similar in tobacco budworm (Plapp et al. 1987), so many of our bollworm populations throughout the southern U.S. are resistant to pyrethroid insecticides, and control from this class of chemistry will be inconsistent at best.

Bollworm adults are highly mobile (Lingren et al. 1994, Beerwinkle et al. 1995), which would suggest that pyrethroid resistance would quickly spread from one region to another. Pyrethroid resistance persisted in pockets for several years, but now appears to have become widespread throughout the cotton belt. Erratic field control of larvae observed for a number of years is consistent with this pattern of resistance development.

Moth survival has traditionally been highest during July and August. Since most larvae develop on corn during June to early July, the moths captured during late July and August mostly developed on corn, an excellent host plant for bollworm (Musser et al. 2010). As a result, bollworms can tolerate a higher concentration of insecticide. This trend continued to be observed in 2015 and 2016 when overall survival was much higher than in previous years (Fig 3).

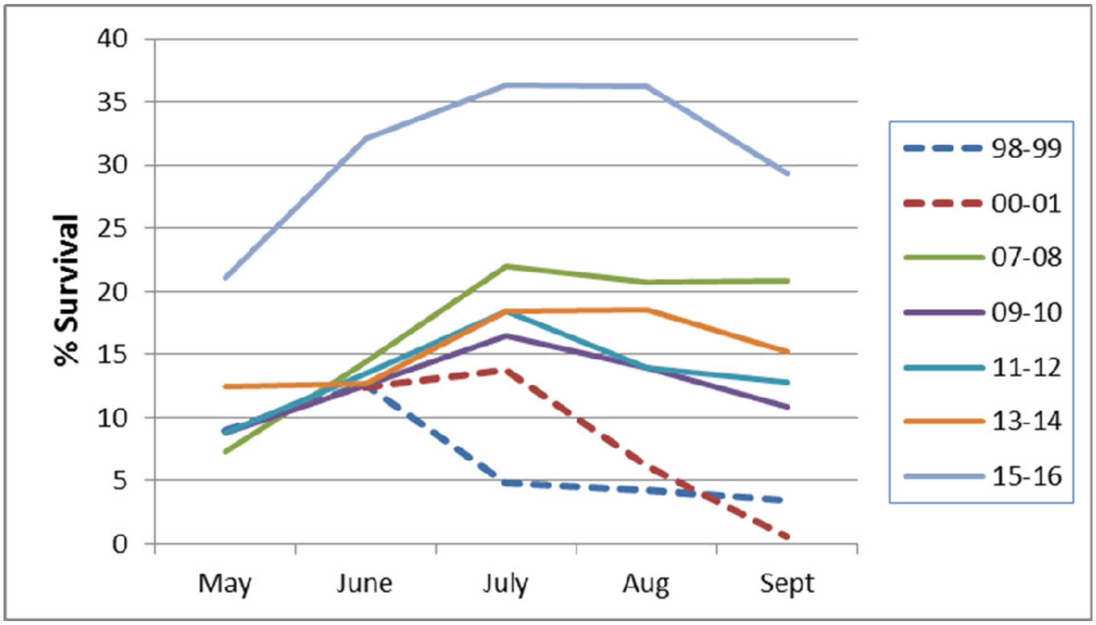


Figure 3. Average bollworm survival by month in 2-year increments at 5µg cypermethrin per vial during 1998-2001 and 2007– 2016.

Even though pyrethroids are not applied to control bollworms as frequently as in the past, there are still many pyrethroid applications made in the agricultural landscape for various pests. This sustained selection for resistance genes continues to decrease pyrethroid susceptibility, making the choice of this class of chemistry for managing bollworms a risky decision that will often result in unsatisfactory control.

Conclusions

Pyrethroid susceptibility in bollworms over the cotton belt has decreased during the last 10 years in all states. Resistance appeared first in a few states, but over the last 2 years has spread to all participating states. The level of resistance observed in bollworm during 2016 was comparable to survival rates of tobacco budworm when it was first considered resistant to pyrethroid insecticides during the 1980s. Because pyrethroid insecticides are still frequently used to control other pests in the agricultural landscape, selection for more pyrethroid resistance continues. Control of bollworm larvae with pyrethroids at this time is erratic and often unacceptable. Therefore, some states have removed pyrethroids from their list of insecticides recommended for bollworm control.

Acknowledgements

The authors thank Cotton Inc. and all the cooperating universities for providing partial funding for this project.

References

Abbott, W. S. 1925. A method of computing the effectiveness of an insecticide. J. Econ. Entomol. 18: 265-267.

Beerwinkle, K. R., J. D. Lopez, D. Cheng, P. D. Lingren, and R. W. Meola. 1995. Flight potential of feral *Helicoverpa zea* (Lepidoptera: Noctuidae) males measured with a 32-channel, computer-monitored, flight-mill system. Environ. Entomol. 24: 1122-1130.

Beuzelin, J., S. Brown, J. Davis, L. D. Foil, K. Healy, F. Huang, D. Kerns, A. Morgan, D. Pollet, G. Reagan, D. Reed, D. Ring, T. Schowalter, M. Stout, and T. Smith. 2016. 2016 Louisiana Insect Pest Management Guide, LSU AgCenter, Pub. 1838.

Catchot, A., C. Allen, J. Bibb, D. Cook, W. Crow, J. Dean, D. Fleming, D. Dodds, J. Gore, T. Irby, E. Larson, B. Layton, N. Little, J. MacGown, S. Meyers, F. Musser, and S. Winter. 2017. Insect Control Guide for Agronomic Crops, Mississippi State University Extension Service, Publ. 2471.

Lingren, P. D., J. K. Westbrook, V. M. Bryant, J. R. Raulston, J. F. Esquivel, and G. D. Jones. 1994. Origin of corn earworm (Lepidoptera: Noctuidae) migrants as determined by citrus pollen markers and synoptic weather systems. Environ. Entomol. 23: 562-570.

Martin, S. H., R. D. Bagwell, M. L. Boyd, B. L. Freeman, G. A. Herzog, D. R. Johnson, M. B. Layton, B. R. Leonard, N. Liu, G. T. Payne, P. V. Pietrantonio, M. E. Roof, M. J. Sullivan, J. W. Van Duyn, and J. R. Weeks. 1999. Status of bollworm, *Helicoverpa zea*, susceptibility to pyrethroids: IRAC-US 1998 update, pp. 867-871. *In:* Proceedings, Beltwide Cotton Conferences. 3-7 January, 1999. Orlando, FL. National Cotton Council, Memphis, TN.

Musser, F. R., R. E. Jackson, J. K. Greene, B. R. Leonard, S. D. Stewart, M. N. Parajulee, J. J. Adamczyk, G. M. Lorenz, D. S. Akin, K. V. Tindall, D. A. Herbert, and P. M. Roberts. 2010. Pyrethroid resistance monitoring of bollworms, pp. 1259-1264. *In:* Proceedings, Beltwide Cotton Conferences. Jan. 4-7, 2010. New Orleans, LA. National Cotton Council, Memphis, TN.

Plapp, F. W., Jr. 1987. Managing resistance to synthetic pyrethroids in the tobacco budworm, pp. 224-226. *In:* Proceedings, Beltwide Cotton Conferences. Jan. 4-8, 1987. Dallas, TX. National Cotton Council, Memphis, TN.

Plapp, F. W., Jr., G. M. McWhorter, and W. H. Vance. 1987. Monitoring for pyrethroid resistance in the tobacco budworm in Texas - 1986, pp. 324-326. *In:* Proceedings, Beltwide Cotton Conferences. Jan. 4-8, 1987. Dallas, TX. National Cotton Council, Memphis, TN.

Rogers, B., H. D. Feese, S. L. Riley, C. A. Staetz, J. Whitehead, and W. Mullins. 1990. *Heliothis* resistance monitoring in the cotton belt: PEG-US update, pp. 163-164. *In:* Proceedings, Beltwide Cotton Conferences. Jan. 9-14, 1990. Las Vegas, NV. National Cotton Council, Memphis, TN.

Studebaker, G., J. Davis, J. D. Hopkins, D. R. Johnson, K. Loftin, G. Lorenz, N. Seiter, P. Spradley, J. Zawislak, D. T. Johnson, and T. Teague. 2017. Insecticide recommendations for Arkansas, University of Arkansas Cooperative Extension Service, MP 144.

MANAGEMENT OF PLANT BUGS UNDER WATER-DEFICIT COTTON PRODUCTION SYSTEMS IN THE TEXAS HIGH PLAINS

Abdul Hakeem
Megha Parajulee
Katie Lewis
Texas A&M AgriLife Research and Extension Center
Lubbock, TX

Abstract

Multi-year field studies were conducted to determine the impact of plant bug infestations under a range of water levels on Texas High Plains cotton. Various densities of cotton fleahopper and *Lygus* bugs were released on cotton squares and mid-season bolls, respectively. In 2012, two *Lygus* densities (0 and 5 adults per plant) were released on cotton plants. From 2013-2015, three fleahopper densities (0, 2 and 5 fleahoppers per plant) were released on cotton squares. One week following the releases, plant bugs were removed and the test plants were sprayed with insecticides. Overall, significantly higher lint yield was recorded from control plots compared to cotton fleahopper released plots in all years. Additionally, cotton significantly compensated lint yield loss caused by cotton fleahopper feeding under high water regime. *Lygus* boll injury was observed 3rd to 4th week into flowering and significantly higher lint yield was recorded from control plots compared with *Lygus* released treatments.

Introduction

The United States is the third largest cotton producing country in the world. In 2015, cotton was grown on an area of 8.2 million acres in the United States. Texas planted approximately 55% (4.48 million acres) of the total U.S. cotton. Texas High Plains plays an important role in U.S. agriculture and significantly contributes to Texas cotton production. More than 65% of Texas cotton is produced in Texas High Plains. In 2015, arthropod pests caused 2.83% reduction in U.S. cotton lint yield. *Lygus* species ranked second while cotton fleahopper ranked 5th and caused 0.79% and 0.35% cotton fiber yield loss in the U.S., respectively (Williams 2016). Late-instar *Lygus* nymphs can cause greater damage to young bolls than adults (Jubb and Carruth 1971, Parajulee et al. 2011). In Texas High Plains, cotton generally compensates losses caused by early *Lygus* infestation, but a significant lint loss is possible if the infestation occurs around mid-season coinciding with the major boll developmental period (Hakeem et al. 2016). Plant health also contributes significantly to compensate for insect-induced fruit losses. Available nitrogen and water also play an important role in plant's compensatory performance. The objective of this study was to determine the impact of plant bug infestations under a range of water levels on Texas High Plains cotton.

Materials and Methods

Studies were conducted at the Agricultural Complex for Advanced Research and Extension Systems, Lamesa, Texas, to determine the impact of plant bug infestations under a range of water levels on cotton lint yield. Cotton fleahopper (incubated from overwintered eggs) and *Lygus* bugs (field collected) were released on cotton plants and allowed to feed for a week (Hakeem and Parajulee 2015). One week after releases, plants were sprayed with Orthene® 97UP and the fields were kept pest free for the remainder of the growing season. Plant mapping was done two weeks after insect release and before harvest. Cotton cultivars varied across the study years while the irrigation levels remained the same.

Figure 1. A) Cotton fleahopper adult, B) Lygus adult, C) fleahopper-infested cotton square, D) Lygus feeding injury on cotton boll in Lamesa, TX.

Figure 2. A and B) Multi-plant cages used to release fleahopper and Lygus bugs on cotton, C) Pre-harvest plant mapping and harvesting of the test plants.

Results and Discussion

Cotton fleahopper infestations resulted in increased square abscission compared to that in uninfested control plots. In 2012, cotton variety PHY 367WRF produced a significantly higher number of harvestable bolls under high irrigation level but no significant difference in number of bolls were recorded between the control and *Lygus* released plots. For cotton variety ST 5458B2RF, no significant differences in the number of bolls from water levels and *Lygus* infestation were observed (Table 1).

Table 1. Average number of bolls harvested from *Lygus*-infested cotton under variable irrigation level, Lamesa, Texas, 2012.

Insect Treatment	Number of Harvestable Bolls/Plant					
	PHY 367WRF			ST 5458B2RF		
	High water	Low water	Average	High water	Low water	Average
Control	8.0	7.7	7.9 a	6.5	4.6	5.6 a
Infested	9.7	6.1	7.9 a	7.1	4.2	5.7 a
Average	8.9 A	6.9 B		6.8 A	4.4 A	

No significant differences in lint yield between the low and high water regime was recorded for cotton variety PHY 367WRF; however, control plots had significantly higher lint yield compared to *Lygus*-infested plots. No significant differences in lint yield was observed between the high and low irrigation regimes nor between control and treated plots for ST 5458B2RF (Table 2).

Table 2. Lint yield influenced by a late-season *Lygus* infestation in an irrigation level x variety study, Lamesa, Texas, 2012.

Insect Treatment	Lint Yield (lb/acre)					
	PHY 367WRF			ST 5458B2RF		
	High irrigation	Low irrigation	Average	High irrigation	Low irrigation	Average
Control	1088.0	711.2	899.6 a	762.5	577.7	670.1 a
Infested	1090.0	522.7	806.4 b	818.5	621.6	720.1 a
Average	1089.0 A	671.0 A		790.5 A	599.7 A	

In 2013, no significant differences in lint yield were observed in the high irrigation treatment which may have compensated fruit loss. However, higher lint yield was observed from the control plots compared to fleahopper released plots grown under low irrigation level (Fig. 3) which indicated that water-stressed plants displayed lower compensatory ability compared to fully irrigated plants.

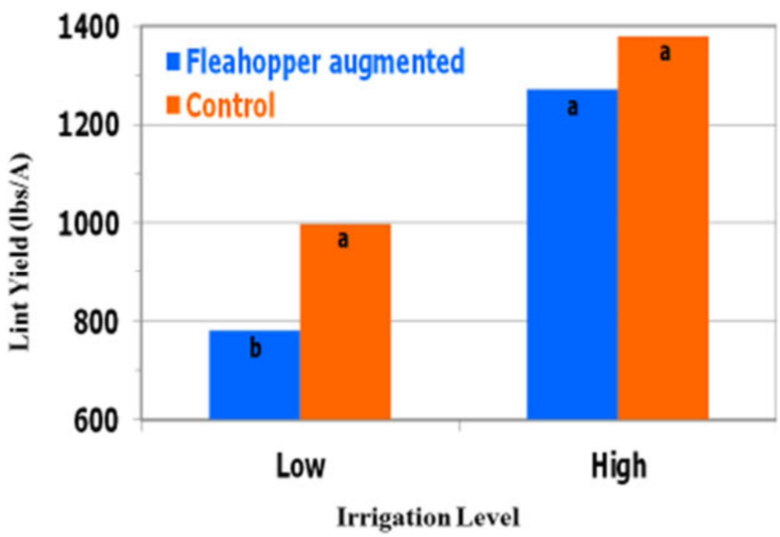


Figure. 3. Average lint yield from simulated acute infestation of cotton fleahoppers under low and high irrigation regimes, Lamesa, Texas, 2013.

In 2014, significantly higher square loss was observed from fleahopper-infested plots compared to control plots under both low and high irrigation regimes (Fig. 4); however, no significant differences in lint yield was observed (Fig. 5).

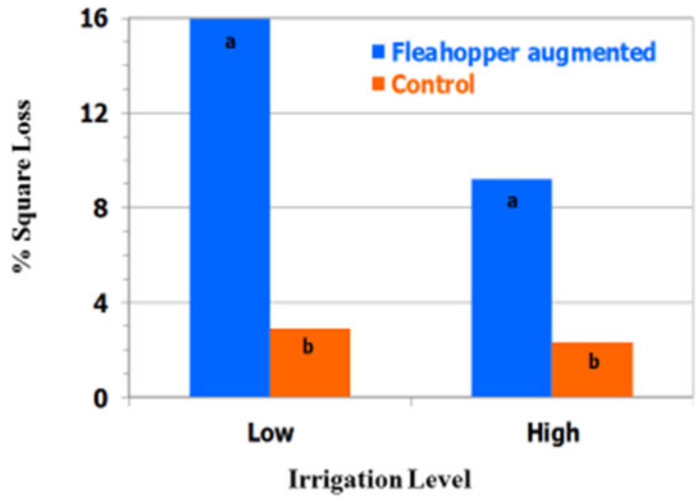


Figure. 4. Percent square loss caused by cotton fleahoppers nymphs under low and high irrigation regimes, Lamesa, Texas, 2014.

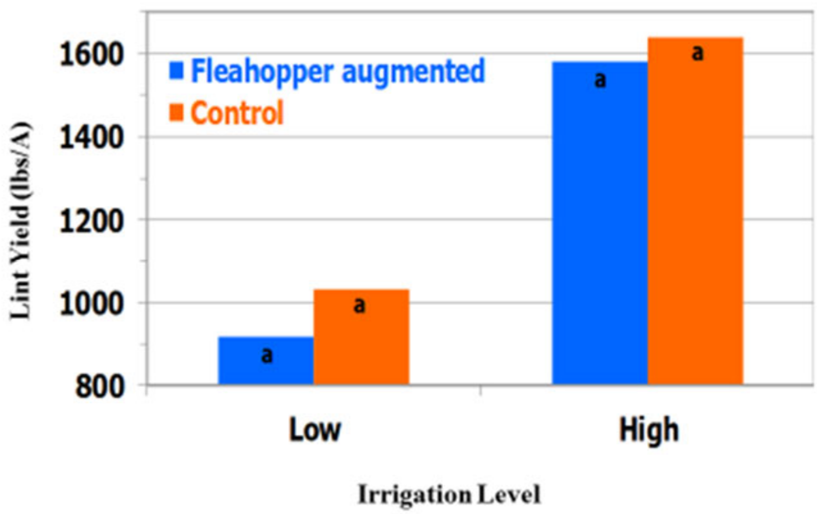


Figure. 5. Average lint yield from simulated acute infestation of cotton fleahoppers under low and high irrigation regimes, Lamesa, Texas, 2014.

In 2015, significantly higher square loss was observed with increased fleahopper density (2 versus 5 fleahoppers/plant) as compared to control plots under both low and high irrigation regimes (Fig. 6). The staircase effect of insect-induced square loss trend was similar between low and high water regimes. The fleahopper-induced early-season square loss resulted in a significant reduction in lint yield, particularly under the high water (full irrigation) production system, whereas lint yield did not vary significantly between the uninfested and fleahopper-infested plots under the low irrigation production system (Fig. 7). It is unclear why the full-irrigated treatment showed reduced lint yield.

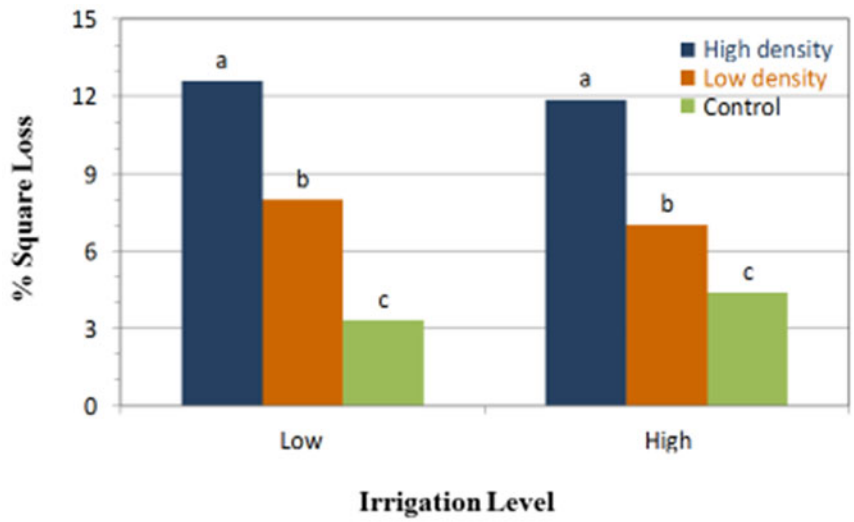


Figure 6. Percent square loss caused by cotton fleahopper infestations under high and low irrigation regimes, Lamesa, Texas, 2015.

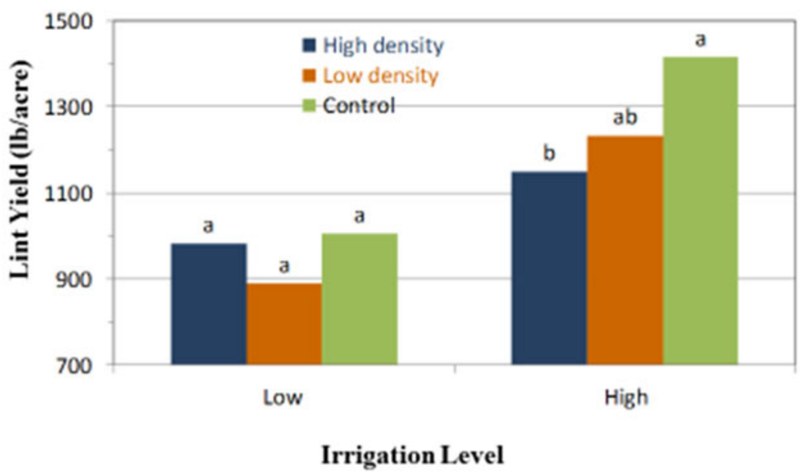


Figure 7. Impact of cotton fleahopper infestations on cotton lint yield under high and low irrigation regimes, Lamesa, Texas, 2015.

<u>**References**</u>

Hakeem, A., and M. N. Parajulee. 2015. Moisture conditions for laboratory rearing of cotton fleahoppers from overwintered eggs laid on woolly croton plants. Southwestern Entomologist. 40: 455-462.

Hakeem, A., M. N. Parajulee, S. Coyle, and S. Carroll. 2016. Modified field-cage study to estimate *Lygus* treatment thresholds in Texas cotton, pp. 858-861. *In* Proceedings, Beltwide Cotton Conferences, National Cotton Council, New Orleans, LA.

Jubb, Jr. G. L., and L. A. Carruth. 1971. Growth and yield of caged cotton plants infested with nymphs and adults of *Lygus hesperus.* J. Econ. Entomol. 64: 1229-1236.

Williams, M. R. 2016. Cotton insect loss estimates-2015, pp. 507-525. *In* Proceedings, Beltwide Cotton Conferences, National Cotton Council, New Orleans, LA.

MANAGEMENT OF RESURGING ARTHROPOD PESTS ON *BT* COTTON IN PAKISTAN

Tahammal Hussain
Khuram Zia
Mumammad Jalal Arif
University of Agriculture
Faisalabad, Pakistan
Megha Parajulee
Abdul Hakeem
Texas A&M AgriLife Research and Extension Center
Lubbock, TX

Abstract

Cotton is produced in 125 countries with the resulting lint used either domestically or exported as a textile raw material. Pakistan produces ~10 million bales of cotton lint and ranks 4th among cotton producing countries in the world. Cotton is widely grown in Pakistan and is an important cash crop in the country's economy. Pakistan produces cotton on about 2.9 million hectares, with the production of about 10 million bales. Primary cotton cultivars used in Pakistan include FH-Lalazar, CIM 599, CIM-602, BH-178, FH-118, and FH-142. Most of Pakistan's planted cottonseed contains transgenic gene technology for bollworms and other lepidopteran pests. Economic gains from *Bt* cotton in Pakistan was estimated to be US$1.9 billion over a 5-year period (2010-2014) and US$299 million for 2014 alone. Insect pests of cotton in Pakistan represent the greatest arthropod pest diversity within the entire region. The estimated lint yield losses due to insect pests to Pakistani cotton range from 20-40%. A variety of insect pests attack the cotton crop from germination through crop maturity. Recent resurging insect pests of Pakistani cotton which cause severe damage are *Bemisia tabaci*, *Amrasca biguttula, Thrips tabaci, Helicoverpa armigera, Earias vittella*, *Earias insulans,* and *Pectinophora gossypiella.* Some of these pests have developed resistance to our available *Bt* cotton cultivars.

Pink bollworm, *Pectinophora gossypiella,* has emerged as the most serious pest of cotton, especially at a later stage of crop growth cycle (3rd week of August to 4th week of October). There were only 129 severe infestation cases observed in 2014, but these severe cases of pink bollworm infestations increased to 1,314 in 2015. The effect of increased pink bollworm severity has resulted to significant lint yield reduction as well as poor fiber quality. Hotspots (populations exceeding ETL) were observed in Lodhran, Bahawalnagar, Vehari, TT Singh, Bhakkar, Multan, Bahawalpur and Khanewal District of Punjab (Fig. 1), whereas infestation remained below ETL throughout other cotton growing areas of Punjab. Approximately 90% of insecticides are used to manage cotton insect pests in Pakistan and only 10% of the insecticide share goes to other crops. Primary insecticides used in managing resurging pests of cotton include pyriproxyfen, nitenpyram, curacron, and lambda-cyhalothrin. The presentation highlighted our current effort in developing integrated pest management approaches for Pakistan's major cotton insect pests, particularly in light of insect resistance to *Bt* technology.

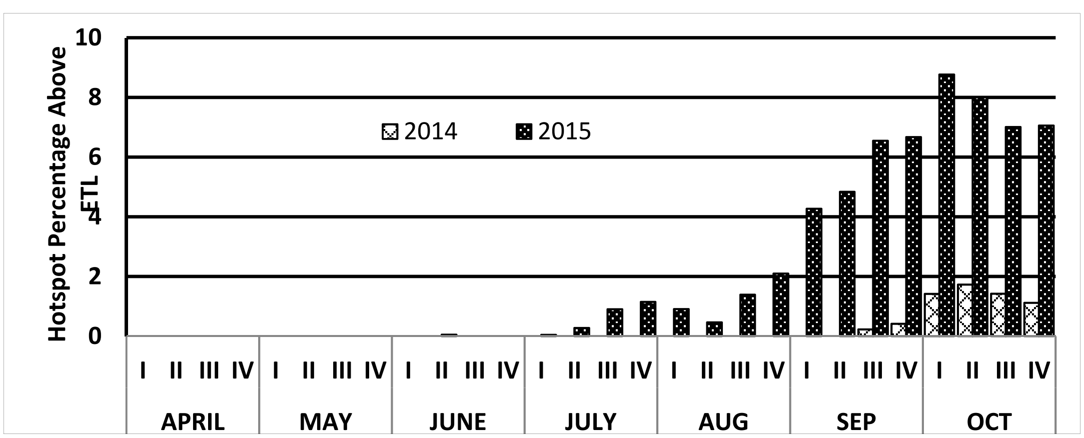


Figure 1. Weekly percentage of cotton fields exceeding pink bollworm economic threshold level in Pakistan for the years 2014 and 2015.

HELICOVERPA ZEA AND *HELICOVERPA ARMIGERA* PHEROMONE LURES: MALE MOTH RESPONSE TO 'TEXAS TRAPS' AND GREEN 'BUCKET TRAPS'

S. C. Carroll
M. N. Parajulee
Texas A&M AgriLife Research & Extension Center
Lubbock, TX
T. Hussain
University of Agriculture
Faisalabad, Pakistan

Abstract

An ongoing study has been conducted in the Texas High Plains to investigate the seasonal moth flight activity patterns of *Helicoverp*a spp. and to possibly detect the presence of the 'Old World' bollworm (OWB, *H. armigera*), if it has already been introduced into the Texas bollworm population. The primary objectives of the study were to: 1) investigate the effectiveness of species-specific pheromone lures obtained from two vendors, and 2) determine the efficiency of two different trap designs in capturing *Helicoverpa* spp. moths. Trap type x pheromone lure combination treatments were deployed in late July, followed by all traps being monitored and the captured moths counted approximately weekly through mid-November. All traps were re-baited with fresh lures approximately every two weeks. Sub-samples of up to 25 moths per trap per sample date are currently in the process of being dissected to determine if the Texas High Plains moth populations contained any *H. armigera*. Trap x lure efficiencies in capturing *Helicoverpa* spp. are discussed. Our current hypothesis is that *H. armigera*, Old World Bollworm (OWB), invasion has not occurred in Texas. During 2016, the traps baited with the USDA Cooperative Agricultural Pest Survey (CAPS) lures were observed to also capture tobacco budworms [*Heliothis virescens* (F.)], while the Trécé™ (*H. zea* and *H. armigera*) lure baited traps did not attract tobacco budworms.

Introduction

The Old World bollworm (OWB), *Helicoverpa armigera*, is a polyphagous pest, feeding on a wide range of crop and non-crop plant hosts. Its global distribution spans Europe, Asia, Africa, Oceania, and South America. During 2014, *H. armigera* was detected in Puerto Rico and Costa Rica, and then on 17 June 2015, one male moth was collected in a pheromone trap in Bradenton, FL. It is anticipated that this pest will invade the southern U.S. in the very near term and some entomologists have speculated that the invasion has already occurred. Ecological niche modeling indicates that the majority of the U.S. is a suitable habitat for the permanent establishment of reproductive OWB populations. Therefore, the current OWB issue in Texas is a rigorous anticipatory survey.

This continuing Texas High Plains study is being conducted to investigate the seasonal moth flight activity patterns of *Helicoverpa* spp. captured on two different trap designs (Fig. 1) and pheromone lures, obtained from two sources, specifically designed to trap *H. zea* or *H. armigera*. It should be noted that *H. zea* moths commonly respond to *H. armigera* pheromone baited traps and the two species are difficult to distinguish from each other without genetic testing or dissecting the adult males.

The study objectives were to: 1) investigate the effectiveness of *H. armigera* and *H. zea* pheromone lures obtained from two sources [Trécé™, Inc. (both species); USDA CAPS (*H. armigera* lures only)], 2) determine the efficiency of two different trap designs ('Texas Trap' vs. green 'Bucket Trap') in capturing *Helicoverpa* spp. moths, and 3) perform dissections of seasonal male adult sub-samples of *Helicoverpa* spp. moths captured on *H. armigera* pheromone baited traps in order to possibly detect 'Old World' bollworm sightings in Texas bollworm moth populations.

Materials and Methods

Survey area for the study included four trapping sites situated in a west-to-east orientation along Texas FM1294 in northern Lubbock County, TX (Fig. 2). Five selected experimental treatments included: 1) 'Texas Traps' baited with Trécé™ *H. zea* lure, 2) 'Texas Traps' with Trécé™ *H. armigera* lure, 3) 'Bucket Trap (green)' with Trécé™ *H. zea* lure, 4) 'Bucket Trap' (green) with Trécé™ *H. armigera* lure, and 5) 'Bucket Trap' (green) with USDA CAPS *H. armigera* pheromone lure. Each treatment was represented at each trapping site, including five treatments and four sites (replications) deployed in a randomized block design.

Figure 2 also displays the yearly trapping periods for 2015 and 2016, typically deploying the traps during mid- to late July with monitoring extending until mid-November annually. Plans include an identical test to continue in 2017. Traps were inspected weekly and re-baited at two-week intervals. All captured moths were counted, placed into Zip-Loc™ bags, and then samples were placed into a freezer for species identification dissections at a later date.

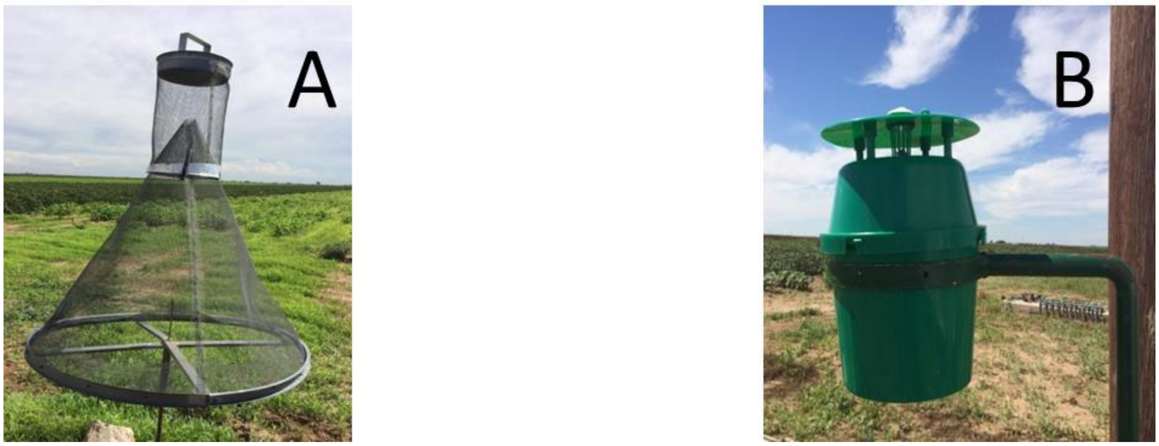


Figure 1. Two trap designs, 'Texas Trap' (A) and green 'Bucket Trap' (B), deployed at four Lubbock County sites.

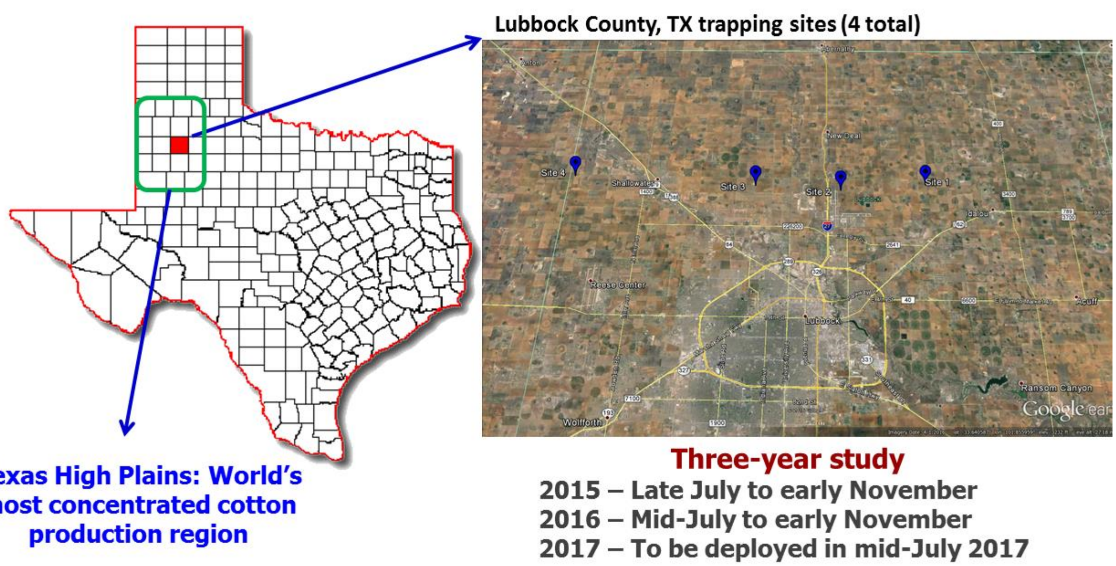


Figure 2. Trapping study sites utilizing two trap designs and two species-specific pheromone lures from two sources. Five traps (one per treatment as listed in section above) were deployed at each of the four Lubbock County sites.

Results and Discussion

'Texas Trap' with Two Associated Pheromone Lure Treatments

The Trécé™ *H. armigera* and Trécé™ *H. zea* lure baited Texas traps yielded 2015 seasonal weekly captures of 119 and 83 bollworms per trap, respectively; while during 2016, similar seasonal weekly moth capture averages of 110 and 80 were observed (Figs. 3 and 4). Overall, it should be noted that among the five study treatments, the Texas Traps baited with Trécé™ *H. armigera* lure captured the highest number of *Helicoverpa* spp. moths during both

2015 and 2016 (Figs. 3, 4 and 5). Because *H. zea* cross-responds to *H. armigera* lure, it appears that the Trécé™ lure that is designed for *H. armigera* is as much or more attractive to *H. zea* (Figs. 3, 4, and 5).

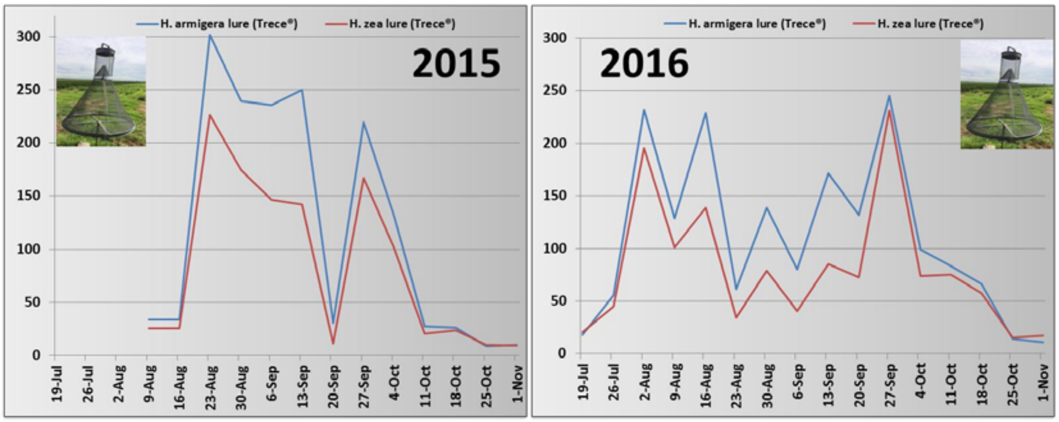


Figure 3. Texas Traps (Texas Pheromone Traps or TP Traps): Weekly *Helicoverpa* spp. male moth captures during 2015 (left) and 2016 (right) on 'Texas Traps' baited with *H. zea* or *H. armigera* Trécé™ pheromone lures.

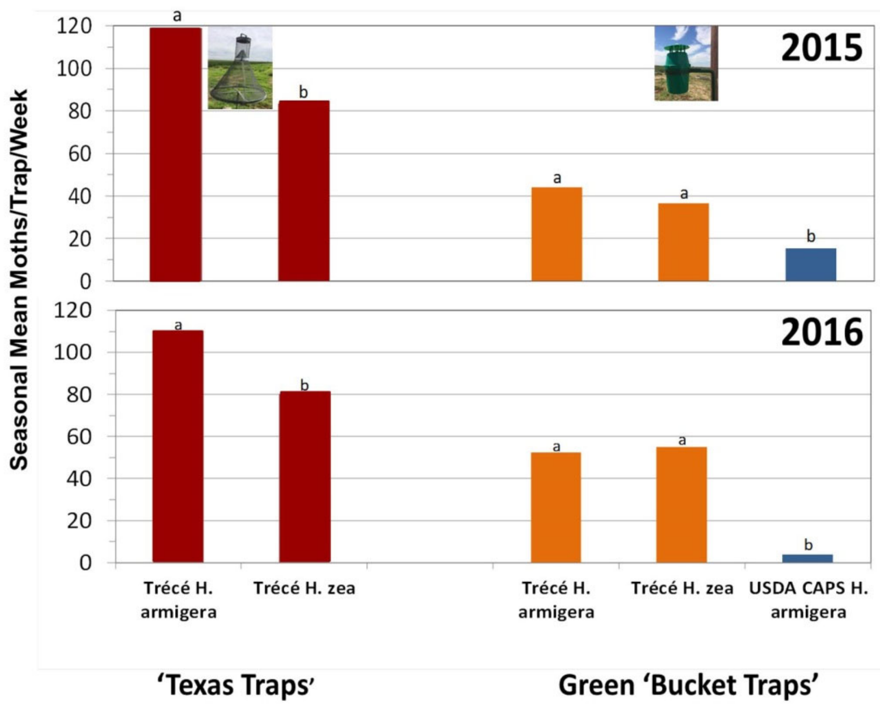


Figure 4. Seasonal mean number of *Helicoverpa* spp. male moths captured per week per trap on Texas Traps (red bars) baited with Trécé™ *H. armigera* and *H. zea* pheromone lures. Likewise, the two orange bars indicate weekly means for green Bucket Traps baited with Trécé™ *H. armigera* and *H. zea* lures. The blue bar illustrates the seasonal weekly means for green Bucket Traps baited with the USDA CAPS *H. armigera* lures. Seasonal means within each trap type indicated by different lowercase letters indicate statistical difference between these means.

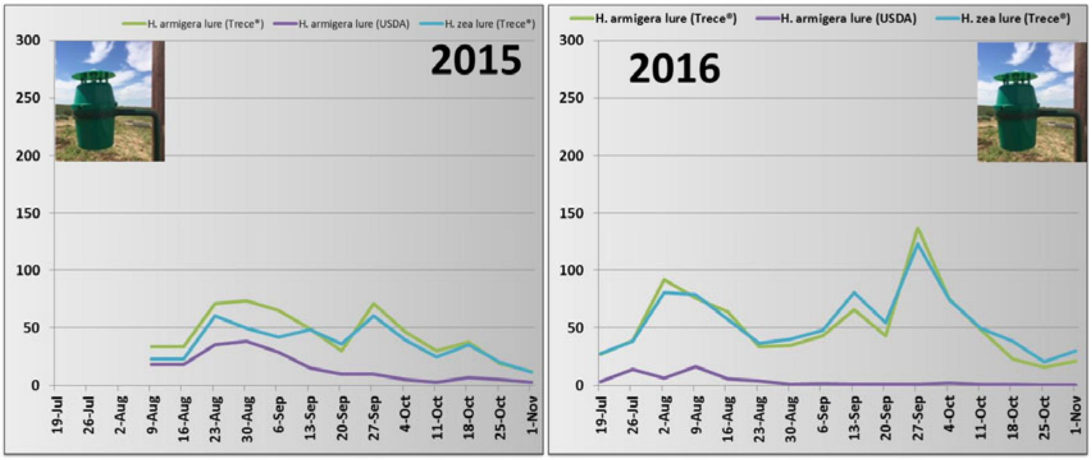


Figure 5. Green 'Bucket Traps': Weekly *Helicoverpa* spp. male moth captures during 2015 (left) and 2016 (right). Traps were baited with *H. zea* or *H. armigera* Trécé™ pheromone lures, and *H. armigera* USDA CAPS lure.

<u>Green 'Bucket Traps' with Three Associated Pheromone Lure Treatments</u>

Overall, green bucket traps baited with the Trécé™ *H. armigera* and *H. zea* lures yielded lower numbers of bollworm moths than the Texas Traps, yet overall peak trap response periods were observed on both trap designs similarly (Figs. 3, 4 and 5). The Trécé™ *H. armigera* and Trécé™ *H. zea* lure baited green bucket traps yielded 2015 seasonal weekly moth captures of 44 and 36 bollworm moths per trap, respectively, reflecting the same general moth activity trend as observed from the Texas traps (Figs. 3 and 4).

During 2016, a slightly different numerical trend was observed whereas the Trécé™ *H. zea* lure baited traps captured a seasonal mean of 55 moths per trap, whereas the Trécé™ *H. armigera* lure captured slightly lower moth numbers (although not statistically different) at 52 moths per trap (Fig. 5).

What should be noted is that the moth captures on the USDA CAPS baited green bucket traps did not reflect the same moth trap response activity patterns of the other four treatments which utilized lures obtained from Trécé™, Inc. Figures 4 and 5 clearly illustrate that the moth numbers were much lower and only the early season peak trap responses were slightly reflected by USDA CAPS lure as compared to the other pheromone lure treatments. While *H. armigera* lure is expected to cross-capture *H. zea*, USDA CAPS lures were designed to be more sensitive toward *H. armigera* compared to commercially available *H. armigera* lure. At the present time, *H. armigera* does not appear to be in the Texas High Plains bollworm population (see below in *Identification* section), therefore it is impossible to determine which lure type (lure supplier) has the best pheromone lure for attracting *H. armigera*.

During 2016, the traps baited with the USDA CAPS lures were observed to also capture tobacco budworm [*Heliothis virescens* (F.)] moths, while the Trécé™ (*H. zea* and *H. armigera*) lure baited traps did not attract tobacco budworm moths. For example, during the eleven week period of 18 August to 4 November, the four USDA CAPS lure baited traps captured a total of 170 tobacco budworm moths, while during the same time period these traps captured only 58 *Helicoverpa* spp. moths.

<u>Dissections to Determine *Helicoverpa* spp. Identifications</u>

A total of 1,252 moths from Trécé™ and USDA CAPS *H. armigera* lure baited traps have been dissected to date. Based upon these initial dissections, we do not believe that the 'Old World' bollworm' (*H. armigera*) has been introduced to the Texas High Plains. All dissected male moths appeared to be *H. zea* specimens. More Texas High Plains specimens are yet to be dissected, along with some samples from South Texas (Hidalgo County location). We plan to repeat this survey in 2017 with two locations from South Texas added to the 2016 study.

<u>Acknowledgements</u>

Research funding which facilitated this ongoing study came from Cotton Incorporated State Support Committee and Plains Cotton Growers, Inc. USDA CAPS lures were provided by USDA APHIS PPQ.