8-1-2014

Summaries of Arkansas Cotton Research 2013

Derrick M. Oosterhuis
University of Arkansas, Fayetteville

Citation

Oosterhuis, D. M. (2014). Summaries of Arkansas Cotton Research 2013. *Arkansas Agricultural Experiment Station Research Series.* Retrieved from https://scholarworks.uark.edu/aaesser/36

UofA
DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

Summaries of Arkansas Cotton Research 2013

Oosterhuis

AAES

Summaries of
Arkansas Cotton Research
2013

Edited by Derrick M. Oosterhuis

UofA
DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

ARKANSAS AGRICULTURAL EXPERIMENT STATION
August 2014 Research Series 618

This publication is available on the Internet at http://arkansasagnews.uark.edu/1356.htm

Layout and editing by Penny McGee
Technical editing and cover design by Gail Halleck

Arkansas Agricultural Experiment Station, University of Arkansas System Division of Agriculture, Fayetteville. Mark J. Cochran, Vice President for Agriculture. Clarence E. Watson, Associate Vice-President for Agriculture–Research and Director, AAES. MG400CS6.

ISSN: 1941-1618 CODEN:AKAMA6

SUMMARIES OF ARKANSAS COTTON RESEARCH 2013

Derrick M. Oosterhuis, Editor

Arkansas Agricultural Experiment Station
University of Arkansas System
Division of Agriculture
Fayetteville, Arkansas 72701

CONTRIBUTORS

Bagavathiannan, Muthu, Post Doctoral Associate, Department of Crop, Soil, and Environmental Sciences, Fayetteville

Barber, Tom L., Assistant Professor, Department of Crop, Soil, and Environmental Sciences, Little Rock

Barnes, Ed M., Senior Director of Agricultural and Environmental Research, Cotton Incorporated, Cary, North Carolina

Bauer, Phillip J., Research Agronomist, Coastal Plain Soil, Water, and Plant Conservation Research Center, Agricultural Research Service, Florence, South Carolina

Bourland, Fred M., Director/Professor, Northeast Research and Extension Center, Keiser

Burke, James M. Graduate Assistant, Department of Crop, Soil, and Environmental Sciences, Fayetteville

Carroll, Doug S., Program Associate, Department of Crop, Soil, and Environmental Sciences Soil Testing and Research Laboratory, Marianna

Chaney, H. Michael. Program Associate, Department of Entomology, Lonoke Extension Center, Lonoke

Clarkson, Derek L., Graduate Assistant, Department of Entomology, Fayetteville

Collie, Leah, Program Technician, Department of Crop, Soil, and Environmental Sciences, Lonoke Extension Center, Lonoke

Coomer, Taylor D., Undergraduate, Department of Crop, Soil, and Environmental Sciences, Fayetteville

Daniels, Mike, Professor, Extension Water Quality, Department of Crop, Soil, and Environmental Sciences, Little Rock

de Paiva Oliveira, Eliege Aparecida, International Scholar, Department of Crop, Soil, and Environmental Sciences, Fayetteville

Dodds, D.M., Associate Extension Professor, Plant and Soil Sciences, Mississippi State University, Mississippi State, Mississippi

Doherty, Ryan C., Program Technician, Southeast Research and Extension Center, Monticello

Espinoza, Leo, Extension Soil Scientist, Department of Crop, Soil, and Environmental Sciences, Little Rock

Everett, Mallory E., Graduate Assistant, Department of Entomology, Fayetteville

FitzSimons, Toby R., Graduate Assistant, Department of Crop, Soil, and Environmental Sciences, Fayetteville

Flanders, Archie, Assistant Professor, Northeast Research and Extension Center, Keiser

Hallmark, Cory, Discovery Farm Technician, Department of Crop, Soil, and Environmental Sciences, Little Rock

Henry, Chris, Assistant Professor, Rice Research and Extension Center, Department of Biological and Agricultural Engineering, Stuttgart

Herron, Cindy G., Program Technician, Department of Crop, Soil, and Environmental Sciences Soil Testing and Research Laboratory, Marianna

Hesselbein, Josh, Program Technician, Department of Crop, Soil, and Environmental Sciences, Little Rock

Hill, Zachary, Graduate Assistant, Department of Crop, Soil, and Environmental Sciences, Fayetteville

Hirsh, Sarah, Program Associate, Rice Research and Extension Center, Stuttgart

Ismanov, Makhammadzakhrab, Program Technician, Lon Mann Cotton Research Station, Marianna

Johnson, D. Brent, Graduate Assistant, Department of Crop, Soil, and Environmental Sciences, Fayetteville

Jones, Michael A., Associate Professor, Department of Entomology, Soils, and Plant Sciences, Clemson University, Clemson, South Carolina

Kathiar, Soolaf, Graduate Assistant, Department of Biology, Little Rock and Department of Biology, University of Baghdad, Baghdad, Iraq

Lanza, Janet, Professor, Department of Biology, Little Rock

Loka, Dimitra A., Post Doctoral Associate, Department of Crop, Soil, and Environmental Sciences, Fayetteville

Longer, David E., Professor, Department of Crop, Soil, and Environmental Sciences, Fayetteville

Lorenz III, Gus M., Associate Department Head, Entomology, Lonoke Extension Center, Lonoke

Meier, Jason R., Program Technician, Weed Science, Southeast Research and Extension Center, Monticello

Monks, Charles D., Extension Specialist/Professor, Department of Agronomy and Soils, Auburn University, Auburn, Alabama

Mozaffari, Morteza, Assistant Professor, Department of Crop, Soil, and Environmental Sciences, Soil Testing and Research Laboratory, Marianna

Neeley, Kamella, Program Technician, Arkansas State University, University of Arkansas System Agricultural Experiment Station, Jonesboro

Norsworthy, Jason K., Associate Professor, Department of Crop, Soil, and Environmental Sciences, Fayetteville

Oosterhuis, Derrick M., Distinguished Professor, Department of Crop, Soil, and Environmental Sciences, Fayetteville

Orellana Jimenez, Luis R., Graduate Assistant, Department of Entomology, Fayetteville

Pilon, Cristiane, Graduate Assistant, Department of Crop, Soil, and Environmental Sciences, Fayetteville

Plummer, Andrew W., Program Technician, Department of Entomology, Cooperative Extension Service, Lonoke

Pretorius, Mathilda M., Graduate Assistant, Department of Crop, Soil, and Environmental Sciences, Fayetteville

Raper, Tyson B., Graduate Assistant, Department of Crop, Soil, and Environmental Sciences, Fayetteville

Reba, Michele L., Research Hydrologist, USDA ARS National Sedimentation Laboratory, Jonesboro

Riar, Dilpreet S., Post Doctoral Associate, Department of Crop, Soil, and Environmental Sciences, Fayetteville

Ritchie, Glen L., Assistant Professor, Department of Plant and Soil Science, Texas Tech University, Lubbock, Texas

Saraswat, Dharmendra, Associate Professor, Department of Biological and Agricultural Engineering, Little Rock

Schrage, Brandon W., Graduate Assistant, Department of Crop, Soil, and Environmental Sciences, Fayetteville

Sharpley, Andrew, Professor, Department of Crop, Soil, and Environmental Sciences, Fayetteville

Slaton, Nathan A., Professor, Department of Crop, Soil, and Environmental Sciences, Fayetteville

Smith, Kenneth L., Extension Weed Scientist/Professor, Southeast Research and Extension Center, Monticello

Snider, John L., Assistant Professor, Department of Crop and Soil Sciences, University of Georgia, Tifton, Georgia

Studebaker, Glen E., Entomologist, Northeast Research and Extension Center, Keiser

Taillon, Nichole M., Program Technician, Entomology, Cooperative Extension Service, Lonoke

Teague, Tina G., Professor, Arkansas State University, University of Arkansas Agricultural Experiment Station, Jonesboro

Thrash, Benjamin C., Program Technician, Department of Entomology, Fayetteville

Towles Logan, Program Technician, Northeast Research and Extension Center, Keiser

Whitaker, Jared R., Public Service Assistant, Department of Crop and Soil Sciences Department, University of Georgia, Tifton, Georgia

CONTENTS

SUMMARIES OF ARKANSAS COTTON RESEARCH 2013

PREFACE

Arkansas cotton producers harvested approximately 305,000 acres in 2013, down 48% from 2012 and setting an all time record low cotton planted acreage in Arkansas. The silver lining in 2013 was that producers averaged a record high yield averaging 1149 lbs lint/A. Increased commodity prices, of corn and soybean with decreased prices for cotton were the main reason for the decline in acres. This was also the first year that Arkansas dropped below 3rd in nationwide rankings for total cotton produced. Arkansas cotton production in 2013 grossed over 730,000 bales resulting in over $345 million in value. The quality of the 2013 Arkansas cotton crop was excellent with 36.8 staple (fiber length), 31.3 strength and 4.6 micronaire, according to cotton classing offices at Memphis and Dumas.

Spring rains and cool temperatures delayed the planting of the 2013 crop well into the month of May (Fig. 1). Record yields were realized due to the cool nighttime temperatures in July and August. Some producers in South Arkansas yielded more than 4 bales/acre or more on some fields. In North Arkansas the crop was not quite as good due to weekly periods of cloudy conditions and rainfall. These conditions led to increased small boll shed. Also in the northern counties of Arkansas, late planted cotton did not receive enough heat units in early September to mature properly.

Early season thrips pressure continued to be an issue, much like 2012. Results from pesticide screening indicate that several populations of tobacco thrips in Arkansas were resistant to thiamethoxam (Cruiser™) seed treatment. Plant bug pressure was variable dependent on location, with growers averaging from 3-7 applications to control plant bug populations.

Glyphosate-resistant Palmer amaranth (pigweed) continues to be the number one weed problem but growers have adopted University of Arkansas Cooperative Extension Service recommendations and overall, did a better job controlling it by overlapping residual herbicides and utilizing multiple tolerant technology systems such as GlyTol® LibertyLink®. Approximately 43% of our cotton acres were planted with varieties that were tolerant to Liberty in 2013 (approximately 25% LibertyLink® and 18% WideStrike®).

Tom Barber and Derrick Oosterhuis

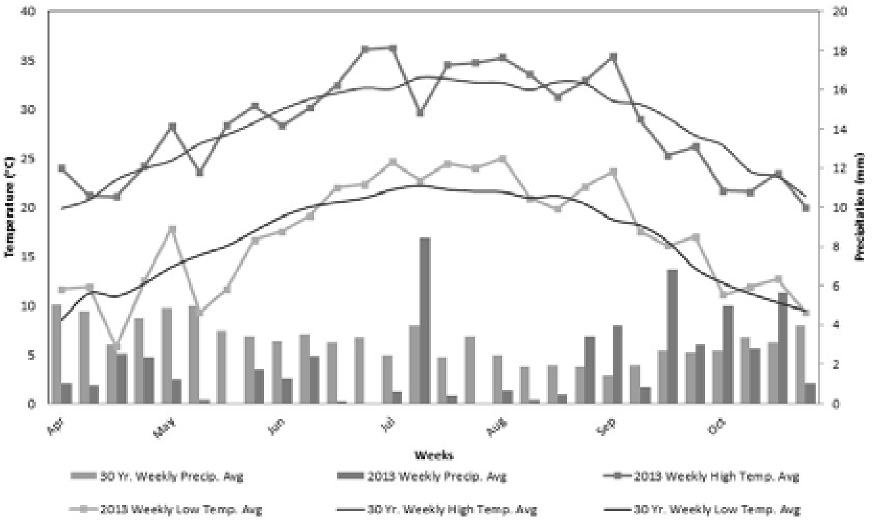


Fig. 1. Weekly maximum and minimum temperatures and rainfall for 2013 compared with the long term 30 year averages in Eastern Arkansas.

COTTON INCORPORATED AND THE ARKANSAS STATE SUPPORT COMMITTEE

The *Summaries of Arkansas Cotton Research 2013* was published with funds supplied by the Arkansas State Support Committee through Cotton Incorporated.

Cotton Incorporated's mission is to increase the demand for cotton and improve the profitability of cotton production through promotion and research. The Arkansas State Support committee is comprised of the Arkansas directors and alternates of the Cotton Board and the Cotton Incorporated Board, and others whom they invite, including representatives of certified producer organizations in Arkansas. Advisors to the Committee include staff members of the University of Arkansas System Division of Agriculture, the Cotton Board, and Cotton Incorporated. Seven and one-half percent of the grower contributions to the Cotton Incorporated budget are allocated to the State Support Committees of cotton-producing states. The sum allocated to Arkansas is proportional to the states' contribution to the total U.S. production and value of cotton fiber over the past five years.

The Cotton Research and Promotion Act is a federal marketing law. The Cotton Board, based in Memphis, Tenn., administers the act, and contracts implementation of the program with Cotton Incorporated, a private company with its world headquarters in Cary, N.C. Cotton Incorporated also maintains offices in New York City, Mexico City, Osaka, Hong Kong, and Shanghai. Both the Cotton Board and Cotton Incorporated are not-for-profit companies with elected boards. Cotton Incorporated's board is comprised of cotton growers, while that of the Cotton Board is comprised of both cotton importers and growers. The budgets of both organizations are reviewed annually by the U.S. Secretary of Agriculture.

Cotton production research in Arkansas is supported in part by Cotton Incorporated directly from its national research budget and also by funding from the Arkansas State Support Committee from its formula funds (Table 1). Several of the projects described in this series of research publications, including publication costs, are supported wholly or partly by these means.

Table 1. Arkansas Cotton State Support Committee Cotton Incorporated Funding 2013.

	2012	2013
New Funds	$264,000	$253,000
Previous Undesignated Funds	$67,202	$55,359
Total	$331,202	$308,359

Researcher	**Short Title**	**2012**	**2013**
Oosterhuis	Cotton Research In Progress	$5,000	$5,000
Bourland	Cotton Improvement	$26,000	$26,000
Barber	Verification Program	$74,208	$74,208
K. Smith	Resistant Pigweed	$20,000	$0
Oosterhuis	Nitrogen Inhibitors	$10,000	$0
Oosterhuis	Heat Tolerance Screening	$5,250	$0
Teague	Extension Sustainability	$30,000	$0
Akin/Lorenz	Rainfastness of Insecticides	$18,495	$24,000
Barber	Management of New Cultivars	$23,275	$26,000
Lorenz	Evaluating New Insecticidal Traits	$24,364	$0
Norsworthy	Modeling Glyphosate-Resistant Barnyardgrass	$12,251	$12,251
Barber	Replant Decision	$13,500	$13,500
Akin/Lorenz	Herbicide, Insecticide Interactions	$13,500	$31,000
Henry	Irrigation	$0	$31,500
Burgos	Palmer amaranth Herbicide Resistance	$0	$13,500
		$275,843	$256,959.00
Uncommitted		$55,359	$51,400
Total		**$331,202**	**$308,359**

ACKNOWLEDGMENTS

The organizing committee would like to express appreciation to Penny McGee for help in typing this special report and formatting it for publication.

SUMMARIES OF
ARKANSAS COTTON RESEARCH
— 2013 —

University of Arkansas Cotton Breeding Program: 2013 Progress Report

F.M. Bourland[1]

RESEARCH PROBLEM

The University of Arkansas Cotton Breeding Program attempts to develop cotton genotypes that are improved with respect to yield, host-plant resistance, fiber quality, and adaptation to Arkansas environments. Such genotypes would be expected to provide higher, more consistent yields with fewer inputs. To maintain a strong breeding program, continued research is needed to develop techniques to identify genotypes with favorable genes, combine those genes into adapted lines, then select and test derived lines.

BACKGROUND INFORMATION

Cotton breeding programs have existed at the University of Arkansas since the 1920s (Bourland and Waddle, 1988). Throughout this time, the primary emphases of the programs have been to identify and develop lines that are highly adapted to Arkansas environments and possess good host-plant resistance traits. Bourland (2013b) provided the most recent update of the current program. The breeding program has primarily focused on conventional genotypes. Conventional genotypes continue to be important to the cotton industry. Transgenic cultivars are usually developed by backcrossing transgenes into advanced conventional genotypes. In addition, the recent advent of glyphosate-resistant pigweed has renewed some interest in conventional cotton cultivars.

RESEARCH DESCRIPTION

Breeding lines and strains are annually evaluated at multiple locations in the University of Arkansas Cotton Breeding Program. Breeding lines are developed and evaluated in non-replicated tests, which include initial crossing of parents, individual plant selections from segregating populations, and evaluation of the progeny grown from seed of individual plants. Once segregating populations are established, each sequential test provides screening of genotypes to identify

---

[1] Director, Northeast Research and Extension Center, Keiser.

ones with specific host-plant resistance and agronomic performance capabilities. Selected progeny are carried forward and evaluated in replicated strain tests at multiple Arkansas locations to determine yield, quality, host-plant resistance and adaptation properties. Superior strains are subsequently evaluated over multiple years and in regional tests. Improved strains are used as parents in the breeding program and/or released as germplasm lines or cultivars. Bourland (2004, 2013a) described the selection criteria presently being used.

RESULTS AND DISCUSSION

Breeding Lines

The primary objectives of crosses made in 2007 through 2013 (F_1 through F_6 generations evaluated in 2013) have included development of enhanced nectariless lines (with the goal of improving resistance to tarnished plant bug), improvement of yield components (how lines achieve yield), and improvement of fiber quality (with specific use of Q-score). Breeding line development is entirely focused on conventional cotton lines.

Each of the 24 sets of crosses made in 2013 was between conventional cotton lines. The primary focus of these crosses was to combine lines having specific morphological traits, enhanced yield components and improved fiber characteristics. The 2013 breeding line effort also included evaluation of 24 F_2 populations, 24 F_3 populations, 24 F_4 populations, 678 1st year progeny, and 240 advanced progeny. Bolls were harvested from superior plants in F_2 and F_3 populations and bulked by population. Individual plants (1170) were selected from the F_4 populations. After discarding individual plants for fiber traits, 720 progeny from the individual plant selections will be evaluated in 2013. Also, 216 superior F_5 progeny were advanced, and 72 F_6 advanced progeny were promoted to strain status. These 72 F_6 advanced progeny included 42 progeny derived from crosses with UA48 (Bourland and Jones, 2012). Hopefully, these are lines that combine fiber quality of UA48 with the enhanced yielding ability of their other parent.

Strain Evaluation

In 2013, 108 conventional and 4 transgenic strains (preliminary, new and advanced) were evaluated at multiple locations. Screening for host-plant resistance included evaluation for resistance to seed deterioration, bacterial blight, Verticillium wilt, tarnished plant bug, and root knot nematode (in greenhouse). Work to improve yield stability by focusing on yield components and to improve fiber quality by reducing bract trichomes continued.

Germplasm Releases

Germplasm releases are a major function of public breeding programs. Since 2004, a total of 48 cotton germplasm lines and three cotton cultivars have been released by the Arkansas Agricultural Experiment Station. Five of these germplasm lines were released in 2013 (Bourland and Jones, 2014a,b) Variation with respect to yield, adaptation, yield components, fiber properties, and specific morphological and host-plant resistance traits are represented in these lines. The lines provide new genetic material to public and private cotton breeders with documented adaptation to the mid-South cotton region. Additional lines are now being considered for release.

PRACTICAL APPLICATION

Genotypes that possess enhanced host-plant resistance, improved yield and yield stability, and good fiber quality are being developed. Improved host-plant resistance should decrease production costs and risks. Selection based on yield components may help to identify and develop lines having improved and more stable yield. Released germplasm lines should be valuable as breeding material to commercial and other public cotton breeders or released as cultivars. In either case, Arkansas cotton producers should benefit from having cultivars that are specifically adapted to their growing conditions.

LITERATURE CITED

Bourland, F.M. 2004. Overview of the University of Arkansas Cotton Breeding Program. pp. 1093-1097. *In:* Proc. Beltwide Cotton Conf., 59 Jan. 2004, San Antonio, Texas. National Cotton Council, Memphis, Tenn.

Bourland, F.M. 2013a. Novel approaches used in the University of Arkansas cotton breeding program. pp. 409-418. *In:* Proc. Beltwide Cotton Conf., 7-10 Jan. 2013, San Antonio, Texas. National Cotton Council, Memphis, Tenn.

Bourland, F.M. 2013b. University of Arkansas cotton breeding program 2012 progress report. pp. 17. *In*: D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research in Progress in 2012. Agricultural Experiment Station Research Series 610. Fayetteville.

Bourland, F.M. and D.C. Jones. 2012. Registration of 'UA48' cotton cultivar. J. Plant Reg. 6:15-18.

Bourland, F.M. and D.C. Jones. 2014a. Registration of Arkot 0111, Arkot 0113, and Arkot 0114 germplasm lines of cotton. J. Plant Reg. 8:68-72.

Bourland, F.M. and D.C. Jones. 2014b. Registration of Arkot 0219 and Arkot 0222 germplasm lines of cotton. J. Plant Reg. 8:73-76.

Bourland, F.M. and B.A. Waddle. 1988. Cotton Research Overview-Breeding. Arkansas Farm Research no 4 37:7.

Assessment of the Slow-Release Nitrogen Foliar Fertilizer Nitamin® in Comparison to Foliar Urea and Soil-Applied Nitrogen to the Yield of Field-Grown Cotton (*Gossypium Hirsutum,* L.)

J. Burke, D. Oosterhuis, and T. Raper[1]

RESEARCH PROBLEM

Effective nitrogen (N) management in cotton production is essential in order to achieve proper growth and development. However, soil-incorporated N can undergo a series of chemical conversions along with numerous loss mechanisms (leaching, volatilization and denitrification) that can make N unavailable to the plant. In addition, soil-incorporated N has faced much scrutiny over the years for its role in many detrimental environmental situations. Methods to reduce the amount of soil-applied N such as foliar fertilization have been examined and studied while simultaneously supplying the N that cotton requires. From root and vegetative growth to reproductive development, N is vital in every phase of cotton development and plant demand is high.

BACKGROUND INFORMATION

For over a century, foliar fertilization has been utilized as a source of correcting nutritional imbalances and supplementing soil incorporated fertilizers in order to achieve proper plant development (Oosterhuis and Weir, 2010). However, foliar fertilization of cotton has only become popular within the last twenty years (Oosterhuis and Weir, 2010). The rationale and theory supporting the use of foliar N fertilization is primarily based on the numerous loss mechanisms that soil-applied N fertilizers can endure and the high demand of N by cotton during the reproductive stage (Thompson et al., 1976). Boll development requires a substantial amount of N that is mainly provided by the leaves (Zhu and Oosterhuis, 1992) and any deficiencies in leaf N can result in decreased boll growth and overall yield (Bondada et al., 1997). Therefore, nitrogen applied to cotton via foliar fertilization is looked upon as an option of correcting leaf N deficiencies (Craig Jr., 2002).

---

[1] Graduate assistant, distinguished professor, and graduate assistant, respectively, Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville.

RESEARCH DESCRIPTION

The 2013 field experiment was conducted at the University of Arkansas System Division of Agriculture, Soil Testing and Reaserach Laboratory in Marianna, Ark. and used a randomized complete block design consisting of 3 treatments and 4 replications. A total of 12 plots, each composed of 4 rows, 50 ft by 38 in., were used for the experiment along with cotton (*Gossypium hirsutum* L.) cultivar Stoneville 4288 B2RF. Urea-ammonium nitrate (UAN 32) was soil-incorporated to all treatment plots at a rate of 45 lb N/acre while foliar applications of urea (46-0-0) and Nitamin (30-0-0), at rate equivalents of 6 lb N/acre respectively, occurred approximately 1 week after first flower using a pressurized CO_2 backpack sprayer. A single measurement of overall yield was determined by a mechanical picker at harvest. Analysis of variance methods were used to determine any significant differences between treatment means at the $P \leq 0.05$ and $P \leq 0.10$ levels using the "Fit Model" platform provided by JMP Pro 10.0 software (SAS Institute, Cary, N.C.).

RESULTS AND DISCUSSION

Statistical analysis of treatment yields determined by a mechanical picker showed significant differences throughout the treatments regarding plot weight measured either in lbs per 100 row ft ($P = 0.0018$) or an extrapolated plot weight demonstrated in lbs per acre ($P = 0.0018$) at $P \leq 0.05$ (Table 1). At this level of significance, the foliar urea and Nitamin treatments were not significantly different from one another but had significantly higher yields than the control. When the analysis was run at the $P \leq 0.10$ level, all treatments were significantly different with the Nitamin treatment having significantly greater yields than the foliar urea treatment which in turn was significantly higher than the control for both yield measurements ($P = 0.0018$) (Table 1).

PRACTICAL APPLICATION

These analyses display a positive response to foliar-applied N in cotton grown under field conditions of limited or low N fertility regardless of the foliar N source. The 45 lb N/acre rate of soil-incorporated UAN was well below the N rates typically recommended for cotton production in Arkansas (97-100 lb N/acre). This limitation of soil-available N may have been the key factor in enhancing effective absorption and utilization of foliar-applied N by cotton leaves as well as its subsequent translocation throughout the plant and to the developing bolls.

ACKNOWLEDGMENTS

The authors thank Koch Agronomic Services, LLC for supplying the Nitamin used in this study, and the staff at the Lon Mann Cotton Research Station in Marianna, Arkansas.

LITERATURE CITED

Bondada, B.R., D.M. Oosterhuis, and R.J. Norman. 1997. Cotton leaf age, epicuticular wax, and nitrogen-15 absorption. Crop Sci. 37:807-811.

Craig Jr., C.C. 2002. Nitrogen use efficiency of cotton following corn in rotation and foliar fertilization of cotton using leaf blade analysis. Ph.D. Diss., Louisiana State University, Baton Rouge, La.

Oosterhuis, D.M. and B.L. Weir. 2010. Foliar Fertilization of Cotton. pp. 272-288. *In* J.M. Stewart et al. (eds.) Physiology of Cotton. Springer Science+Business Media, New York, N.Y.

Thompson, A.C., H.C. Jones, J.W. Jones and J.D. Hesketh. 1976. Nitrogen concentration of cotton leaves, buds, and bolls in relation to age and nitrogen fertilization. Agron. J. 68:617-621.

Zhu, B. and D. Oosterhuis. 1992. Nitrogen distribution within a sympodial branch of cotton. J. Plant Nutr. 15:1-14.

Table 1. Harvest yield means per treatment for the 2013 Marianna yield study.

Treatment	Yield (lb/100 row ft.)	Yield (lb/acre)	Yield (lb/acre)
UAN	20.70 b[†]	2862 b[†]	2862 c[‡]
Foliar Urea + UAN	22.27 a	3080 a	3080 b
Nitamin + UAN	23.02 a	3184 a	3184 a

[†] Columns not sharing a common letter are significantly different ($P \leq 0.05$).

[‡] Column not sharing a common letter are significantly different ($P \leq 0.10$).

Cotton Response to Combinations of Urea and Environmentally Smart Nitrogen in an Arkansas Silt Loam

M. Mozaffari, N.A. Slaton, C.G. Herron, and S.D. Carroll[1]

RESEARCH PROBLEM

Cotton (*Gossypium hirsutumn* L.) yield in many Arkansas soils can be optimized by nitrogen (N) fertilization. However, soil and fertilizer N can be lost by processes such as runoff, leaching and denitrification. Improving N use efficiency will increase the growers' profit margin and reduce potential environmental risks of excessive N application.

BACKGROUND INFORMATION

Polymer coated controlled release (slow release) N fertilizers may provide the growers with the opportunity to increase their N use efficiency. A polymer-coated urea (44% N; Agrium Advanced Technologies, Loveland, Colo.) is currently being marketed in Arkansas under the trade name of Environmentally Smart Nitrogen or ESN[2]. The objective of this study was to evaluate furrow-irrigated cotton response to ESN and urea fertilizers in a representative Arkansas soil used for cotton production.

RESEARCH DESCRIPTION

An N fertilization experiment was conducted to evaluate cotton yield response to preplant application of urea, ESN and their combinations at the Lon Mann Cotton Research Station (LMCRS) in Marianna, Ark. on a Memphis silt loam in 2013. Before applying any fertilizer, soil samples were collected from the 0-to 6-inch depth and composited by replication. Soil samples were oven-dried, crushed, for soil pH, organic matter, and Mehlich-3 extractable nutrients measurement. Average soil properties in the 0-to 6-inch depth were 1.6% organic matter, 56 ppm P, 109 ppm K, and 6.9 pH. Agronomically important information is presented in Table 1.

The experimental design was a randomized complete block design with a factorial arrangement of four preplant-applied, urea-ESN combinations that included

---

[1] Assistant professor, professor, program technician, and program associate, respectively, Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville.

[2] Mention of a trade name is for facilitating communication only. It does not imply any endorsement of a particular product by the authors or the University of Arkansas; or exclusion of any other product that may perform similarly.

five rates ranging from 30 to 150 lb N/acre in 30 lb N/acre increments and a no N control. The four urea and ESN-N combinations were: 100% urea-N; 50% urea-N plus 50% ESN-N; 25% urea-N plus 75% ESN-N, and 100% ESN-N. Each treatment was replicated six times. We applied muriate of potash and triple superphosphate to supply 90 lb K_2O and 46 lb P_2O_5/acre to the entire experimental area. All fertilizers (including the N-fertilizer treatments) were hand applied onto the soil surface and incorporated immediately with a Do-all cultivator. After fertilizers were incorporated, the beds were pulled with a hipper and the cotton was planted on top of the beds. Each plot was 40-ft long and 12.6-ft wide allowing for four rows of cotton planted in 38-inch wide rows. Cotton was furrow-irrigated as needed and we closely followed the University of Arkansas Cooperative Extension Service cultural recommendations for irrigated-cotton production. The two center rows of cotton in each plot were harvested with a spindle-type picker. We obtained monthly precipitation data from weather stations at LMCRS. Long-term average precipitation data were obtained from the Arkansas Variety Testing Site (http://www.arkansasvarietytesting.com/crop/data/2). Analysis of variance (ANOVA) was performed by using the GLM procedure of SAS (SAS Institute, Inc., Cary, N.C.). The data from the control (0 lb N/acre) were not included in the ANOVA. When appropriate, means were separated using Fisher's protected least significant difference (LSD) method and interpreted as significant when $P \leq 0.10$.

RESULTS AND DISCUSSION

At the LMCRS, monthly precipitation amounts in June, July, and August were lower than the long-term average (Table 2). Thus, the weather conditions were not conducive for significant N loss at the test site. Neither N source, nor the N source × N rate interaction, significantly influenced seedcotton yield at the LMCRS ($P > 0.10$, Table 3). Seedcotton yields were significantly ($P < 0.0001$) affected only by the N-fertilizer rate. Seedcotton yield for the cotton that received no N was 2255 lb/acre, which was numerically (13%) lower than the yield of cotton that received the lowest actual N rate of 30 lb N/acre, averaged across N sources. Averaged across the four urea and ESN blends, seedcotton yield increased numerically and often significantly as N rate increased. When urea was included in the N-fertilizer blend, numerically maximal seedcotton yields were produced with application of 150 lb N/acre, but when ESN was the sole source of N, numerically maximal yields were produced with application of 120 lb N/acre. Maximum seedcotton yields were produced by applying 90 to 150 lb N/acre. During the growing season, we observed that at N rates of 60-120 lb N/acre, ESN-fertilized cotton appeared more vigorous. In in the months of August and September, the sky was cloudy on many days and limited the cotton yield potential.

PRACTICAL APPLICATION

The amount of early-season precipitation during the 2013 growing season was below normal and was likely conducive for efficient uptake of preplant N regardless of the source. Nitrogen application rate significantly increased seedcotton yields and maximal yields were produced by 90 to 150 lb N/acre. Averaged across N rates, cotton yields were not different among the various combinations of urea and ESN. These results suggest that ESN can be preplant-incorporated in irrigated cotton production in Arkansas.

ACKNOWLEDGMENTS

This research was funded by a gift from Agrium Advanced Technologies, who also donated the enhanced efficiency fertilizer. We acknowledge the assistance of the University of Arkansas Soil Testing and Research Laboratory staff with soil analyses.

Table 1. Selected agronomically important information for a cotton N fertilization trial established at the Lon Mann Cotton Research Station in Marianna, Ark. during 2013.

Previous crop	Soil series	Cultivar	Planting date	N application date	Harvest date
corn	Memphis	ST5458	28 May	20 May	23-Oct

Table 2. Actual rainfall received by month in 2013 and the long-term (1960-2007) average monthly mean rainfall data at the Lon Mann Cotton Research Station in Marianna, Ark.

Precipitation	May	June	July	August	September	Total
	--------------------------- Precipitation (inches) ------------------------------					
2013[a]	7.42	0.72	2.79	1.88	4.25	17.06
Average[b]	5.90	3.90	3.90	2.80	3.20	19.70

[a] Cotton was planted 28 May and harvested 23 October.
[b] Long-term average for 1960-2007.

Table 3. Seedcotton yield as affected by the non-significant N source and nonsignificant N source × N rate interaction (*P* > 0.10) and significant (*P* < 0.0001) N rate (averaged across N sources) effect for a cotton fertility experiments conducted in Marianna, Arkansas during 2013.

	N-fertilizer source						
N rate	100% Urea-N	50%Urea-N 50%ESN-N[a]	25% Urea-N 75% ESN-N	100% ESN-N	**N rate mean**	**N-fertilizer source**	**N source mean**
lb N/acre	---------------- Seedcotton yield (lb/acre)				------------------		lb/acre
0	2255[b]					None	2255[b]
30	2319	2750	2727	2593	2598	100% Urea-N	2859
60	2804	2473	2725	2802	2707	50%Urea-N, 50%ESN-N	2876
90	3024	2982	2910	2808	2929	25% Urea-N,75% ESN-N	2891
120	3054	2819	2901	3176	2980	100% ESN-N	2839
150	3131	3134	3115	3106	3124		
LSD 0.10	NS[c](interaction)				177[d]	LSD 0.10	NS
P value	0.4848				<0.0001	*P* value	0.9147

[a] ESN, Environmentally Smart N, polymer coated urea.
[b] The no N control is listed for reference only as it was not included in the analysis of variance.
[c] NS, not significant (*P* > 0.10).
[d] LSD, least significant difference, compares the yield of treatments that received N, averaged across N sources.

Analysis of Sensitivity of Two Canopy Nitrogen Stress Indices to Available Potassium and Variety

T.D. Coomer, D.M. Oosterhuis, T.B. Raper, L. Espinoza,
C Pilon, and J.M. Burke[1]

RESEARCH PROBLEM

Variable rate application of fertilizer nitrogen (N) is being partially driven by the expanding availability and advances in canopy reflectance technology. While the spectral response to N stress has been well documented (Samborski et al., 2009), the spectral response to differing varieties and available potassium (K) has not yet been defined. A consequence from the unknown spectral response by alternate growth factors besides N stress has led to over application of N when N is not the limiting growth factor (Zillman et al., 2006). This excess fertilizer N can be an environmental hazard and a financial burden to the grower.

BACKGROUND INFORMATION

The relationship between leaf reflectance measured by a spectrometer and changing N status is typically strong. However, when K is not sufficient, this correlation deteriorates (Fridgen and Varco, 2004). Potassium deficiency symptoms can appear suddenly, even on soils with K sufficient soil test levels (Cope, 1981), further complicating sensor-driven, variable rate applications of N (Oosterhuis and Weir, 2010). The exceedingly differing structural features and physiological maturity patterns among the range of varieties grown in upland cotton production further cloud the reflectance responses. The most commonly utilized index, normalized vegetation difference index (NDVI), has been demonstrated to be sensitive to variety during the flowering period of cotton, while those relationships regress later in the growing season (Benitez Ramirez and Wilkerson, 2010).

The development of a canopy reflectance based N-sensitive index does not take response to variety or available K into account. Nonetheless, the response of each index to these variables must be considered to prevent inaccurate N fertilization and the consequent repercussions. Therefore, the main objective of this research was to examine the response of two contrasting indices to changes in available K and variety.

---

[1] Graduate assistant, distinguished professor, graduate assistant, associate professor, graduate assistant, and graduate assistant, respectively, Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville.

RESEARCH DESCRIPTION

A more complete description of methods and results can be found in Raper et al. (2013). A randomized strip, complete block trial with five replications was conducted in 2012 and 2013 at the Lon Mann Cotton Research Center in Marianna, Arkansas. Soil samples were taken from bed shoulders at 6 inch depths from each plot pre-plant in 2012 and analyzed by Mehlich-3 extraction. Treatments consisted of four K applications of an untreated check (0 lb K_2O/acre), 30, 60, and 90 lb K_2O/acre applied to Phytogen 499 WRF, Stoneville 5458 B2RF, and DeltaPine 912 B2RF varieties. All other thresholds and inputs were established and maintained to set K apart as the sole yield-restricting input.

In both years, reflectance measurements were taken on two dates, one early and one later in the growing season after visible K deficiency characteristics were evident. Reflectance measurements were taken using the Crop Circle ACS-470 (Holland Scientific Inc., Lincoln, Neb.) in the center two rows of each plot at a height of 36 inches from sensor to canopy. The wavelengths measured were centered in the red (560 nm), red-edge (670 nm), and near infared (760 nm) regions, and wavelengths were then used to calculate two contrasting indices: NDVI, which has been shown to be sensitive to changes in plant biomass and structure, and the Canopy Chlorophyll Content Index (CCCI) which is more responsive to N stress but less sensitive to plant biomass than NDVI (Raper and Varco, 2011). Data was trimmed to eliminate values taken within five feet of the plot ends. The 2012 seedcotton yield was calculated by mechanical harvest of the center two 50-foot rows of each plot.

The response of seedcotton yield and index readings to changes in available K_2O was tested by regression analysis. Analysis of variance was conducted for both reflectance dates in both years and yield data for 2012 in JMP 10 (SAS Institute Inc., Cary, N.C.). Independent variables in the model included block, variety, available K, and the interaction between variety and available K. Available K_2O was calculated as [(ppm soil test K × 2.0 × 1.2) + lb K_2O fertilizer/acre] where 2.0 is the factor for converting ppm to lb/acre assuming 2 million pounds soil/acre-furrow-slice and 1.2 is the factor for converting K to K_2O.

RESULTS AND DISCUSSION

2012 Results

Seedcotton response to changes in variety and available K_2O were significant ($P \leq 0.05$), as was the interaction between these two terms ($P \leq 0.10$). Phytogen 499 yields were not significantly increased with available K_2O, but available K_2O did increase Stoneville 5458 and DeltaPine 912 yields. Severe K deficiencies were not noted, as is evident by the available K_2O levels and relatively high yields. The moderately strong response to increased available K_2O of Stoneville 5458 yields and slight response of DeltaPine 912 yields suggests that increased K_2O availability could increase yields for these varieties; however, the high soil

K levels may have contributed to the lack of response of Phytogen 499 yields to increased available K_2O.

Stoneville 5458 in control plots contained visual K deficiency at the first week of flowering, and were consistent across the field at peak flower. Therefore, reflectance was measured at mid-flower and after peak flower. Responses were similar from both sampling dates. The interaction effects between available K_2O and variety on NDVI readings were significant ($P \leq 0.10$; Fig. 1), however, CCCI was significantly affected by variety, but not by available K_2O ($P \leq 0.05$; Fig. 1).

First year results suggest NDVI is sensitive to both variety and changes in available K_2O, suggesting that developing individual models will be necessary to characterize specific NDVI response to an individual variety's sensitivity to changes in available K_2O. In comparison, CCCI was only significantly affected by variety, suggesting only a variety specific correction term could be developed and implemented. A response to variety only, such as CCCI, is preferred to a response to only available K_2O, due to the spatial consistency of variety and the spatial inconsistency of available K_2O.

2013 Results

Reflectance was measured at an early to mid-season and a late season date because visual K deficiency in control plots began mid-season and was consistent across control plots by peak flower. There was no interaction between available K_2O and variety or reflectance index on either sampling dates. Normalized vegetation difference index was only significantly ($P \leq 0.05$) affected by variety late in the season (Table 1). In contrast, CCCI was significantly ($P \leq 0.05$) affected by variety both early and late season (Table 2).

Second year results suggest that neither index algorithm will require calibration of individual models for available K_2O and variety, but only require a variety specific correction factor. However the early-season sensitivity of K deficiency of CCCI is preferred to the late-season deficiency detection of NDVI. Correcting deficiencies early season by applying deficient nutrients can lead to less yield loss than late-season fertilizer application.

PRACTICAL APPLICATION

Application algorithms utilizing CCCI appear to have the potential to be less susceptible to errors of recommending increased fertilizer N when K deficiencies are present than do NDVI-based algorithms. CCCI response is also preferred over the response of NDVI to available K_2O and variety. Variety is consistent spatially, and ramp calibrations or an in-season well fertilized index reference will account for response of reflectance to this variable.

LITERATURE CITED

Benitez Ramirez, M. and J.B. Wilkerson. 2010. Monitoring nitrogen levels in the cotton canopy using real-time active-illumination spectral sensing.

Master's Thesis. University of Tennessee. http://trace.tennessee.edu/utk gradthes/604/.

Cope, J.T. 1981. Effects of 50 years of fertilization with phosphorus and potassium on soil test levels and yields at six locations. Soil Sci. Soc. Am. J. 45:342-347.

Fridgen, J.L. and J.J. Varco. 2004. Dependency of cotton leaf nitrogen, chlorophyll, and reflectance on nitrogen and potassium availability. Agron. J. 96:63-69.

Oosterhuis, D.M. and B.L. Weir. 2010. Foliar fertilization of cotton. pp. 272-288. *In:* J.M. Stewart, D.M. Oosterhuis, J.J. Heithold, and J.R. Mauney (eds.) Physiology of Cotton. Springer, New York.

Raper, T.B. and J.J. Varco. 2011. Effectiveness of crop reflectance sensors in detection of cotton growth and nitrogen status. Master's Thesis. Mississippi State University. http://gradworks.umi.corn/14/97!1497285. html.

Raper, T.B., D.M. Oosterhuis, and L. Espinoza. 2013. Spectral characteristics of potassium deficiencies in multiple cotton cultivars at the canopy scale. pp. 292-298. *In:* Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Samborski, S.M., N. Tremblay, and E. Fallon. 2009. Strategies to make use of plant sensors-based diagnostic information for nitrogen recommendations. Agron. J. 101:800-816.

Zillman, E., S. Graeff, J. Link, W.D. Batchelor, and W. Claupein. 2006. Assessment of cereal nitrogen requirements derived by optical on-the-go sensors on heterogeneous soils. Agron. J. 98:682-690.

Table 1. Response of the normalized difference vegetation index (NDVI) to variety early and late season.

Cultivar	18 July 2013	22 August 2013
DP 0912	0.846810	0.852192
PHY 499	0.845675	0.858117[a]
ST 5458	0.860378	0.844719

[a]Treatments within a column are significantly different ($P < 0.05$).

Table 2. Response of the canopy chlorophyll content index (CCCI) to variety early and late season.

Cultivar	18 July 2013	22 August 2013
DP 0912	0.800435	0.812491[a]
PHY 499	0.813805	0.826682[a]
ST 5458	0.805141	0.822063

[a]Treatments within a column are significantly different ($P < 0.05$).

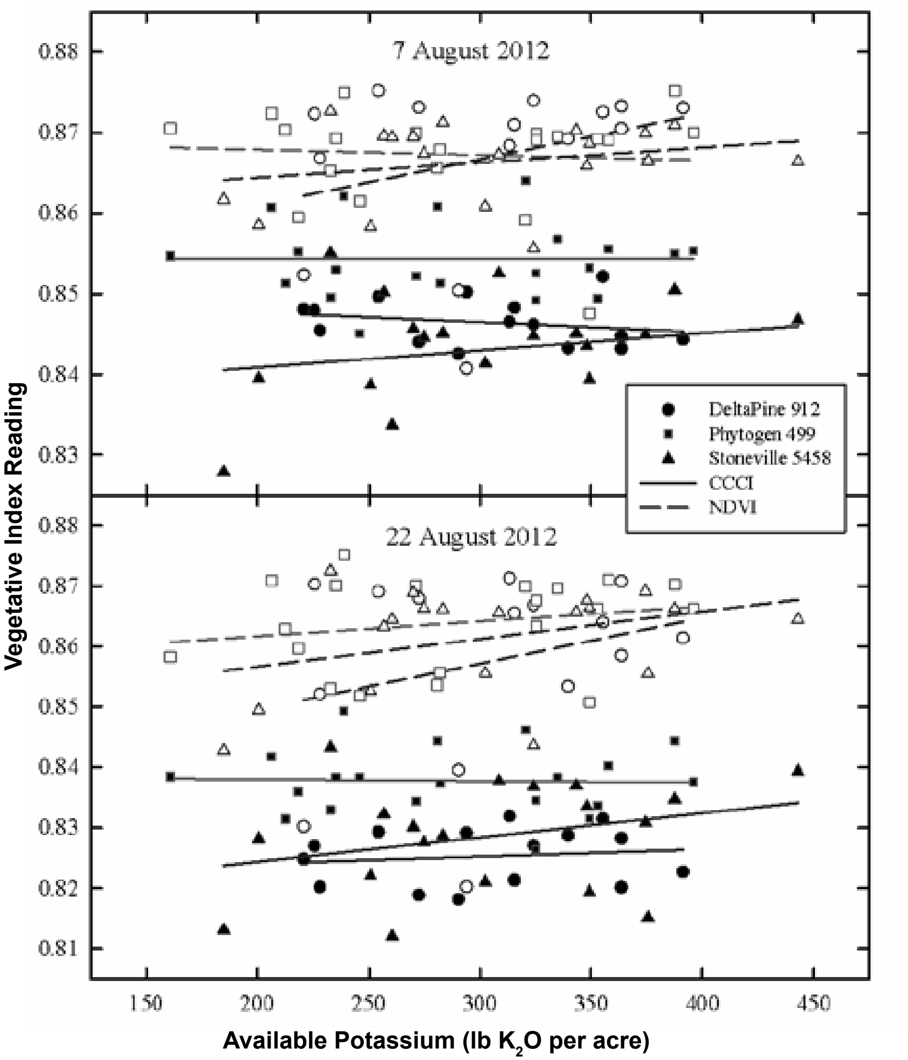


Fig. 1. Response of the normalized difference vegetation index (NDVI) and the canopy chlorophyll content index (CCCI) by variety to changes in available K_2O.

Comparison of Biochar Source on the Vegetative Development of Cotton Seedlings

J.M. Burke, D.E. Longer, and D.M. Oosterhuis[1]

RESEARCH PROBLEM

In cotton (*Gossypium hirsutum* L.) production, the amount of fertilizer input along with plant demand for nutrients can be substantial throughout the growing season. Although conventional fertilization has been instrumental in improving cotton yields, there are drawbacks that accompany their use such as nutrient groundwater leaching and surface runoff, substantial amounts of fossil fuel consumption used in their creation and the ever increasing expense associated with these fertilizers (Barrow, 2012). Therefore, the use of sustainable fertilization strategies could be considered beneficial to maintaining ideal yields while promoting environmental awareness.

BACKGROUND INFORMATION

Biochar is an end product of the low-oxygen combustion of biomass in a process called pyrolysis. Biomass sources used to generate biochar are varied and diverse. Agronomic benefits involving the use of biochars are heavily dependent on what type of biomass source is used in biochar production. Biochars originating from wood typically possess elevated levels of carbon (C) while having lower concentrations of essential plant nutrients such as nitrogen (N) and potassium (K) (Atkinson et al., 2010). Conversely, biochars originating from poultry litter have been proclaimed to possess higher values of N than biochars derived from plant-based sources (Chan et al., 2008). Although evaluations of the effect of biochar source on crops such as corn (Kimetu et al., 2008) have been documented worldwide, the influence of biochar source on the vegetative development of cotton is less understood.

RESEARCH DESCRIPTION

A greenhouse experiment was conducted in Fayetteville at the University of Arkansas System Division of Agriculture, Arkansas Agricultural Research and

---

[1] Graduate assistant, professor, and distinguished professor, respectively, Department of Crop, Soil and Environmental Sciences, University of Arkansas, Fayetteville.

Extension Center in 2011. Cotton cultivar ST4288B2RF was planted in a complete randomized design with 9 treatments and 6 replications. A total of 108 1.5 liter pots (54 per biochar source) were each filled with 1.8 kilograms (kg) of a Memphis silt loam soil (Typic hapludalf) selected from the Lon Mann Cotton Research Station in Marianna, Ark. A fine mixed-hardwood based biochar (EE) and a coarse-textured poultry litter based biochar (BES) were used as biochar sources. Both biochar types were added at three equivalent rates: no biochar (control) (C); 5,000 kg/ha (1B); and 10,000 kg/ha (2B) while fertilizer was also added to pots at three equivalent rates: no fertilizer (control); 31-23-49 kg/ha (N-P-K); and 62-46-98 kg/ha (N-P-K). The plants were grown for 7 weeks and then harvested. Data collected at harvest included plant height, chlorophyll concentrations, leaf area and number of main-stem nodes along with plant dry matter. Statistical analysis was performed using JMP Pro 11 (SAS Institute, Inc., Cary, N.C.) software to determine if the main effect of biochar source had any significant influence on the vegetative development of cotton seedlings. Statistical outliers greater than 2 standard deviations from the overall mean were excluded from individual response variable analyses.

RESULTS AND DISCUSSION

Statistical analysis demonstrated that both types of biochars (EE and BES) positively impacted various characteristics of cotton vegetative development. The EE biochar significantly increased plant height and leaf area (Table 1) along with all dry matter measurements (Table 2). Additionally, the BES biochar significantly enhanced plant height (Table 3) as well as all dry matter measurements (Table 4). Although there were differences in the textural compositions of each respective biochar, these results indicate that the developing root network of these young cotton seedlings were able to access the nutrients contained by these biochars and effectively partition them to areas of active vegetative growth throughout the plant.

PRACTICAL APPLICATIONS

Investigation into analyses of specific biochar rates displayed enhancements in numerous vegetative growth parameters of young cotton seedlings. However in comparison, the mixed-hardwood based biochar significantly increased leaf area, whereas the poultry litter based biochar did not; therefore improving the potential for increased light interception and subsequent assimilate production by cotton leaves. Nevertheless, this experiment has potentially opened up other avenues related to biochar research in cotton. Additional focus is warranted on the rate of nutrient release from these multi-source biochars to the developing plant as well as biochar's potential influence on other sectors of agricultural production.

ACKNOWLEDGMENTS

EE biochar was provided by Enginuity, Mechanicsburg, Pennsylvania and BES biochar was provided by BioEnergy Systems LLC, Springdale, Akansas.

LITERATURE CITED

Atkinson, C.J., J.D. Fitzgerald, and N.A. Hipps. 2010. Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review. Plant Soil 337:1-18.

Barrow, C.J. 2012. Biochar: potential for countering land degradation and for improving agriculture. Appl. Geogr. 34:21-28.

Chan, K.Y., L. Van Zwieten, I. Meszaros, A. Downie, and S. Joseph. 2008. Using poultry litter biochars as soil amendments. Aust. J. Soil Res. 46:437-444.

Kimetu, J.M., J. Lehmann, and S.O. Ngoze. 2008. Reversibility of soil productivity decline with organic matter of differing quality along a degradation gradient. Ecosystems 11:726-739.

Table 1. Node number, plant height, leaf area, and chlorophyll (Chl.) means for mixed hardwoods (EE) biochar.

Biochar treatment	Node number	Plant height (cm)	Leaf Area (cm^2)	Chlorophyl (SPAD)
C	5.72 a[†]	18.45 c	233.77 b	51.61 a
1B	5.94 a	19.97 b	264.13 a	52.04 a
2B	6.00 a	21.15 a	254.30 a	53.66 a

[†] Columns not sharing a common letter are significantly different ($P \leq 0.05$).

Table 2. Stem, leaf, and total plant dry matter (DM) means for mixed hardwoods (EE) biochar.

Biochar Treatment	Stem DM (g)	Leaf DM (g)	Total DM (g)
C	0.95 c[†]	1.62 b	2.60 b
1B	1.16 b	1.81 ab	3.01 a
2B	1.37 a	1.92 a	3.30 a

[†] Columns not sharing a common letter are significantly different ($P \leq 0.05$).

Table 3. Node number, plant height, leaf area, and chlorophyll (Chl.) means for poultry litter (BES) biochar.

Biochar Treatment	Node Number	Plant Height (cm)	Leaf Area (cm^2)	Chlorophyl (SPAD)
C	6.00 a[†]	18.93 b	236.36 a	49.29 a
1B	5.72 b	20.68 a	234.35 a	50.81 a
2B	6.00 a	21.20 a	251.94 a	51.26 a

[†] Columns not sharing a common letter are significantly different ($P \leq 0.05$).

Table 4. Stem, leaf, and total plant dry matter (DM) means for poultry litter (BES) biochar.

Biochar Treatment	Stem DM (g)	Leaf DM (g)	Total DM (g)
C	1.12 b[†]	1.73 b	2.85 b
1B	1.22 b	1.75 b	2.97 b
2B	1.37 a	2.04 a	3.42 a

[†] Columns not sharing a common letter are significantly different ($P \leq 0.05$).

Increasing Water Use Efficiency for Sustainable Cotton Production

L. Espinoza[1], C. Henry[2], and M. Ismanov[3]

RESEARCH PROBLEM

Irrigation management is of paramount importance to maximize yield potential in cotton. Lint quality and quantity including lint length, micronaire, strength, length uniformity, leaf grade and even color are all affected by water management. With irrigation costs as high as $70 per acre, there is a critical need to optimize water use for sustainable cotton production in Arkansas. Research has shown the importance of irrigation initiation and some guidelines have been developed for irrigation termination. But there is an urgent need to develop tools and Extension recommendations for farmers to help them trigger irrigations.

BACKGROUND INFORMATION

Irrigation scheduling is based on information on soil moisture conditions and crop evapotranspiration. Atmometers and check-book irrigation schedulers such as the Arkansas Irrigation Scheduler can be used to estimate crop evapotranspiration and used to schedule irrigation. Using soil moisture information from sensors installed in the field is another approach to sense the soil water balance. Ocampo (2007) conducted a study to compare different approaches, including the atmometers, a weather station, and the Arkansas Irrigation Scheduler. His results showed that the user-friendly atmometers provide similar estimates of evapotranspiration than those obtained with a weather station, which use the modified Penman equation. The objective of this study was to evaluate the yield response of a current cotton cultivar under different irrigation scheduling regimes, with emphasis on atmometers and soil moisture sensors.

RESEARCH DESCRIPTION

A 2.6-acre field located at the Lon Mann Cotton Research Station (LMCRS) in Marianna, Ark. was selected to conduct a test involving different furrow-irrigation scheduling regimes. The soil at the location is classified as a Memphis silt

---

[1] Extension soil scientist, Department of Crop, Soil, and Environmental Sciences, Little Rock.
[2] Assistant professor, Rice Research and Extension Center, Stuttgart.
[3] Program technician, Lon Mann Cotton Research Station, Marianna.

loam (fine silty-mixed, thermic, Typic Hapludalfs). The field was disked in the fall of 2012 after harvesting soybeans. Two additional studies were established with collaborating farmers but in soils of silty-clay texture.

Stoneville 5458 cotton was planted on 5 June, at a rate of 44.324 seeds per acre. Cotton plants began emerging 10 June. Plants were fertilized and disease and insect control was done according to University of Arkansas Cooperative Extension Service recommendations. The same cotton variety was planted at the two demonstration sites.

At LMCRS, plots consisted of 6 rows 38-in in width and approximately 600 ft in length. Irrigation treatments included 2, 3, and 4 inch deficits. Treatments were arranged in a randomized strip design and were replicated 3 times. Plots with collaborating farmers consisted of 24 rows 38-in in width by 300-500 ft in length. Atmometers were used to determine the time of the first irrigation event (The Etgage Company, Loveland, Colo.). Irrigation scheduling calculations were based on actual Evapotranspiration measurements (ETc) and rainfall. Irrigation was terminated following current COTMAN™ protocols (Oosterhuis and Bourland, 2008).

Plots were instrumented with watermark sensors (The Irrometer Company, Riverside, Calif.) installed at 6- and 12-inch depth and were periodically read with a portable reader. Soil moisture was periodically measured at random locations in the testing area using a ML 3 Theta probe (Dynamax Inc., Houston, Texas). The whole plots were harvested using a 4-row cotton picker, with total weight measured manually using a portable scale system.

RESULTS AND DISCUSSION

The response of seed cotton yield to varying irrigation regimes was significant ($P \leq 0.1$). There was a significant difference among irrigation treatments, with higher yields observed when a 2 inch deficit was used (Fig. 1). Yields obtained with a 2-inch irrigation regime were 387 and 530 lb/acre of seed cotton higher than the 3- and 4-inch irrigation regimes, respectively.

Table 1 shows the number of gallons used under each irrigation regime and the number of associated irrigation events. In order to maximize yields, under the conditions of this study, more than 471,000 gallons were needed compared to 297,759 and 214,075 for irrigation regimes equivalent to 3 and 4 inches deficit respectively.

Table 2 shows seed cotton yields of the irrigation demonstration tests established on silty clay soils. There was no significant yield difference between a 2- and a 3-inch irrigation deficit in Site 1. At site 2, however, seed cotton yields were significantly higher for the 3-inch irrigation regime than the rest of the treatments.

PRACTICAL APPLICATION

The objective of these tests was to characterize the seed cotton yield response of current cotton cultivars to varying irrigation regimes when grown in a silt loam and a silty clay soil. Preliminary results show that an irrigation deficit of 2 inches appears to be appropriate for a silt loam and a 3-inch deficit will be appropriate when growing cotton in clayey soils.

ACKNOWLEDGMENTS

Financial support provided by the Arkansas Cotton State Support Committee is appreciated.

LITERATURE CITED

Ocampo, L. 2007. Level basin approaches to improve water management in surface irrigation for northeast louisiana. Master's thesis, Louisiana State University, Baton Rouge.

Oosterhuis and Bourland. 2008. (eds.) COTMAN Crop Management System. University of Arkansas Agricultural Experiment Station, Fayetteville, Ark. and Cotton Incorporated, Cary, N.C. 107 pp.

Table 1. Water used and number of irrigations according to treatment at the Lon Mann Cotton Research Station.

Irrigation regime	2 inch	3 inch	4 inch
Water use, Gallons	471465	297759	214075
Number of irrigations	5	4	3

Table 2. Water used and number of irrigations according to treatment at the Lon Mann Cotton Research Station.

	-----------------Seed cotton yield (lb/acre)---------------		
Irrigation regime	Dryland	2 inch	3 inch
Site 1	2140 b[†]	2567a	2625a
Irrigations	0	4	3
Site 2	2352c	2840b	3205a
Irrigations	0	6	4

[†] Numbers within a row with the same letter are not significantly different ($P \leq 0.10$).

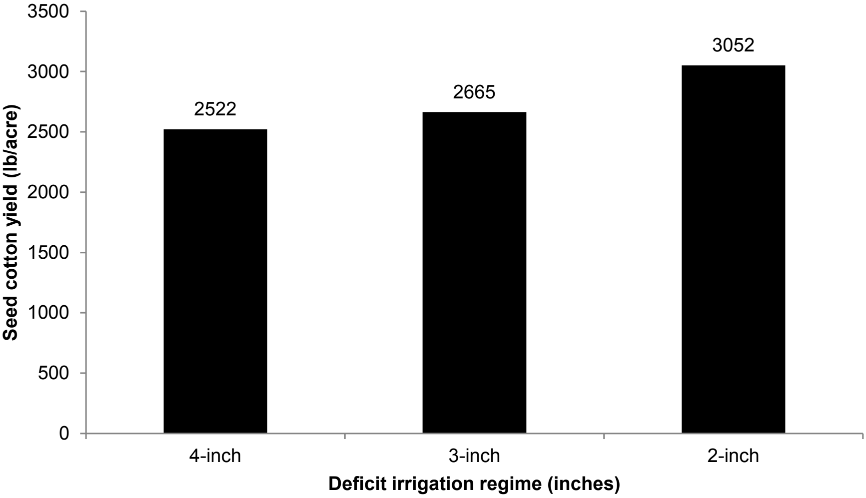


Fig. 1. Seed cotton yield response to varying irrigation regimes in a silt loam at the Lon Mann Cotton Research Station, near Marianna. Numbers followed by the same letter are not statistically significant ($P < 0.1$).

Final Irrigation Timing 2013 in Northeast Arkansas Cotton

T.G. Teague[1] *and M.L. Reba*[2]

RESEARCH PROBLEM

Uncertainty on irrigation termination timing based simply on plant maturity arises when managers lack confidence that their plants have access to adequate available soil moisture to complete maturity of the last effective bolls. Soil moisture sensors may provide the needed cue to give managers confidence in the decision to stop irrigating. In this 2013 on-farm study, we compared cotton yields with termination timing based on seasonal cutout compared to an extended irrigation. Soil moisture sensors were used to reference soil water availability in the furrow-irrigated field. We hypothesized that if maturity of the last effective bolls indicate that the crop has reached the irrigation termination threshold, and soil moisture sensors indicate adequate plant-available soil water, further irrigation would be unnecessary.

BACKGROUND INFORMATION

The perennial nature of the cotton plant (*Gossypium hirsutum*) often complicates end-of-season decision-making. The question of *when to quit* has been the focus of a longstanding research effort that includes work on termination timing of insect control and irrigation, and for defoliation (Oosterhuis and Bourland 2008, Vories et al., 2011). A key component for decision-making on termination timing is identification of the final population of bolls that effectively contribute to yield (Bourland et al., 1992). The date of *cutout* is the flowering date of that last economically significant boll population. Subsequent termination timing decisions are based on maturity of those bolls measured using accumulated heat units. Irrigation termination timing studies in the mid-South conducted over a 10-year period by Vories et al. (2011) suggests little to no benefit to applying furrow irrigation applications after the crop has accumulated 350 heat units following cutout. If a field reaches physiological cutout (average number of main stem sympodial nodes above white flower = 5 (NAWF = 5)) in late July or early August in Arkansas, then heat units are accumulated from the NAWF = 5 date. Otherwise, heat units are accumulated from a seasonal cutout date based on historical weather for that production region. The weather restricted, seasonal cutout date is the calendar

---

[1] Professor, Arkansas State University, University of Arkansas Agricultural Experiment Station, Jonesboro.
[2] Research Hydrologist, USDA-ARS-Watershed Physical Processes Research Unit, Jonesboro, ARUSDA-ARS.

date on which there is a 50% probability that the crop will have the benefit of late season temperatures sufficient to develop a mature boll. Seasonal cutout dates range across the state from 8 August in northernmost parts of Arkansas (Clay County) to 21 August in the most southern portions of the state (Ashley County). Heat units, often referred to as Growing Degree Days, are calculated using the base temperature for cotton, 60 °F, expressed as DD60s. Users calculate DD60s values by subtracting 60 from the mean daily temperature, an average of daily maximum and minimum air temperatures. Typically a boll needs 850 DD60s to mature with acceptable size and quality.

Efficient timing of irrigation termination in cotton can result in early and high yields along with reduced late season irrigation water use. Benefits to timely irrigation termination include reduced pumping costs, typically more expensive in late season due to the increased depth to groundwater after a full crop year of irrigation. Producers who identify and avoid *unproductive* late season irrigation applications can reduce lush fall plant growth that exacerbates risks of boll rots, makes defoliation more complex and costly, and delays harvest. Rank plant growth also can increase control costs for insect pests attracted to late-season squares in still actively growing plant terminals. Subsequent high pest numbers typically trigger expensive insecticide sprays to protect upper canopy, immature fruiting forms that do not contribute to economic yield (Teague, 2011). With timely irrigation termination, producers can reduce these insect pest control risks (Monge et al., 2007). Thus, optimum irrigation termination practices are an important component to cultural control in an overall integrated pest management (IPM) system.

RESEARCH DESCRIPTION

The experiment was carried out in a commercial field on Wildy Family Farms, Manila, Ark. The latest possible cutout dates for this production area—that date with a 50% or 85% probability of attaining 850 DD60s from cutout—are August 11 and July 31, respectively (Oosterhuis and Bourland, 2008). There were two treatments: irrigation termination based on seasonal cutout timing and a final late season irrigation. The strip plots were 600 ft long, 18 rows wide, and there were 3 replications. The field had been continuously planted in cotton for more than 10 years. Raised beds were spaced at 38 inches, and the row grade was 0.1%. Cotton cultivar, Deltapine L1311B2R, was planted 9 May. On 21 June, at 43 days after planting (DAP), the producer cleared row middles for irrigation using a V-shaped plow. The first furrow irrigation using poly-pipe was applied 48 DAP with subsequent irrigations applied 61, 69 and 104 DAP. For the experiment, irrigation was withheld in the termination treatment plots at 104 DAP (21 August). Irrigation timing and schedule of production activities in relation to crop cutout are listed in Table 1.

Soils in the field were classified as a Routon Dundee – Crevasse Complex. The heterogeneous soils range from fine sandy loam to smaller isolated areas of "sand blows" (coarse sands related to historic seismic events). Both soil moisture and plant monitoring sampling activities were stratified based on soil textures identified using soil electrical conductivity (EC) measurements. A Veris® 3150 Soil Surveyor (Veris Technologies, Inc., Salina, Kan.) was used to map soil textures in a 10-acre portion of the field where studies were located. Approximately 11% of the field was identified with extremely low soil EC values (< 5 mS/M determined at shallow depth), and these areas were categorized as sand blows. We categorized the remainder of the field broadly as sandy loam. Plant monitoring sample sites within each strip plot among soil textures were randomly selected for weekly sampling from squaring period through cutout using COTMAN™ sampling protocols (Oosterhuis and Bourland, 2008). Sampling for insect pests also was conducted in each site. Soil moisture measurements were made using Watermark sensors (Irrometer Company, Inc., Riverside, Calif.) with data recorded using AM 400 M.K. Hanson data loggers (M.K. Hanson Company, Wenatchee, Wash.). Watermark sensors were installed at the top of the bed between plants. A set of three soil moisture sensors were installed within 18 inches of each other with one sensor positioned at 16-inch depth and located between two 8-inch deep sensors. In early season, at the time of installation, we had not anticipated this irrigation termination trial, and therefore we installed watermarks only in the portions of the field receiving extended irrigation. Yield data were acquired with the yield monitor on the cooperating producer's cotton picker. Data were post-calibrated, and lint yields determined from the center 6 rows of each strip. Crop monitoring and yield data were analyzed using analysis of variance (ANOVA) with mean separation using Fisher's protected least significant differenct (LSD).

RESULTS AND DISCUSSION

The 2013 production season in Northeast Arkansas was characterized by high rainfall early and in mid-season during the effective flowering period followed by late August dry period (Fig. 1). COTMAN growth curves show plant response to the favorable early-season conditions with the pace of sympodial development for plants growing in sandy loam soil comparable to the COTMAN standard Target Development Curve (TDC) through the first flowers, ~ 60 DAP. Plants growing in sand blows were delayed in relation to the TDC. The apogee of the TDC occurs at first flower with 9.25 mean no. squaring nodes (NAWF = 9.25). In our samples from the week of first flowers, plants in coarse sand and sandy loam had a mean of 6.8 and 9.0 main stem sympodia, respectively, indicating a likely difference in yield potential for plants in these two soil texture classes. First position square shed levels at first flowers were 20% and 38% for sand blows and sandy loam, respectively. These are relatively high levels of injury resulting from feeding damage from pre-flower infestations of tarnished plant bug adults.

Plant maturity delays for the 2013 crop were documented using NAWF monitoring. Plants in all treatments reached physiological cutout (mean NAWF = 5) on 94 DAP, two days after the latest possible cutout date using an 50% probability of attaining 850 DD60s and 11 days after the latest possible cutout date for 85% probability of attaining 850 DD60s. Plant maturity delays in 2013 likely were related to reduced fruit retention associated with pre-flower feeding injury by tarnished plant bugs as well as cloudy, rainy weather that occurred during weeks 2 through 4 of the effective flowering period. The final irrigation on 21 August occurred 366 DD60s after seasonal cutout (85% probability).

Soil moisture measurement results indicate great variability in the wetting pattern among the two soil textures (Fig. 2). Following rain events, there was accelerated dry-down observed in the coarse sand compared to the sandy loam. It also appeared that capillary rise (upward movement of water) and lateral movement from the furrow into the bed was less consistent with the sandy loam following furrow irrigation compared to the coarse sand. For the first and final irrigations, the sensors in the sandy loam at 8 or 16 inches did not detect the irrigation events. Poor infiltration has been previously observed in soils of this region and is likely due to surface seals and crusting that can reduce infiltration. Soil moisture sensors indicated that there was sufficient moisture at the timing of the final irrigation with soil water potential values at both 8 and 16 inches in sandy loam and sand blow soil ranged >-10 kPa and >-50 kPa, respectively. Currently there are no established irrigation triggers recommended in Arkansas; however, recommendations from other mid-South and SE states suggest irrigation when soil moisture readings in the rooting zone range between -30 to -60 kPa (Lieb and Fisher, 2012) depending on soil texture.

Rainy fall weather delayed harvest until 25 October (169 DAP). We observed no yield penalty from the early irrigation termination timing compared to the additional late August application with mean yields of 1047 and 1036 for the early and extended irrigation treatments, respectively ($P = 0.60$). In hand-harvested 10-ft plots associated with watermark sensors, mean yield of cotton with the extended irrigation was 1036 compared to 717 lb lint/ac for plants in sandy loam compared to sand blow soils ($P < 0.01$).

PRACTICAL APPLICATION

Research results reported by Vories et al. (2011) suggest evaluating the crop for timing the final irrigation at 350 after cutout. We had similar findings in 2013. Extending the irrigation season with an additional irrigation on 21 August at seasonal cutout + 366 DD60s had no effect on yield. Based on Watermark sensors, soil moisture appeared sufficient at the crop stage appropriate for termination. Soil moisture dropped below those values prior to harvest. It is unknown if additional irrigations would have impacted yield, although in previous research with multiple extended end-dates for final irrigation at the same production farm, this has not been shown (Vories et al., 2011).

Soil moisture sensors should inform irrigation managers on not only *when* to schedule irrigations but also the *effectiveness* of their irrigations. The Watermark sensors failed to detect irrigation events in sandy loam soils. These data suggest a lack of capillary rise in the raised beds. The apparent lack of plant-available water resulted due to reduced infiltration and greater runoff. Expanded research is needed in improving irrigation water availability to plants and also on placement of sensors to detect plant-available water. Efficient use of soil sensor information ultimately should provide irrigation managers with greater confidence in using plant-based irrigation termination timing. Adoption of irrigation best management practices in irrigation will help conserve precious groundwater supplies and will benefit Arkansas's cotton growers by reducing production costs without sacrificing yield.

ACKNOWLEDGMENTS

We thank David Wildy and Wildy Family Farms for their long-term support of cotton research. This project was funded by a Cotton Incorporated Core Sustainability project. The University of Arkansas System Division of Agriculture, Agricultural Experiment Station and Arkansas State University also contributed. We thank E.J. Kelly for technical support.

LITERATURE CITED

Bourland, F.M., D.M. Oosterhuis, and N.P. Tugwell. 1992. The concept for monitoring the growth and development of cotton plants using main-stem node counts. J. Prod. Agric. 532-538.

Lieb, Brian and D.K. Fisher. 2012. Sensor-based scheduling. *In:* C. Perry and Ed Barns (eds.), Cotton irrigation management for humid regions. Cotton, Inc. Cary, N.C.

Monge, Juan Jose, T. G. Teague, M.J. Cochran, and D.M. Danforth, 2007. Economic impacts of termination timing for irrigation and plant bug control. pp. 1396-1405. *In:* Proc. Beltwide Cotton Conf., New Orleans, La., 9-12 Jan. National Cotton Council, Memphis Tenn.

Oosterhuis, D.M. and F.M. Bourland. 2008. (eds.) COTMAN Crop Management System. University of Arkansas Agricultural Experiment Station, Fayetteville, Ark. and Cotton Incorporated, Cary, N.C. 107 pp.

Teague, T.G. 2011. Irrigation Timing and Tarnished Plant Bug Management – Implications for Late Season Susceptibility to Tarnished Plant Bug and Crop Termination Decisions - Year III. pp.1186-1198. *In*: Proc. Beltwide Cotton Conf., Atlanta, Ga., 4-7 Jan. 2011. National Cotton Council, Memphis, Tenn.

Vories E.D., J.K. Greene, T.G. Teague, J.H. Stewart, B.J. Phipps, H.C. Pringle, E.L. Clawson, R.J. Hogan, P.F. O'Leary, and T.W. Griffin. 2011. Determining the optimum timing for the final furrow irrigation on Mid-South cotton. Appl. Eng. Agric. 27:737-745.

Table 1. Dates and timing of phenological crop endpoints for furrow irrigation termination trial at Wildy Family Farms, Manila, Ark. 2013.

			Heat Units (DD60s) from cutout		
End-of-season production activity	Date	Days after planting	Seasonal-85%[a] 31 July	Seasonal-50% 11 August	NAWF=5[b] 13 August
Final irrigation	21 August	104	366	175	117
Defoliant application	17 September	131	870	677	621

[a] The weather restricted, seasonal cutout date is the calendar date based on historical weather on which there is a 50% or 85% probability that the crop will have the benefit of late season temperatures sufficient to develop a mature boll.

[b] Physiological cutout (NAWF = 5) was not observed until after the latest possible cutout dates, 31 July and 11 August.

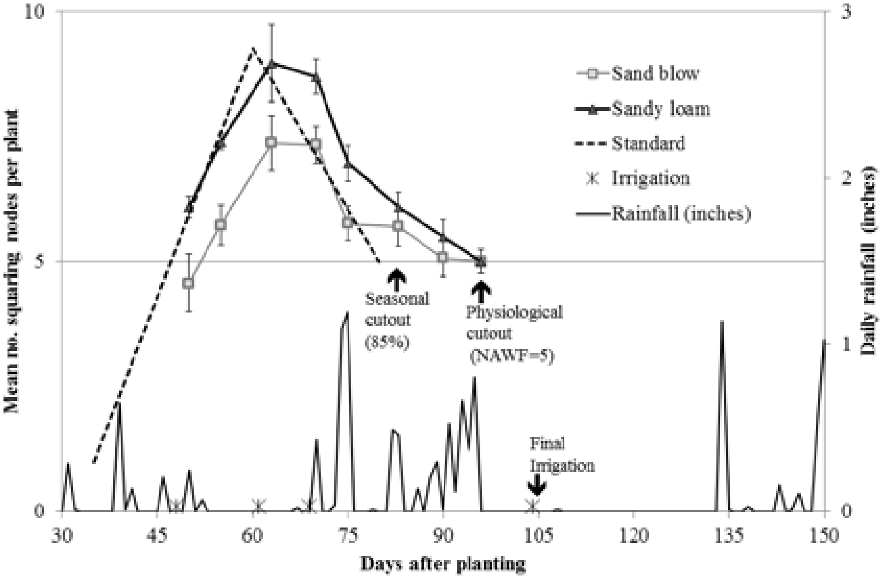


Fig. 1. COTMAN growth curves for plants in irrigated sandy loam soil and coarse sand (sand blow areas) in 2013 irrigation trial at Wildy Family Farms, Manila, Ark.; daily rainfall (inches) also is shown.

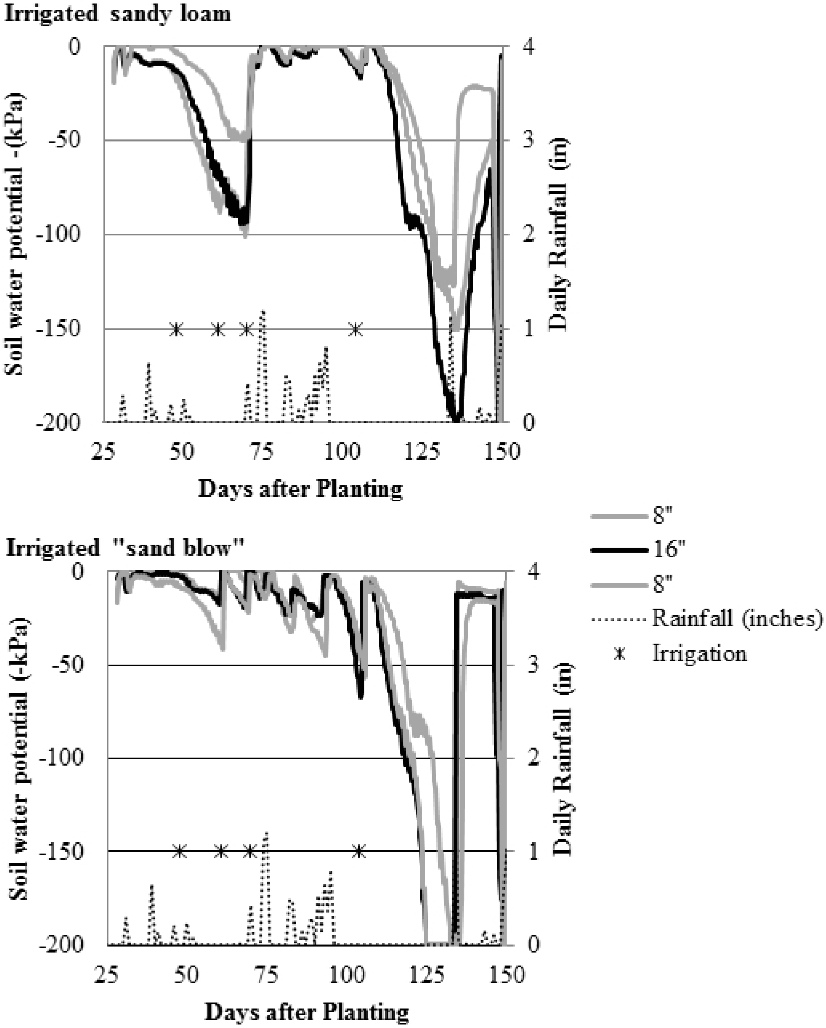


Fig. 2. Soil water potential measurements in two different soil textures, sandy loam and coarse sand (sand blow area) in 2013 irrigation trial at Wildy Family Farms, Manila, Ark.

Development and Testing of an Available Soil Moisture Index to Characterize Drought Stress

T.B. Raper, D.M. Oosterhuis[1], E.M. Barnes[2], P.J. Bauer[3], J.L. Snider[4], D.M. Dodds[5], G.C. Collins[6], J. Whitaker[7], C.D. Monks[8], and M.A. Jones[9]

RESEARCH PROBLEM

Drought tolerance is an important factor for dryland producers selecting varieties for their production system. This varietal characteristic is also important for irrigated producers interested in reducing the amount of applied irrigation water. Currently varietal drought tolerance is derived from dryland variety trials conducted throughout the Cotton Belt, but drought in these trials is characterized by rainfall amounts alone. This parameter does not give producers insight into the timing, length, frequency, or magnitude of the water deficits experienced during the growing season. Subsequently, attempts to combine resulting yields from dryland variety trails across locations have been difficult when using the parameter of rainfall to characterize experienced drought. A drought stress index which utilizes in-field measurements has the potential to define drought parameters and therefore serve as the framework for compiling regional yield responses to drought stress.

BACKGROUND INFORMATION

The concept of a drought-stress quantifying index was first thoroughly defined by Hiler and Clark (1971) as a method of increasing water use efficiency by optimizing irrigation scheduling. Proposed parameters to calculate this index were either coarse-resolution plant measurements or meteorological data. Jackson et al. (1981) advanced this concept by developing the Crop Water Stress Index (CWSI) which utilized the much higher-resolution plant measurement of canopy temperature as the main stress indicator. Still, this index was developed in climates

---

[1] Graduate assistant and distinguished professor, respectively, Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville.

[2] Senior director of agricultural and environmental research, Cotton Incorporated, Cary, N.C.

[3] Research agronomist, Coastal Plain Soil, Water and Plant Conservation Research Center, Agricultural Research Service, Florence, S.C.

[4] Assistant professor, Crop and Soil Sciences, University of Georgia, Tifton, Ga.

[5] Associate extension professor, Department of Plant and Soil Sciences, Mississippi State University, Mississippi State, Miss.

[6] Assistant professor and extension cotton agronomist, Department of Crop and Soil Sciences, University of Georgia, Tifton, Ga.

[7] Public Service assistant, Department of Crop and Soil Sciences, University of Georgia, Tifton, Ga.

[8] Extension specialist professor, Department of Agronomy and Soils, Auburn University, Auburn, Ala.

[9] Associate professor, Department of Entomology, Soils, and Plant Sciences, Clemson University, Clemson, S.C.

which rarely experience cloud cover or afternoon thunderstorms. These conditions greatly contrast conditions of the humid Southeast and mid-South regions where a large percentage of dryland cotton is produced.

The recent development of capacitance-based, dielectric constant volumetric water content (VWC) sensors are capable of accurately quantifying soil moisture at a very high temporal frequency. These sensors are characterized by a small field of influence; but due to their low cost, large deployments are feasible in many situations (Czarnomski et al., 2005). Deployments of these sensors in cotton variety trials have the potential to characterize soil moisture deficit stress and therefore give insight into drought timing, magnitude, frequency, and length of water deficit. Therefore, the main objectives of this research were to develop a soil moisture-based index to quantify drought stress in dryland cotton variety trials and determine the plausibility of extrapolating accumulated index readings to the field scale from a limited number of point measurements.

RESEARCH DESCRIPTION

Two types of trials were deployed in the 2013 growing season. The first type, referred to as ‘developmental’, was conducted in order to create a range of water statuses within one field and to determine the influence of varietal water uptake on calculated index readings. The second type, referred to as ‘testing’, was conducted in order to determine if small deployments of soil moisture sensors into existing dryland variety trials could be used to calculate the developed index and therefore characterize experienced drought. During the 2013 season, a total of 3 developmental and 8 testing trials were conducted. Site locations included Alabama, Arkansas, Georgia, Mississippi, and South Carolina.

Regardless of trial type, each observed profile was characterized by 4 low-frequency, capacitance-based Decagon EC-5 or 5TE soil moisture sensors (Decagon Devices, Inc., Pullman, Wash.). These sensors were installed into an augured, in-row down-hole at 3, 9, 18, and 30-inches immediately after emergence and removed prior to defoliation. In order to test the sensitivity of the drought stress index to reductions in yield, seedcotton yields from all trials were collected and compared to accumulated Soil Moisture Stress Index (SMSI) units.

RESULTS AND DISCUSSION

The developed SMSI is a function of a stress parameter derived from plant-available water (PAW) and a general crop susceptibility curve (Fig. 1A, 1B). These two parameters are multiplied together and accumulated on an hourly time-scale. Since the volume of PAW is influenced by multiple soil parameters, the upper and lower limits of PAW were selected for each sensor depth from in-season sensor readings. The upper threshold of PAW was defined as the maximum sensor reading from a calculated four-day moving average. The lower threshold of PAW was defined as the lowest sensor reading observed in the trial. These thresholds rely on multiple assumptions: first, that saturated and near-permanent wilting point conditions existed at least once during the growing season for one sensor at all depths; second, that the four day moving average will result in selection of a value roughly two days after the saturating event, and therefore, this reading will correlate strongly with field capacity; third, that absolute sensor readings across within-field locations are stable; and finally, that the profiles in which deployments were made are relatively uniform in soil properties.

Many trials experienced abnormally large rainfall amounts during the 2013 growing season. Still, this rainfall was not always well-timed and drought stress did occur in multiple trials. For example, the developmental trial conducted at the Lon Mann Cotton Research Station in Marianna, Arkansas did not receive sufficient rainfall during much of the effective boll fill period. Plant-available water declined substantially during this period and as a result substantial drought stress developed in multiple plots (Fig. 2). This stress was prevented or reduced in several plots through furrow irrigation and larger soil water reserves. The resulting decrease in seedcotton yields relative to experienced drought stress, proxied by accumulated SMSI units, is displayed in Fig. 3. It should be noted that this type of within-field variability in drought status will not typically be experienced within dryland variety trials and is a function of plot manipulation for the development of the drought-quantifying index. In contrast, accumulated SMSI units across a several-acre dryland variety trial would theoretically be very similar. Still, the moderate- to strong relationships between absolute seedcotton yields and accumulated SMSI units noted from the autonomous threshold selection procedure at the Arkansas location suggest this index has potential for characterizing yield-reducing water-deficit stresses without user bias.

Volumetric water content measurement stability across dryland variety trials can be tested by comparing within-field locations. One example comparison can be found in Fig. 4, where estimated volumetric water contents at the four monitored depths in Eupora, Missippi were summarized by in-field location and compared to other in-field locations. Strong coefficients of determination ($0.951 < r^2 < 0.986$) suggest relative values from location to location are fairly consistent. Further analysis will be conducted to compare calculated PAW across these locations and determine if the number of sensors required to accurately characterize each location could be reduced.

PRACTICAL APPLICATIONS

The developed SMSI appears to be a practical method of monitoring drought stress experienced during the growing season. As a result, calculation and accumulation of SMSI units in local dryland variety trials has the potential to provide producers with insight into the relative varietal yield response to a range of drought timings, magnitudes, and lengths. This type of dataset would be much more powerful than single point observations of individual variety trials. Furthermore, the SMSI index has potential to be calculated under irrigated conditions for the purpose of better irrigation scheduling.

ACKNOWLEDGMENTS

Support for this research was provided by Cotton Incorporated. The authors would like to thank all collaborating county agents, producers, station managers, specialists, and industry contacts.

LITERATURE CITED

Czarnomski, N., G. Moore, T. Pypker, J. Licata, and B. Bond. 2005. Precision and accuracy of three alternative instruments for measuring soil water content in two forest soils of the Pacific Northwest. Can. J. For. Res. 35:1867-1876.

Hiler, E.A., and R. N. Clark. 1971. Stress-day index to characterize effects of water stress on crop yields. Trans. Amer. Soc. Agr. Eng. 144:757-761.

Jackson, R.D., D.B. Idso, R.J. Reginato, and P.J. Pinter Jr. 1981. Canopy temperature as a crop water stress indicator. Water Resour. Res. 17:1133-1138.

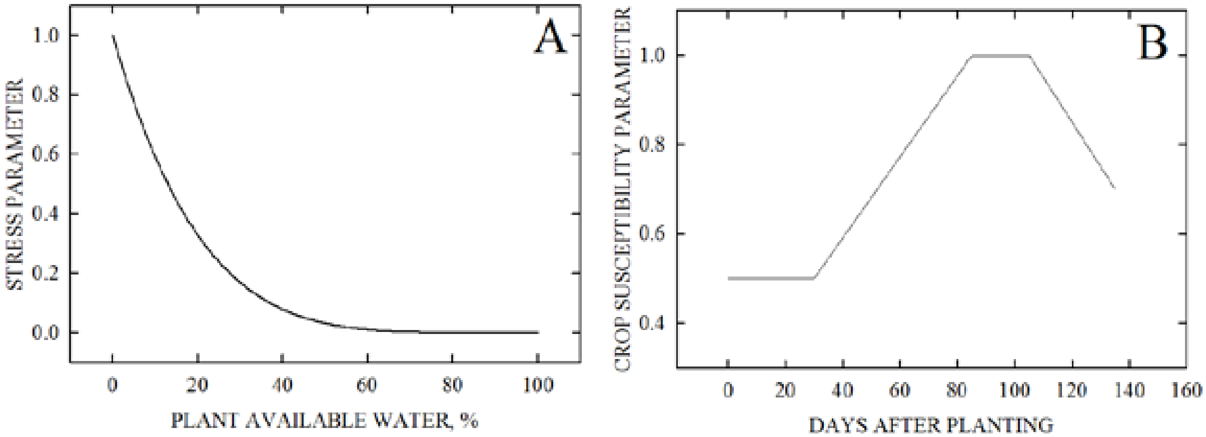


Fig. 1. (A) Relationship between the stress parameter and plant-available water. (B) Relationship between the crop susceptibility parameter and days after planting.

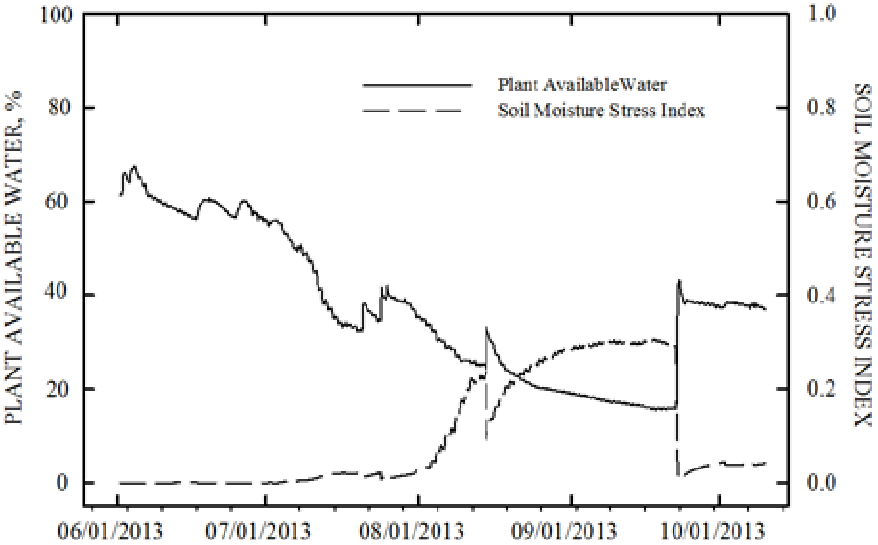


Fig. 2. Observed plant-available water and corresponding Soil Moisture Stress Index values over time for one monitored profile in Marianna, Ark. Upper and lower limits of plant-available water are derived from soil moisture sensor readings noted within the trial. Spikes in plant-available water relate to either irrigation or rainfall events.

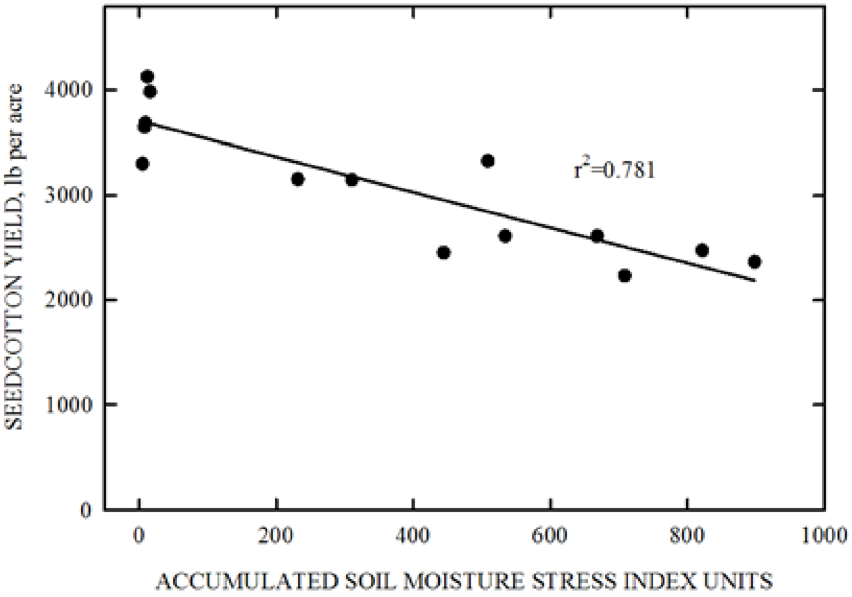


Fig. 3. Relationship between accumulated Soil Moisture Stress Index units calculated from sensors under three varieties and corresponding seedcotton yields in the Marianna, Ark. development trial.

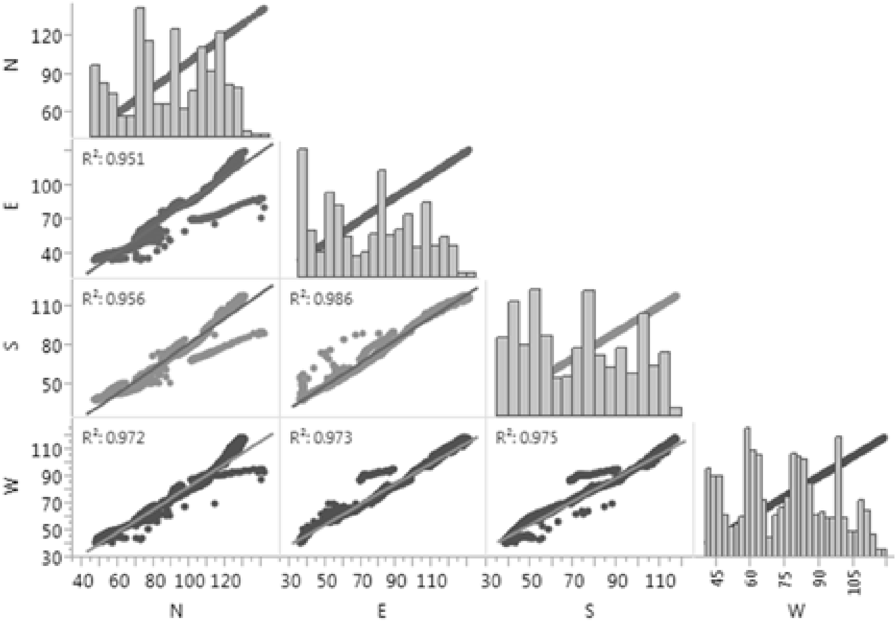


Fig. 4. Relationships between summarized volumetric water contents noted at the northern, eastern, southern, and western monitored profiles in the Eupora, Miss. testing deployment.

Sensitivity of Two Inexpensive, Commercially Produced Soil Moisture Sensors to Changes in Water Content and Soil Texture

T.B. Raper[1], C. Henry[2], L. Espinoza[3], M. Ismanov[4], and D.M. Oosterhuis[1]

RESEARCH PROBLEM

The most critical step in irrigation scheduling is the determination of plant-available water relative to a yield-reducing lower water limit. In the humid mid-South and Southeastern regions of the U.S., this step has traditionally consisted of an indirect inference on water status through a visual inspection of the crop or soil. In more recent years, more advanced water balance, or 'checkbook', methods have been introduced (Vories et al., 2001). Although typically better than arbitrary time-based irrigation scheduling regimes, these methods may fail to estimate runoff, leaching, or soil moisture at initiation. Furthermore, some of these methods rely on estimated volumes of daily crop water use instead of experimentally verified volumes (Vories et al., 2004). The characterization of in-field conditions through some real-time measurement has the potential to give producers insight into actual crop water status and remove many uncertainties associated with more arbitrary methods of irrigation scheduling.

BACKGROUND INFORMATION

Recent advancements in electronics have resulted in a drastic increase in the number of commercially available soil moisture sensors, many of which vary substantially in cost and application (Chávez and Evett, 2012; Muñoz-Carpena, 2006; Robinson et al., 2008). Still, only a few of these sensors are inexpensive enough to be appropriate for large deployments necessary for spatially dense readings. Two sensor types which currently meet these criteria are granular matrix sensors and low-frequency, capacitance-based sensors. Granular matrix sensors have been commercially available for many years and use resistance between two electrodes to infer soil water potential. Low-frequency, capacitance-based sen-

---

[1] Graduate student and distinguished professor, respectively, Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville.

[2] Assistant professor, Rice Research and Extension Center, Department of Biological and Agricultural Engineering, Stuttgart.

[3] Associate professor, Department of Crop, Soil, and Environmental Sciences, Little Rock.

[4] Program technician, Lon Mann Cotton Research Station, Department of Crop, Soil, and Environmental Sciences, Marianna.

sors have been commercially introduced more recently. In contrast to the granular matrix, tensiometric sensors, the low-frequency, capacitance-based sensors rely on the dielectric characteristics of the sensing medium to infer volumetric water content (VWC).

Two low-cost soil moisture sensors and their associated data loggers were selected based on price and availability. These included the Decagon 10HS and Em50 Data Logger (Decagon Devices, Inc., Pullman, Wash.), and the Watermark 200SS and Watermark 900M Monitor (Irrometer Company, Inc., Riverside, Calif.).

The Decagon 10HS Soil Moisture Sensor Probe is a 70 MHz capacitance/frequency domain sensor. This probe also infers soil moisture by measuring the dielectric constant of the surrounding media. The output range of the unit is isolated from input voltage by an internal voltage regulator; as a result, excitation can vary from 3-15 V. This unit is composed of two independent probes and can also be installed into undisturbed soil horizons. According to the manufacturer, this device is accurate to within ±3 VWC when utilizing the standard calibration equation.

In contrast to the Decagon 10HS sensor, the Watermark 200SS sensor estimates soil water potential by monitoring electrical resistance. The 200SS consists of two electrodes placed in a granular matrix surrounded by stainless-steel mesh which allows the sensor to equilibrate with the surrounding soil after installation. The sensor also contains gypsum as a method to decrease sensor sensitivity to salinity.

The objective of this research was to test the responses of two commercially produced, low cost soil moisture sensors to changes in water content of three dissimilar soils representing common soils in Arkansas row-crop production.

RESEARCH DESCRIPTION

A container experiment was conducted at the Lon Mann Cotton Branch Experiment station in Marianna, Ark. during 2013. Three dissimilar soils were selected for inclusion in the study. Tested soils included an Alligator silty clay loam, a Calloway silt loam, and a Robinsonville sandy-loam. Prior to the initiation of the study, roughly 60 kg of each soil was dried, ground, and sieved through a number 4 mesh screen. After processing, 17 kg of each soil was placed in a plastic, 19-L container with multiple drilled holes in the bottom and sides to allow drainage to occur. This process was repeated three times for each soil, resulting in nine total containers.

Saturated conditions were created by either allowing rainfall to wet the containers or by pouring water into the containers. After each saturating event, the containers were left exposed to the atmosphere. Containers were covered with a plastic tarp if rainfall was expected. These practices ensured that a substantial, prolonged dry-down period occurred. Each container was weighed daily to determine gravimetric water content. Volumetric water content was calculated by multiplying gravimetric water content by the bulk density of each soil.

One Decagon 10HS and one Watermark 200SS sensor was placed near the center of each container within an inch of the soil surface in a vertical orientation. Each sensor was monitored by data loggers produced by the same manufacturer. Data was collected from sensors at an hourly interval and the manufacturer provided conversions were used to convert from sensor readings to either soil water potential or VWC.

RESULTS AND DISCUSSION

All nine Decagon 10HS sensors reported logical, consistent data throughout the examined time period. The relationship between container VWC and 10HS estimated VWC was best characterized by a three parameter, nonlinear exponential rise to a maximum curve (Fig. 1). Since this relationship was hypothesized to be linear, trends over time were further examined (data not shown). Outside of a three or four day buffer immediately prior and following the re-wetting events, the 10HS sensors consistently over-predicted soil moisture at most sampling points. These discrepancies, which were influenced by soil texture, can be best explained by non-uniform drying of the soil container and the small sphere of influence on the 10HS sensors relative to the large volume of soil placed in each container. Since sensors were placed near the center of each container, it is logical that as the soil dried from the exterior and upper portions of the container and therefore the measured VWC of the container declined more rapidly than the soil contained in the sensor's sphere of influence.

The Watermark 200SS sensors' responses over time for individual containers generally followed the inverse of the container VWC (Fig. 2). Trends did highlight an over prediction of soil water potential relative to the container VWC due to non-uniform drying of the tested containers (data not shown). As expected, the response of each soil water potential sensor was highly influenced by soil texture. This response is most evident when considering the rate of soil water potential decline immediately after each saturating irrigation event for each tested soil texture. Watermark 200SS sensors placed in the silty clay loam containers were characterized by a very rapid decline in soil water potential which began almost immediately after the saturating event. In contrast, sensors placed in the sandy loam containers were best characterized by two distinct rates of decline: an initial, fairly slow rate of decline followed by a much more rapid rate of decline. Temperature effects on sensor reading were substantial (data not shown). Figure 2 highlights the narrow range of water potentials in which useful data can be collected with the 200SS sensor. Although the 200SS may perform well under near-field capacity levels of soil water, another sensor, such as the 10HS, may be more appropriate for deployments into fields which will most likely experience some stage of drought during the year.

Relationships between 10HS estimated VWCs and 200SS estimated soil water potentials graphed by texture can be found in Fig 3. The most consistent relationships between these two sensor types are found in the coarser sandy loam containers (Fig. 3C). The much weaker relationships observed in the finer textured silt loam and silty clay loam containers (Fig. 3A, B) can be partially attributed to hysteresis of the 200SS sensor, changes in soil-to-sensor contact of both the 10HS and 200SS sensors, temperature sensitivity of the 200SS sensors, and slight variations in water content immediately adjacent to each tested sensor.

PRACTICAL APPLICATION

The failure of the sensors to accurately predict container VWC emphasizes the relatively small quantity of soil on which these sensors rely as well as the potential variability in soil moisture within a very limited volume. This study did indicate that the 10HS was not substantially impacted by texture or temperature. In contrast, the 200SS was not as well buffered to variations in soil temperature. Still, measurements taken near dawn from the 200SS reduced the temperature influence on sensor readings. Fortunately the large shifts in soil temperatures and the substantial preferential drying observed in these containers will most likely not characterize field conditions. This research suggests both sensors could be used to give insight on in-field water status given that influential parameters other than water content/potential are considered.

ACKNOWLEDGMENTS

The authors thank Mukhammadzakhrab Ismanov for initiating the trial as well as collecting and organizing this experimental data.

LITERATURE CITED

Chávez, J.L. and S.R. Evett. 2012. Using soil water sensors to improve irrigation management. pp. 187-202. *In:* Proc. 24th Ann. Central Plains Irrig. Conf., Colby, Kan. 21-22 Feb. 2012.

Muñoz-Carpena, R. 2006. Field devices for monitoring soil water content. Deptepartment of Agricultural and Biological Engineering, University of Florida Institute of Food and Agricultural Sciences Extension Bulletin 343.

Robinson, D.A., C.S. Campbell, J.W. Hopmans, B.K. Hornbuckle, S.B. Jones, R. Knight, F. Ogden, J. Selker and O. Wendroth. 2008. Soil moisture measurement for ecological and hydrological watershed scale observatories: a review. Vadose Zone J. 7:358-389.

Vories, E.D., P.L. Tacker, and R.E. Glover. 2001. Improving cotton irrigation scheduling in Arkansas. pp. 54-58. *In*: D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research 2001. Agricultural Experiment Station Research Series 497.

Vories, E.D., P.L. Tacker and R.E. Glover. 2004. Improving cotton irrigation scheduling in Arkansas. pp. 62-67. *In*: D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research 2003. Agricultural Experiment Station Research Series 521.

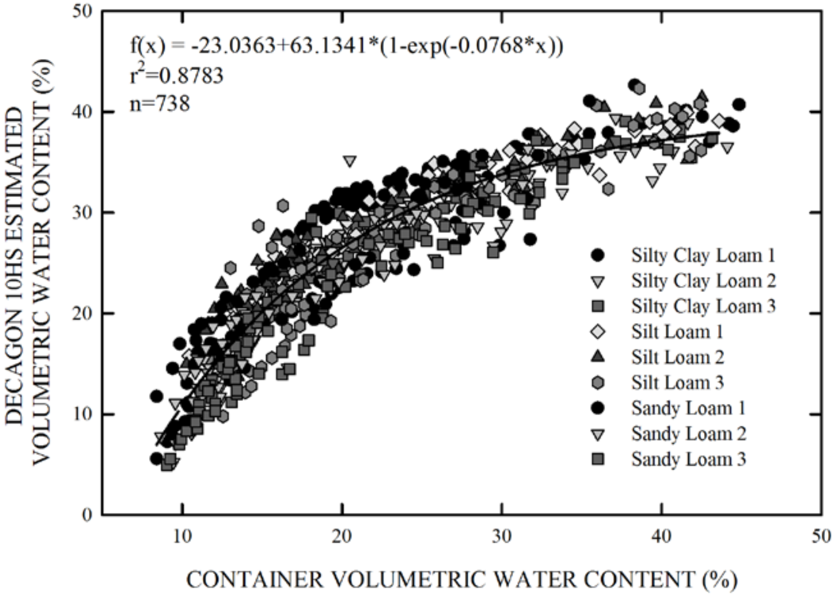


Fig. 1. Relationships between measured container volumetric water content and predicted volumetric water content by the Decagon 10HS Sensors.

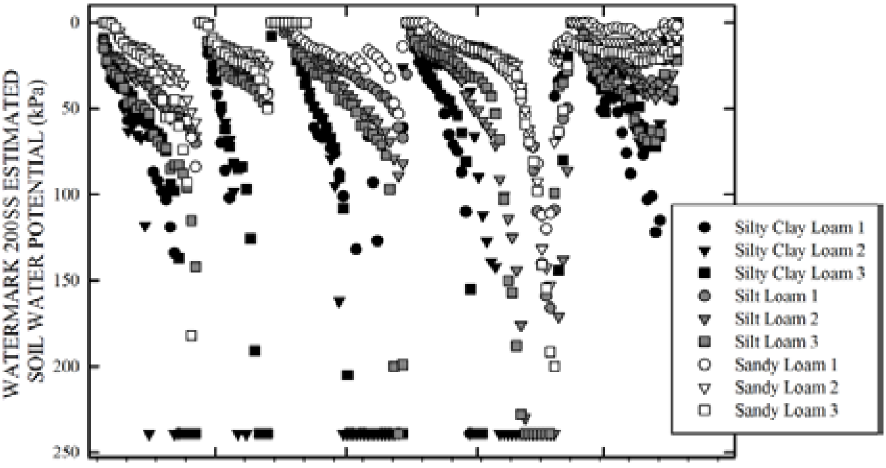


Fig. 2. Watermark 200SS reported soil water potentials during the trial period. Each point represents an individual observation for one container at 0800 CST.

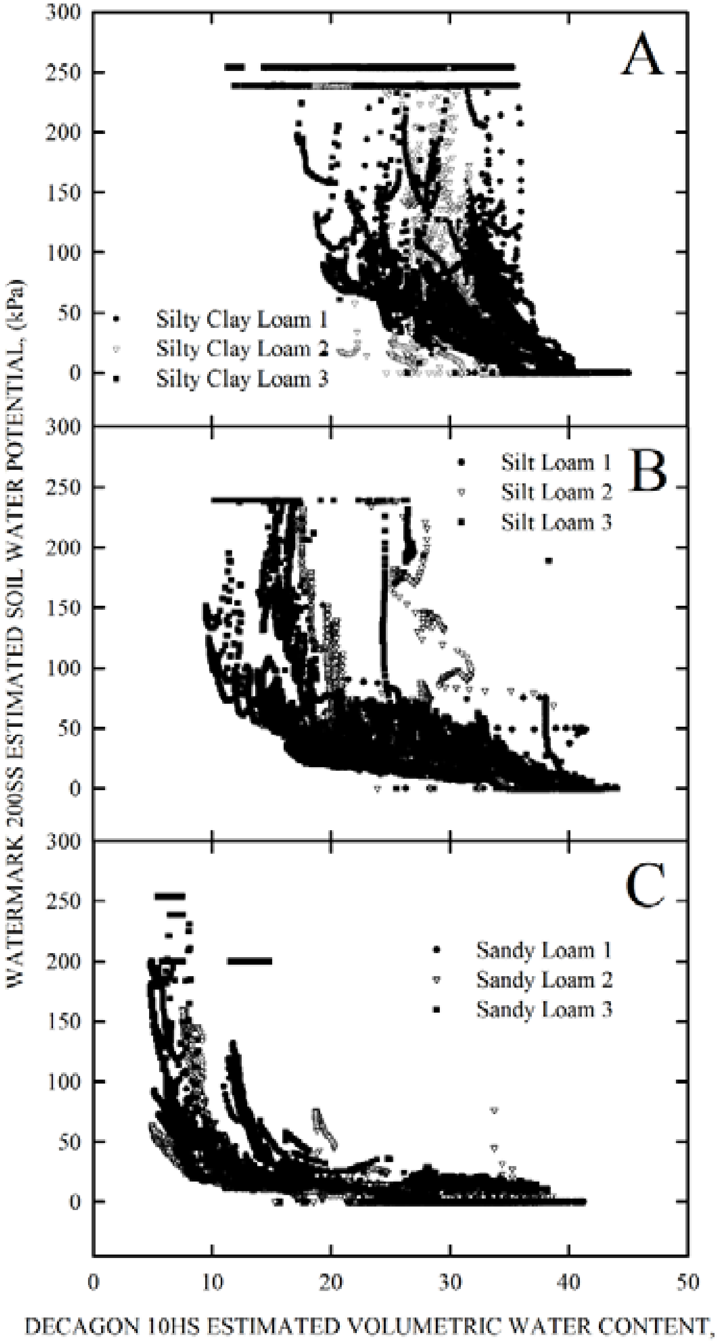


Fig. 3. Relationship between Watermark 200SS estimated soil water potential and Decagon 10HS estimated volumetric water content for the silty clay loam (A), silt loam (B), and sandy loam (C) containers.

Effect of Drought in the Osmotic Adjustment of Cotton Plants

C. Pilon[1], D.M. Oosterhuis[1], G. Ritchie[2], and E.A. de Paiva Oliveira[1]

RESEARCH PROBLEM

Water is crucial for crop growth and productivity. Cotton metabolism and yield are compromised under drought conditions, especially at flowering stage. Differences in drought tolerance exist among cultivars but the metabolic reasons for this that could be used to find traits for enhancing drought tolerance have not been clearly elucidated. Under drought stress, osmotic adjustment occurs in plant cells through accumulation of compatible solutes in the cytosol and plays a role of reducing the osmotic potential of the cell in order to maintain cell turgor and growth. Research has been reported on osmotic adjustment of cotton leaves and roots. However, there is no information on the osmotic adjustment in the reproductive organ of cotton plants. Therefore, studies are needed on the response of the reproductive organ in order to fully understand the osmotic adjustment mechanism in cotton plants under drought stress.

BACKGROUND INFORMATION

Water deficit is the most important factor limiting crop yield worldwide (Kramer, 1983). Plant growth, including biochemical and physiological processes, is affected by water deficit stress (Gardner et al., 1983). The results of water deficit stress depend on the severity and duration of drought as well as the growth stage and genotype of the plant (Kramer, 1983).

In cotton plants, the sensitivity to drought stress during flowering and boll development has been well established (Constable and Hearn, 1981; Turner et al., 1986). Lint yield is reduced by decrease in boll production due to reduction in flowering sites and increased boll abscission when the plant is exposed to extreme drought during reproductive development (McMichael and Hesketh, 1982; Turner et al., 1986; Pettigrew, 2004). There is a positive correlation between yield and number of bolls produced (Grimes et al., 1969), but the biochemical and metabolic processes affecting boll maintenance are not well understood.

Under drought stress, osmotic adjustment occurs in plant cells through accumulation of compatible solutes in the cytosol (Xiong and Zhu, 2002). Compatible

---

[1] Graduate assistant, distinguished professsor, and international scholar, respectively, Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville.

[2] Assistant professor, Texas Tech University, Department of Plant and Soil Sciences, Lubbock, Texas.

solutes, such as proline, glycine betaine, and sorbitol, are highly soluble and do not interfere with cell metabolism even in high concentrations (Bray et al., 2000). In most plants, osmoregulation through the accumulation of solutes has the function of reducing the osmotic potential of the cell in order to maintain cell turgor and growth (Mafakheri et al., 2010). Proline is one of the most common compatible solutes in plants under drought stress (Bray et al., 2000). Proline accumulation represents a regulatory mechanism of water loss by reducing the cell water potential (Fumis and Pedras, 2002). As in most plants, leaf water potential (ψ_l) is reduced under drought conditions. Cotton has the ability to osmotically adjust and maintain a higher leaf turgor potential (ψ_t) (Oosterhuis and Wullschleger, 1987; Turner et al., 1986; Nepomuceno et al., 1998). However, water relations and osmotic adjustment in the ovaries of cotton flowers is uncertain.

The purpose of this study was to characterize the osmotic adjustment of two commercial cotton cultivars under drought stress during the flowering stage.

RESEARCH DESCRIPTION

A field experiment was conducted in 2013 at the New Deal Farm, Texas Tech University in New Deal, Texas. Treatments consisted of two cotton (*Gossypium hirsutum* L.) cultivars, Stoneville 5288 B2RF and Phytogen 499 WRF, and two water regimes, an untreated control with no water-deficit stress, and water deficit imposed at flowering stage. The experimental design was a split-plot with the water regimes as the main plots and the cultivars as split plots. Cotton was planted on 21 May 2013 at a plant density of 3.5 plants/foot. Plots consisted of four rows, 50 feet in length. Row spacing was 38 inches. The experiment was uniformly fertilized according to pre-season soil tests and recommended rates. Weeds and insect control were performed according to recommendations. Mepiquat chloride was added as needed to control vegetative growth. The field was maintained well-watered until the flowering stage. The "control treatment" received the optimum quantity of water throughout the duration of the experiment using a drip irrigation system. Water stress was imposed by withholding water from the "stress treatments" for ten days. Then, the field was re-watered 12 hours before the measurements were taken. Leaf discs from the 4th leaves at the main stems and ovaries from white flowers were collected for determination of osmotic potential (MPa). Samples were measured with screen-caged thermocouple psychrometers (model 74 series, J.R.D. Merrill Specialty Equipment, Logan, Utah) equipped with stainless steel sample chambers using the technique described by Oosterhuis (1987). Osmotic potentials were determined after the psychrometer-chambers were frozen in liquid N for 5 minutes, thawed at room temperature for 30 minutes, and then allowed to equilibrate in waterbath at 25 °C for 4 hours. Readings were made using a micro-voltmeter and chart recorder. Proline concentration (μmol g^{-1} DM) was measured using methodology by Bates et al. (1973). For the colorimetric test, 1 mL of extract, 1 mL of acid ninhydrin, and 1 mL of glacial acetic acid were pipetted. After samples were maintained in waterbath at 95 °C for 60 minutes, tubes were cooled and readings were made in spectrophotometer at 520 nm. L-proline p.a. was used as standard curve. At the harvest, bolls from 1 m of harvest row of each plot were collected for determination of number of bolls and weight of bolls. Seedcotton yield was determined by mechanically harvesting the center two rows of each plot.

RESULTS AND DISCUSSION

Osmotic potential response to water regime was significant ($P \leq 0.05$) for the leaves of ST5288 and ovaries of PHY499 (Fig. 1). Under drought stress, the osmotic potential in the leaves of ST5288 and ovaries of PHY499 were approximately 57% and 240% higher, respectively, than the osmotic potential obtained in well-watered plants. Even though the leaves of PHY499 and ovaries of ST5288 under drought stress showed osmotic potential approximately 14% and 7% higher, respectively, compared with the well-watered treatment (Fig. 1), this increase in the osmotic potential could not be considered as osmotic adjustment of the plants grown under limiting water condition.

Accumulation of proline in the ovaries of plants from ST5288 and PHY499 cultivars was higher under drought stress compared with the well-watered treatment (Fig. 2). However, the proline concentration in the leaves of both cultivars was not significantly different between the water regimes (Fig. 2). It indicates that the osmotic adjustment in cotton plants is higher in the reproductive organs than the vegetative organs under limiting water conditions in the field.

Cotton yield was reduced by the drought stress in both cultivars (Fig. 3). Weight of bolls of water-stressed plants was maintained similar to the well-watered treatment in the two cultivars (data not shown). However, the number of bolls was reduced by the drought stress in plants from ST5288 and PHY499 (data not shown). The drought stress was sufficiently severe to cause shedding of bolls despite osmotic adjustment, which contributed to the lower yield in the water stress treatment.

Osmotic adjustment is an acclimation strategy for cotton to maintain the cells active. There were genotypic differences in osmotic adjustment. For PHY499, higher osmotic adjustment occurred in the ovaries; while for ST5288 it was in the leaves. Drought stress caused shedding of bolls reducing the yield, but the osmotic adjustment contributed to the plant's ability to maintain the weight of retained bolls.

PRACTICAL APPLICATION

Studies have revealed that reproductive organs of several crops exhibit osmotic adjustment under water-deficit stress conditions, but this mechanism has not been shown in the reproductive organ of cotton plants. The knowledge of osmotic adjustment mechanism in cotton flowers is important, since we speculate that osmotic adjustment in the cotton reproductive organs could contribute to alleviate the effects of drought stress by maintaining active cells.

LITERATURE CITED

Bates, L.S., R.P. Waldren, and I.D. Teare. 1973. Rapid determination of free proline for water-stress studies. Plant Soil 39:205–207.

Bray, E.A., J. Bailey-Serres, and E. Weretilnyk. 2000. Response to abiotic stresses. pp. 1158-1203. *In*: B. B. Buchanan, W. Gruissem, and R. L. Jones (eds.). Biochemistry and Molecular Biology of Plants. American Society of Plant Physiologists, Rockville, Md.

Constable, G.A., and A.B. Hearn. 1981. Irrigation of crops in a subhumid climate, 6: effects of irrigation and nitrogen fertilizer on growth, yield and quality of cotton. Irrig. Sci. 2:17-28.

Fumis, T. F. and J. F. Pedras. 2002. Variation in levels of proline, diamine and polyamines in wheat cultivars under drought stress (in Portuguese, with English abstract), Pesq. Agropec. Bras. 37:449-459.

Gardner, W.R. and H.R. Gardner. 1983. Principles of water management under drought conditions. Agric. Water Manage. 7:143-155.

Grimes, D.W., W.L. Dickens, and W.D. Anderson. 1969. Functions for cotton (*Gossypium hirsutum* L.) production from irrigation and nitrogen fertilization variables. II. Yield components and quality characteristics. Agron. J. 61:773-776.

Kramer, P.J. 1983. Water deficits and plant growth. pp: 342-389. *In*: P.J. Kramer (ed.). Water relations of plants. Academic Press, New York, N.Y.

Mafakheri, A., A. Siosemardeh, B. Bahramnejad, P.C. Struik, and Y. Sohrabi. 2010. Effect of drought stress on yield, proline and chlorophyll contents in three chickpea cultivars. Aust. J. Crop Sci. 4:580-585.

McMichael, B.L. and J.D. Hesketh. 1982. Field investigations of the response of cotton to water deficits. Field Crops Res. 5:319-333.

Nepomuceno, A.L., D.M. Oosterhuis, and J.M. Stewart. 1998. Physiological response of cotton leaves and roots to water deficit induced by polyethylene glycol. Environ. Exp. Bot. 40:29-41.

Oosterhuis, D.M. 1987. A technique to measure the components of root water potential using screen-caged thermocouple psychrometers. Plant Soil 103:285-288.

Oosterhuis, D.M. and S.D. Wullschleger. 1987. Osmotic adjustment in cotton (*Gossypium hirsutum* L.) leaves and roots in response to water stress. Plant Physiol. 84:1154-1157.

Pettigrew, W.T. 2004. Moisture deficit effects on cotton lint yield, yield components, and boll distribution. Agron. J. 96:377-383.

Turner, N.C., A.B. Hearn, J.E. Begg, and G.A. Constable. 1986. Cotton (*Gossypium hirsutum* L.) physiological and morphological responses to water deficits and their relationship to yield. Field Crops Res. 14:153-170.

Xiong, L. and J. K. Zhu. 2002. Molecular and genetic aspects of plant response to osmotic stress. Plant Cell and Environ. 25:131-139.

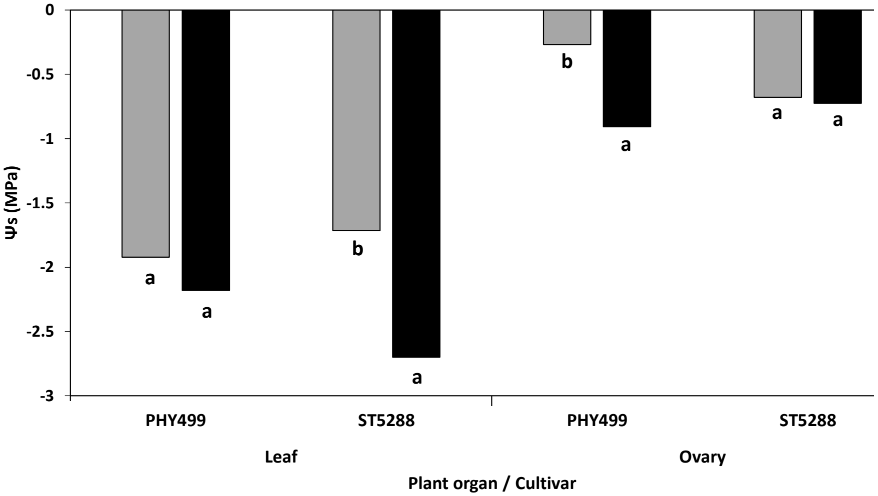


Fig. 1. Osmotic potential (MPa) in the leaves and ovaries of two cotton cultivars, ST5288 and PHY499. Black bars: water stress treatment; gray bars: well watered treatment. Pairs of bars with the same lowercase letters are not significantly different ($P \leq 0.05$).

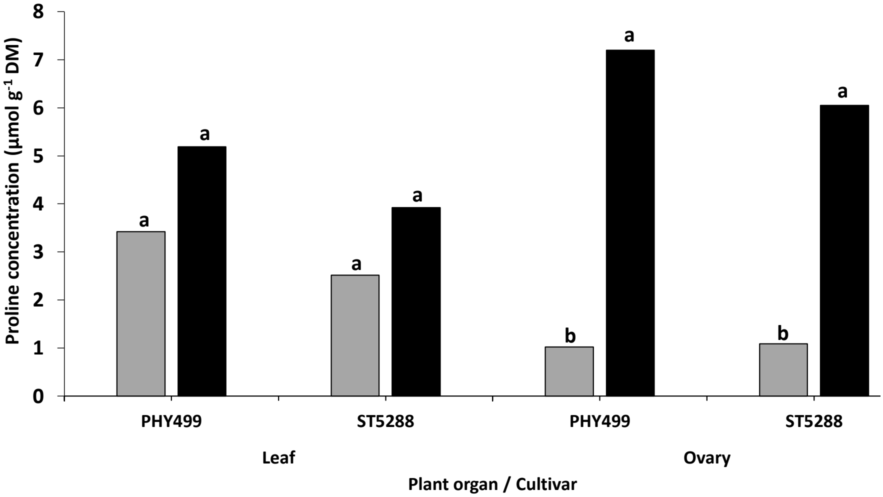


Fig. 2. Proline concentration (µmol g^{-1} DM) in the leaves and ovaries of two cotton cultivars, ST5288 and PHY499. Black bars: water stress treatment; gray bars: well watered treatment. Pairs of bars with the same lowercase letters are not significantly different ($P \leq 0.05$).

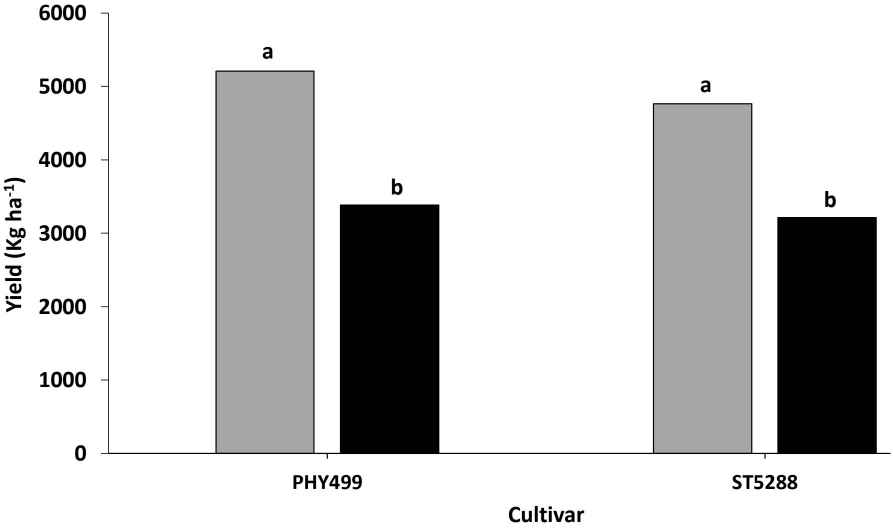


Fig. 3. Seedcotton yield (kg ha^{-1}) of two cotton cultivars, ST5288 and PHY499. Black bars: water stress treatment; gray bars: well watered treatment. Pairs of bars with the same lowercase letters are not significantly different ($P \leq 0.05$).

Development of a Solar Radiation Stress Index for Cotton

M.L. Reba[1] *and T.G. Teague*[2]

RESEARCH PROBLEM

In mid-South cotton fields, a marked increase in small boll abscission following a progression of cloudy days may be erroneously attributed to effects of arthropod pests. The boll shed actually results from a physiological plant response to reduced solar radiation (Dunlap, 1943). Photosynthesis is negatively affected during overcast, cloudy days. Cotton plant sensitivity to light intensity is highest when photosynthetic demand is highest—during the plant reproductive development period (Zhao and Oosterhuis, 1998). With inadequate photosynthetically active radiation, plants will shed young bolls that are less than two weeks old. Overcast conditions during the pre-flower growth stage, when photosynthetic demand is not as high, does not result in square shed, but those same conditions during flowering and boll filling stages will result in fruit loss. If overcast conditions linger, the net results are delayed maturity and lower lint yields (Zhao and Oosterhuis, 1996; Zhao and Oosterhuis, 2000). Fiber quality also is impacted negatively (Pettigrew, 2001). A field measurement of cloudiness will facilitate determination of plant response and help improve our understanding of yield variability in the cloudy, mid-South production region.

BACKGROUND INFORMATION

Fruiting patterns of cotton plants are such that after appearance of the first flower, about 60 days after planting, there typically will be a flower appearing to move up the main stem sympodia every 2.7 to 3 days. Zhao and Oosterhuis (2000) found that 4 days of shading impacted yield especially during the period of effective flowering and boll maturation.

In recent years, state and university weather stations have been upgraded to include a real-time measurement of solar radiation using a pyranometer. Coupling measurements of solar radiation with information from in-season plant monitoring allows for the opportunity to begin development of a solar radiation stress metric for cotton associated with cloudiness. This metric could be used both retrospectively to understand seasonal yield trends and in real-time to anticipate, understand and correctly diagnose plant response to environmental conditions.

---

[1] Research hydrologist, USDA ARS Watershed Physical Processes Research Unit, Jonesboro.

[2] Professor, University of Arkansas System Agricultural Experiment Station, Arkansas State University, Jonesboro.

RESEARCH DESCRIPTION

In development of a solar radiation stress metric, we first quantified cloudiness on a daily time scale and then tracked if the cloudiness persisted for several days. Incoming solar radiation was measured in 2012 and 2013 at the Judd Hill Cooperative Research Station, near Trumann, Ark., with a LP02 Pyranometer (Campbell Scientific, Logan, Utah), a full-spectrum solar radiometer. Hourly totals of incoming solar radiation were cumulated for each day to determine total incoming solar radiation in MJ m^{-2} day^{-1}. Clear sky radiation is the maximum amount of incoming solar radiation for a given day at a specific location, and is calculated from daily extraterrestrial radiation. Daily extraterrestrial radiation was calculated from the solar constant, solar declination and time of year. Clear sky radiation was generated from extraterrestrial radiation corrected for elevation. The cloudiness for a given day was taken to be the ratio of measured incoming solar radiation to calculated-clear sky radiation, hereafter referred to as the cloudiness ratio. To track the persistence of cloudy conditions, a three-day running mean of the cloudiness ratio, centered on the third day, was the basis for the solar radiation stress index.

We coupled the stress index values with seasonal plant monitoring results from a 2013 small plot furrow irrigation trial on the Judd Hill Research Farm. In the field trial, cotton (*Gossypium hirsutum* L.) cultivar DPL 0912 B2RF was planted 15 May in a Dundee silt loam soil. Production practices were similar across all treatments; only irrigation inputs (rain-fed, full-season irrigated and full season plus polyacrilamide (PAM)) were varied for the study. Crop monitoring with COTMAN (Oosterhuis and Bourland, 2008) was performed each week from first squares through the latest possible cutout date—seasonal cutout (11 August).

RESULTS AND DISCUSSION

The calculated clear-sky and incoming radiation illustrates the seasonal variation expected with maximums at the summer and minimums in the winter (Fig.1a). The cloudiness ratio and solar radiation stress index for 2012 and 2013 are shown in Fig. 1b. The average ratio for May 1 through September 15 of 2012 was 0.77 and 0.73 for 2013.

Using the three-day running mean as the basis for a stress metric, we determined the initial threshold for stress to be 0.7. These calculations merit further investigation. Eventually, we anticipate establishing a three-day running average of the ratio below a threshold that could be used to indicate cloud induced radiation deficit stress (Fig. 1a,b).

When the number of days that the three-day running average of the ratio was below the initial stress threshold during the two production seasons studied, we found that there was more cloud stress in 2013 compared to 2012. Summing the number of days the three-day running average was below 0.7 in August was 10 in 2012 and 15 in 2013.

Coupling the stress index with plant growth monitoring helps us understand the potential utility of the metric. The 2013 crop season was atypical for northeast

Arkansas in that an extended period of rainy, cloudy weather befell the area in early August during the effective flowering period of the crop. Figure 2 shows the COTMAN crop growth curves for plants in the rain-fed and irrigated treatments at the Judd Hill Foundation Research Station and the three-day running mean of the stress index. Cloudy weather during the effective flowering period, illustrated in Fig. 2 with a reduction in the solar radiation stress index, likely affected small boll retention (i.e. physiological shed of bolls <12 days old) ultimately reducing yield and delaying crop maturity in 2013. First flowers were observed in samples taken at 61 days after planting. By 68 DAP, the remaining effective flowering period was characterized by a low ratio of solar to clear-sky radiation. Small boll shed levels were lower in rain-fed cotton compared to irrigated cotton (data not shown). There were fewer main-stem sympodia produced in the rain-fed treatments compared to irrigated plants. Although irrigated plants had higher yield potential because of increased fruiting positions compared to rain-fed plants, overall yields were similar between treatments, most likely because of lower retention of upper canopy bolls during the overcast, cloudy conditions between 60 and 92 days after planting (data not shown).

These initial calculations were made using measured incoming solar radiation. An additional measure of photosynthetically active radiation (PAR) was added to our Judd Hill weather station. These data were not included in this analysis but will be in future research.

PRACTICAL APPLICATION

The incorporation of solar radiation measurements into production management has the potential to help improve our understanding of yield variability in the cloudy, mid-South production region. This could be applicable in interpreting yield and fiber quality results from regional variety trials to understand response to overcast conditions. Real-time weather station data also could be made available to producers and crop advisors, as well as researchers, alerting them to the potential for reduced boll retention and maturity delay should the solar radiation deficit stress occur during the effective flowering period and during boll maturation.

LITERATURE CITED

Dunlap, A.A. 1943. Low light intensity and cotton boll shedding. Science 98:268-269.

Oosterhuis, D.M. and F.M. Bourland (eds.). 2008. COTMAN Crop Management System. University of Arkansas Agricultural Experiment Station, Fayetteville, Ark. and Cotton Incorporated, Cary, N.C. 107 pp.

Pettigrew, W.T. 2001. Environmental effects on cotton fiber carbohydrate concentration and quality. Crop Sci. 41:1108-1113.

Zhao, D.L. and D.M. Oosterhuis. 1996. Effects of shade on fiber quality of field-grown cotton. pp. 131-135. *In*: D.M. Oosterhuis (ed.). Summaries of

Arkansas Cotton Research 1996. Arkansas Agricultural Experiment Station Research Series 178.

Zhao, D.L. and D.M.Oosterhuis. 1998. Cotton responses to shade at different growth stages: Nonstructural carbohydrate composition. Crop Sci. 38:1196-1203.

Zhao, D. and D.M. Oosterhuis. 2000. Cotton responses to shade at different growth stages: growth, lint yield and fibre quality. Exp. Agr. 36:27-39.

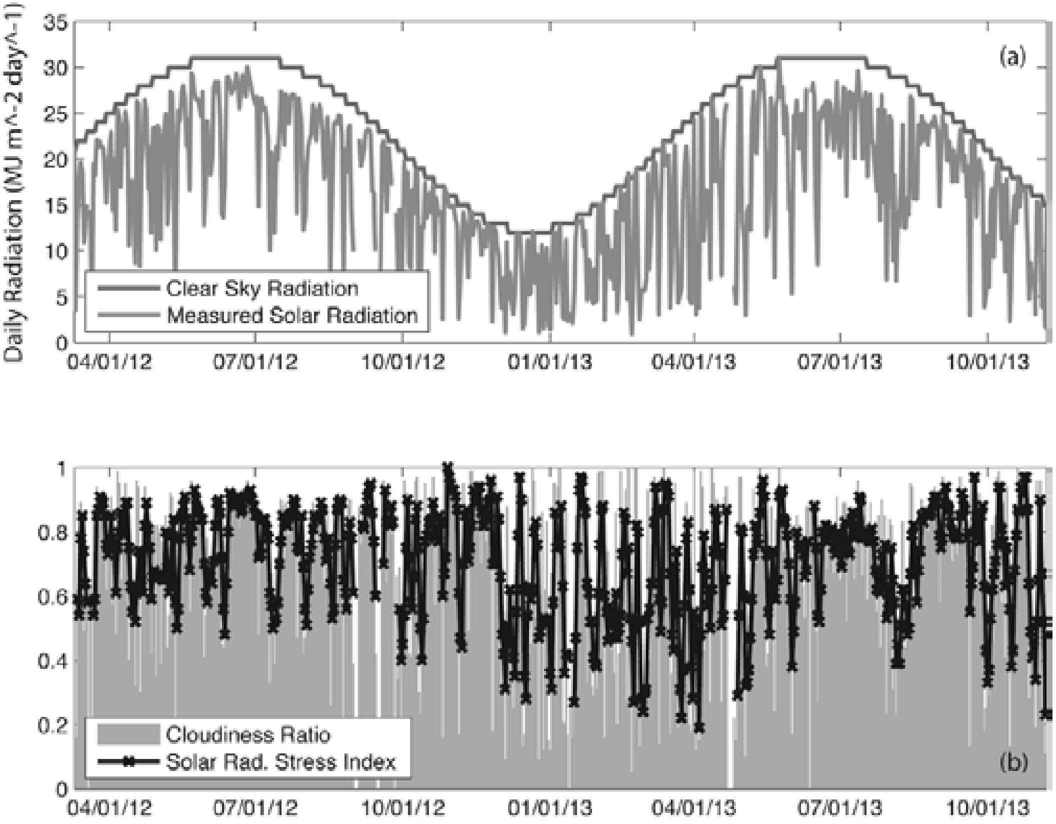


Fig. 1. (a) Measured incoming solar radiation and calculated clear sky radiation at the Judd Hill Cooperative Research Station near Trumann, Ark., and (b) cloudiness ratio with solar radiation stress index.

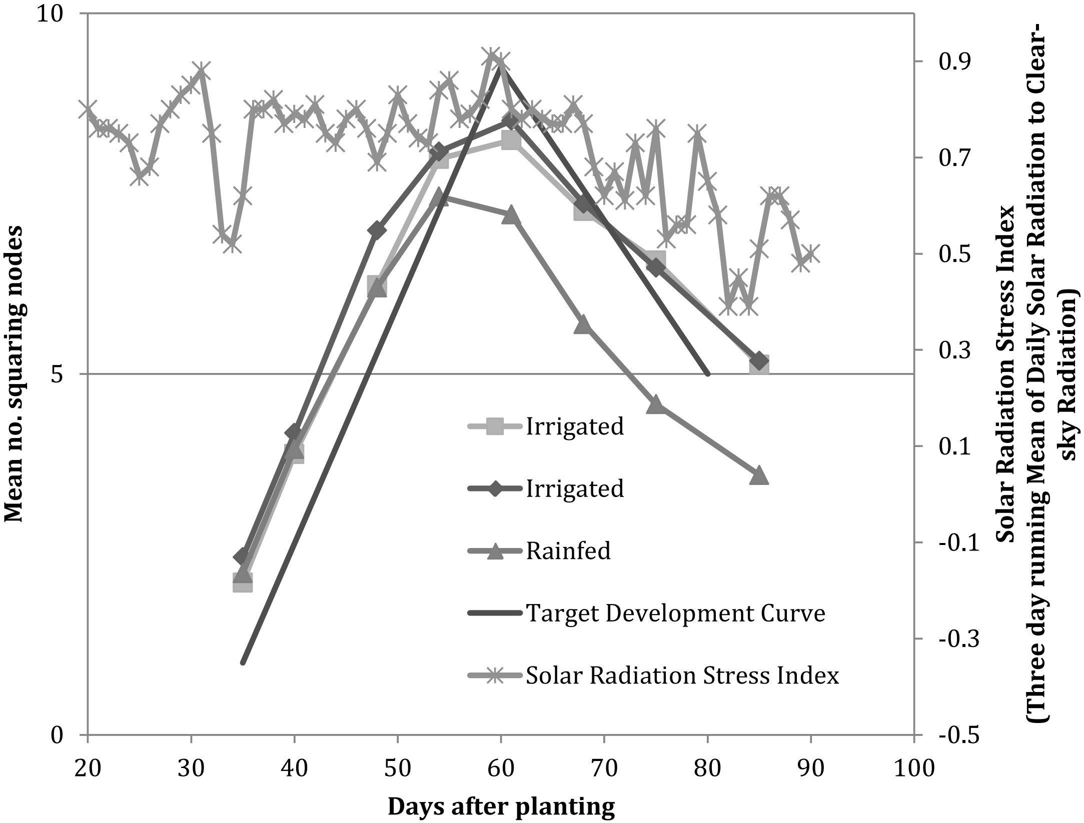


Fig. 2. COTMAN growth curves and solar radiation stress index (three day running mean of daily solar radiation to clear-sky radiation) after 4 June 2013 from a small plot irrigation study at the Judd Hill Foundation Research Farm, Trumann, Arkansas.

Effect of High Night Temperatures During the Vegetative Stage of Cotton

D.A. Loka and D.M. Oosterhuis[1]

RESEARCH PROBLEM

High temperatures are considered to be a major environmental stress contributing to yield reduction. Even though extensive research has been conducted on the effects of high day temperatures on cotton, limited information exists on the effects of high night temperature on cotton growth and productivity.

BACKGROUND INFORMATION

Global temperature is expected to increase by 1.4 to 5.8 ºC by the end of the 21st century due to increases in greenhouse gases concentrations (IPCC, 2007). High temperatures are considered to be a major environmental stress contributing to yield loss; however, night temperatures are anticipated to increase faster than day temperatures due to increased cloudiness that will result in decreased radiant heat loss (Alward et al., 1999**.** Previous research has reported that higher than optimum night temperatures during cotton's vegetative stage of growth resulted in significant increases in respiration rates (Loka and Oosterhuis, 2010). Consequently, depletion in leaf carbohydrates content and significant reductions in leaf adenosine triphosphate levels were observed (Loka and Oosterhuis, 2010), ultimately resulting in yield reduction (Arevalo et al., 2008). The reproductive stage appears to be more susceptible to heat stress compared to the vegetative stage (Hall, 1992). Research in other crops has indicated that high night temperatures during the reproductive phase have detrimental effects on yield due to increased male sterility and floral abscission (Warrag and Hall, 1984; Guinn, 1974), floral bud suppression, decreased pollen viability, spikelet fertility and poor grain filling (Mohammed and Tarpley, 2009). However, little or no attention has been given to the effects of increasing night temperatures on the reproductive forms of cotton. The objective of our study was to evaluate the effect of high night temperatures on carbohydrate content of cotton's squares and their subtending leaves.

---

[1] Post doctoral associate and distinguished professor, respectively, Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville.

RESEARCH DESCRIPTION

Growth chamber studies were conducted in 2013 in the University of Arkansas System Division of Agriculture, Altheimer Laboratory in Fayetteville. Cotton (*Gossypium hirsutum* L.) cultivar ST5288B2F was planted into 2-L pots containing a horticultural mix (Sun-Gro horticulture mix). The growth chambers were set for normal conditions of 32/24 °C (day/night), ±60% relative humidity, and 14 h photoperiod, while half-strength Hoagland's nutrient solution was applied daily in order to maintain adequate nutrients and water. Approximately 5 weeks after planting, plants were randomly divided in two groups: Control (C) and High Night Temperatures (HNT). Control plants were kept at normal day/night temperatures of 32/24 °C while high night temperatures of 30 °C were imposed on the second group from 18:00-06:00 for one week. Plants were arranged in a completely randomized design with twenty replications. Glucose, sucrose, and starch content were estimated from squares and their subtending leaves sampled from the 7th node from each plant at the end of the stress period. Carbohydrate extraction was done according to Zhao et al. (2008) and the supernatants were analyzed with a Multiscan Microplate Reader.

RESULTS AND DISCUSSION

The results showed that high night temperatures had a significant effect on ovary and bract carbohydrate content, whereas subtending leaf carbohydrate levels remained unaffected. Leaf glucose, fructose and sucrose concentrations (Table 1) remained unaltered and the same was observed for leaf starch levels. However, ovary glucose, fructose and sucrose content of heat-stressed plants were significantly increased compared to the control; whereas ovary starch levels remained unaltered (Table 1). A similarity to the ovary carbohydrate concentrations pattern was observed with the bract carbohydrate levels. Bract glucose, fructose and sucrose levels of plants exposed to high night temperatures were significantly increased compared to the control. Bract starch content remained similar to the control (Table 1).

In summary, leaf carbohydrate metabolism appeared to be unaffected by the high night temperatures. On the contrary, carbohydrate metabolism of cotton's reproductive units was significantly affected with both ovary and bract glucose, fructose, and sucrose concentrations significantly increasing under conditions of high night-temperature stress compared to the control indicating a perturbation in carbohydrate metabolism that could lead to inefficient use of carbohydrates.

PRACTICAL APPLICATION

High temperatures are considered to be a basic environmental factor affecting plant growth causing severe yield losses. With the prospect of global temperature significantly increasing in the future due to the greenhouse effect, a better understanding of the physiological, and metabolic responses of cotton's reproductive units under conditions of elevated night temperatures would provide important information for genotypic selection of heat tolerant cultivars, as well as for the formulation of exogenous plant growth regulators.

LITERATURE CITED

Alward, R.D., J.K. Detling, and D.G. Milchunas. 1999. Grassland vegetation changes and nocturnal global warming. Science. 283:229-231.

Arevalo, L.M., D.M. Oosterhuis, D.L. Cocker, and R.S. Brown. 2008. Physiological response of cotton to high night temperatures. Am. J. Plant Sci. Biotech. 2:63-68.

Guinn, G. 1974. Abscission of cotton floral buds as influenced by factors affecting photosynthesis and respiration. Crop Sci. 14:291-293.

Hall, A.E. 1992. Breeding for heat tolerance. Plant Breed. Rev. 10:129-168.

IPCC. Intergovernmental Panel on Climate Change. 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. *In*: Contribution of Working Group II to Fourth Assesment Report of the Intergovernmental Panel on Climate Change. M.L. Parry, O.F. Cnaziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson (eds.) Cambridge University Press, Cambridge, UK.

Loka, D.A., and D.M. Oosterhuis. 2010. Effect of high night temperatures on cotton respiration, ATP levels and carbohydrate content. Environ. Exp. Bot. 68:258-263.

Mohammed, A.R. and L. Tarpley. 2009. High nighttime temperatures affect rice productivity through altered pollen germination and spikelet fertility. Agric. For. Meteor. 149:999-1008.

Warrag, M.O.A. and A.E. Hall. 1984. Reproductive responses of cowpea to heat stress. II. Responses to night air temperature. Field Crops Res. 8:17-33.

Zhao, D., C.T. MacKown, P.J. Starks, and B.K. Kindiger. 2008. Interspecies variation of forage nutritive value and nonstructural carbohydrates in perennial cool-season grasses. Agron. J. 100:837-844.

Table 1. Effect of high night temperatures on leaf, ovary and bract carbohydrate content.

Leaf (mg/mg DW)	**Glucose**	**Fructose**	**Sucrose**	**Starch**
Control	0.009675 a[†]	0.004625 a	0.001193 a	0.012616 a
HNT	0.009493 a	0.005077 a	0.001361 a	0.013138 a
Ovary (mg/mg DW)				
Control	0.010507 b	0.008046 b	0.001701 b	0.01103 a
HNT	0.016426 a	0.016383 a	0.005132 a	0.010889 a
Bract (mg/mg DW)				
Control	0.00825 b	0.002883 b	0.001541 b	0.011127 a
HNT	0.014419 a	0.005970 a	0.003005 a	0.012135 a

[†] Columns with the same letter are not significantly different ($P = 0.05$).

Plasma Membrane Stability During High Temperature Stress and Its Effect on Electron Transport

T. R. FitzSimons and D. M. Oosterhuis[1]

RESEARCH PROBLEM

Under any form of biotic or abiotic stress, a plant must make cellular adjustments to maintain homogeneity within the cell. Among the first cellular components to display a noticeable change is the plasma membrane responsible for maintaining cellular compartmentalization. Under high-temperature stress, the membrane loses its ability to properly regulate permeability, which alters the capability of the cell to maintain homogeneity. Research has focused on recognizing that the cellular membrane becomes more permeable during stress, but little data is currently available on how long the permeability may last. This research focuses on the longer term stress of cotton leaves and adaptation responses to determine the time required for stressed leaves to return to homeostatic levels.

BACKGROUND INFORMATION

Ideal maximal growing temperatures for cotton should not exceed 35 °C (Oosterhuis, 2002). Cotton that is grown in the Mississippi Delta often experience temperatures that surpass this baseline temperature. Thus, temperature stress for cotton remains the greatest unamendable factor affecting crops (Wahid et al., 2007) and is viewed as the most limiting factor associated with diminished crop yields (Crafts-Brandner and Salvucci, 2004). High-temperature stress affects cotton with particular severity due to the thermo-sensitive stages of flowering which occurs during the hottest months of the year (Singh et al., 2007).

Researchers have used both membrane permeability and fluorescence data as proxies to determine the amount of stress that a plant may be experiencing (Bibi et al., 2008). Higher amounts of cellular plasmolytes exuded during stress is representative of a cell's lack of thermotolerance (ur Rahman et al., 2004). Fluorescence identifies the efficiency of the photosystem of the plant which requires a tightly regulated membrane of the thylakoid (Kotak et al., 2007). Using both together, we can make an assessment of the photo-chemical efficiency of the plant during high-temperature stress and its potential adaptation response.

---

[1] Graduate assistant and distinguished professor, respectively, Department of Crop, Soil, and Environmental Sciences, Fayetteville.

RESEARCH DESCRIPTION

Two growth chamber studies were conducted at the University of Arkansas System Division of Agriculture, Altheimer Laboratory in Fayetteville in 2012 and 2013. Cotton (*Gossypium hirsutum* L.) cultivar ST5288 B2RF was grown in 2-L pots with a day/night temperature of 30/20 °C, a relative humidity of 70%, and 14 h photoperiods of 500 µmol m^{-2} s^{-1} of photosynthetically active radiation in two growth chambers. Plants were watered daily to saturation using half-strength Hoagland's solution. At the initiation of flowering, temperatures in one chamber were increased to 38/24 °C. Membrane leakage and fluorescence data were collected daily between 1200-1400 h. Leaf discs were collected on the fourth main-stem leaf of ten random plants in each chamber being careful not to include major leaf veins. Membrane leakages were calculated by comparing the differences from leaf discs held in double distilled water at both room temperature and after autoclaving. Fluorescence data was collected from the same leaves as were selected for membrane at three different locations on the leaf and averaged together for a relative electron transport rate (ETR) of the leaf. Measurements were collected daily for five days.

RESULTS AND DISCUSSION

Membrane leakage displayed a significant difference from the control at the onset of high temperature (Fig. 1). Leakage exhibited by the control remained fairly stable throughout the experiment with no value lower than 70%. On the first day of stress, membrane permeability values of the control plants were 43% lower than the control. Permeability further decreased on the second day with the stressed plants having permeability 84% less than the control. Stressed plants showed improvements on day three with a 33% difference from the control. Day four values of the stress plants were within 5% and 4% of the control on days four and five, respectively. The stabilized relative differences on days four and five indicate that the stressed plants permeability were similar to the control and had adapted to the heat.

Stressed measurements were lower than the control on all days measured (Fig. 2). A 15% decrease of electron transport rate of stressed plants was observed when compared to the control on day one. Day two plants had the biggest disparity between the control and heat-stressed plants with a 37% difference. Relative differences for days three, four, and five were 19%, 21% and 16%, respectively. All values of the heat-stressed plants were suppressed compared to the control, but it should be noted that the greatest disparity of ETR occurred on day two, which also coincided with the greatest disparity in the membrane permeability that same day.

PRACTICAL APPLICATION

The results of this study confirmed that fluorescence and membrane permeability could be used to monitor the stress adaptation of plants. The stressed plants were unable to recover as indicated via the fluorescence data, but demonstrated a recovery from the membrane permeability analysis. This suggests that although the membrane structure is restored after three days following stress, the ability of the plant to return the photosystem to a similar recovery is limited. It should also be emphasized that dependent upon when the membrane permeability is taken can determine the effectiveness of the technique. Three days following the stress, values between both the control and stressed plants were similar. Fluorescence would appear to be a better indicator of identifying leaf related stress over a longer period of time. It is important to continue the research to assess both of these techniques as rapid indicators of stress *in situ*.

ACKNOWLEDGMENTS

We thank Cotton Incorporated for providing the funding of this research.

LITERATURE CITED

Bibi, A.C., D.M. Oosterhuis and E.D. Gonias. 2008. Photosynthesis, quantum yield of photosystem II and membrane leakage as affected by high temperatures in cotton genotypes. J. Cotton Sci. 12:150-159.

Crafts-Brandner, S.J. and M.E. Salvucci. 2004. Analyzing the impact of high temperature and CO_2 on net photosynthesis: biochemical mechanisms, models and genomics. Field Crop. Res. 90:75-85.

Kotak, S., J. Larkindale, U. Lee, P. von Koskull-Döring, E. Vierling, and K.-D. Scharf. 2007. Complexity of the heat stress response in plants. Curr. Opin. Plant Biol. 10:310-316.

Oosterhuis, D.M. 2002. Day or night high temperatures: A major cause of yield variability. Cott. Grow. 46:8-9.

Singh, R.P., P.V. Prasad, K. Sunita, S.N. Giri, K.R. Reddy, and D.L. Sparks. 2007. Influence of high temperature and breeding for heat tolerance in cotton: a review. Adv. Agron. 93:313-385.

ur Rahman, H., S.A. Malik, and M. Saleem. 2004. Heat tolerance of upland cotton during the fruiting stage evaluated using cellular membrane thermostability. Field Crop. Res. 85:149-158.

Wahid, A., S. Gelani, M. Ashraf, and M. Foolad. 2007. Heat tolerance in plants: An overview. Environ. Exp. Bot. 61:199-223.

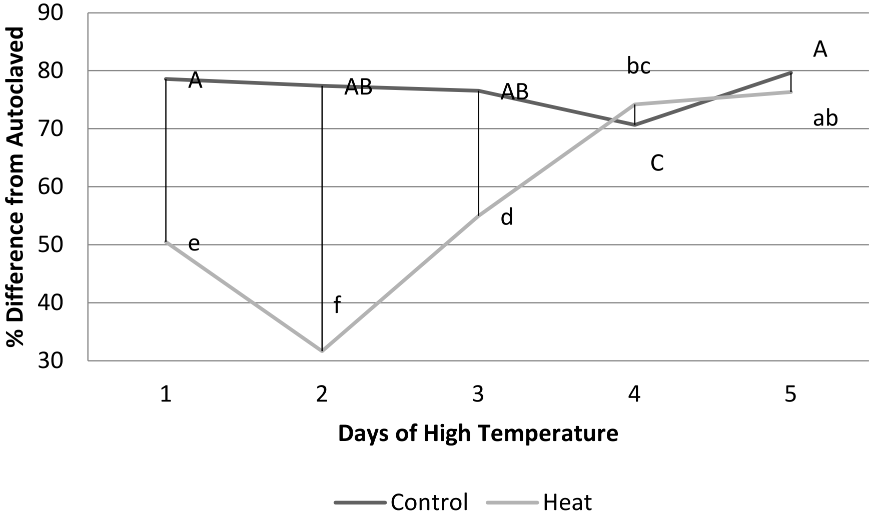


Fig. 1. Membrane leakage percent difference for main-stem leaves for both the control and temperature stress plants from the final autoclaved tissues. Lower relative values indicate greater initial leakage from the leaves sampled. Capitalized letters indicate no significant difference at α = 0.05 level for control values; whereas lowercase letters indicate no significant difference at α = 0.05 level for the heat-stressed leaves.

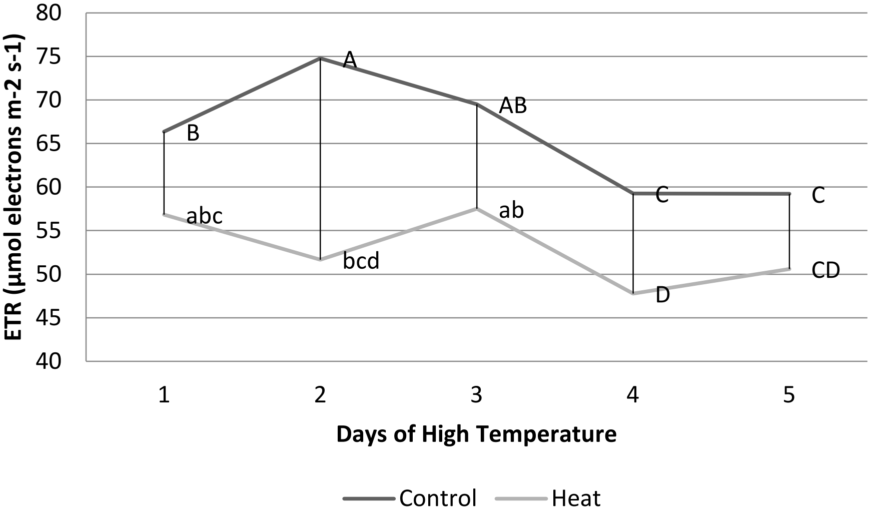


Fig. 2. Electron transport rate (ETR) of leaf photosystems for both the control and temperature stressed plants. Capitalized letters indicate no significant difference at α = 0.05 level for control values; whereas lowercase letters indicate no significant difference at α = 0.05 level for the heat-stressed leaves.

Pollen Germination of Diverse Cotton Cultivars

M.M. Pretorius, D.M. Oosterhuis and T.R. FitzSimons[1]

RESEARCH PROBLEM

High temperatures during cotton flowering and early boll development can detrimentally affect cotton yield. Current commercial cultivars do not have pronounced tolerance to elevated temperatures, and improved methods of screening for thermo-tolerance are needed. The effect of heat stress on cotton has been measured with several different methods including membrane leakage, chlorophyll fluorescence and antioxidant activity. Several researchers have also used pollen germination as a screening technique for heat tolerance, with variable results due to difficulty in germinating cotton pollen. Various growth mediums exist in the literature with contrasting success on cotton pollen germination. Our objective was to determine a viable method of germinating cotton pollen for evaluating thermo-tolerance in cotton genotypes.

BACKGROUND INFORMATION

Although cotton originates from warm climates, it does not necessarily yield best at excessively high temperatures, and a negative correlation has been reported between yield and high temperature during flowering and early boll development (Oosterhuis, 1999). The optimum temperature for cotton is reputed to be 30/20 °C day/night temperatures (Reddy et al., 1991), and once temperatures reach above 35 °C, growth rate and photosynthesis begins to decrease (Bibi et al., 2008). However, average daily maximum temperatures during flowering and boll development are almost always above 32 °C, and well above the optimum for photosynthesis. Reproductive development in cotton is particularly sensitive to high temperature both before and after anthesis (Reddy et al., 1996; Oosterhuis, 2002). Heat stress during flowering leads firstly to inhibition of the male and female gametophyte development, and also leads to a decrease in pollen germination (Snider and Oosterhuis, 2011).

Various methods that have been used to quantify the effect of heat stress on cotton including membrane leakage, chlorophyll fluorescence and antioxidant activity, often with variable results. Viability (germination) of pollen also provides a

---

[1] Graduate assistant, distinguished professor, and graduate assistant, respectively, Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville.

means of identifying genotypic tolerance to heat stress, and numerous techniques have been used to study pollen germination, with inconsistent results, depending on the media and environment. Various factors play a role in the in vitro germination of pollen such as temperature, humidity, pH and growth medium, and therefore optimum conditions should be used to achieve successful germination of cotton pollen grains (Kakani et al., 2005; Liu, et al., 2006). The method of Burke et. al. (2004) has been successfully used in studies in Texas but not always successfully in Arkansas. The overall objectives of this study were to determine the best growth medium and optimal conditions for cotton pollen germination, and (2) to use pollen germination percentages to evaluate the effect of high-temperature stress on cotton cultivars in a controlled environment.

RESEARCH DESCRIPTION

Four cotton (*Gossypium hirsutum L.*) cultivars representing variable tolerance to high temperatures were evaluated in controlled conditions in 2013 in the University of Arkansas System Division of Agriculture, Altheimer Laboratory in Fayetteville. Cultivars planted were one heat tolerant cultivar (VH260), one with moderate heat tolerance (Arkot 9704), one intermediate (DP393) and a cultivar of unknown heat tolerance (DP210). Cotton was planted into 2-L pots and placed in two walk-in growth chambers (Model PGW36; Controlled Environments Limited, Winnipeg, Canada). Growth chambers were set for normal conditions of 30/20 °C (day/night), approximately 60% relative humidity, and watered daily with half-strength Hoagland's nutrient solution to obtain adequate water and nutrients. At flowering one of the chambers received a heat stress of 40/20 °C for one week, while the other chamber remained at the control temperatures of 30/20 °C. Fresh flowers were collected at 9:00 AM between 71 and 77 days after planting.

The growth medium procedure of Burke et al. (2004) was slightly modified by replacing $MnSO_4$ with $CaNO_{3.}$ We used 3.5g agar, 18 g sucrose, 0.03 g calcium nitrate, 0.052 g of potassium nitrate and 0.01026 g boric acid made up to 100 ml deionized water. Gibberellic acid was not included in the growth medium.The pH was raised to 7.6 and after that the agar was added and slowly heated on a hot plate. After the agar was completely dissolved, 10 ml of the germination medium was poured on the required number of petri dishes and left to cool for 15 minutes to let the agar solidify. The pollen of one flower was gently tapped in the middle of each petri dish. The petri dishes were left partially open in a humidity chamber (approximately 50%) for 2 h at 24 °C. Percentage germination was calculated by counting the total number of pollen grains and the number of germinated pollen grains in a random microscopic field on each petri dish using a compound light microscope (Motic BA 200) (4 × 0.10).

RESULTS AND DISCUSSION

After numerous attempts to get pollen to germinate, the modified growth medium of Burke et al. (2004) resulted in successful germination of cotton pollen.

Total pollen germination percentages ranged from 11% for cultivar VH260 that received heat stress (40 °C) compared to 40% for DP210 in the control chamber (30 °C). At normal temperatures (30 °C) cultivar DP393 had higher pollen germination percentages (29.6%) than after a week of high-temperature (40 °C) with germination percentage of 20% (Figs. 1 and 2). This showed that high-temperature stress decreased pollen germination of the heat sensitive cultivar DP393. This study is being continued.

PRACTICAL APPLICATION

Screening for high temperature-tolerant cultivars is needed in order to select cultivars and stabilize yield in the current and future warmer weather conditions. A method of measuring pollen germination was studied and modified resulting in successful germination of pollen grains. Genotypic differences in pollen germination were found, and these will be used as a method to screen for temperature-tolerant cultivars.

ACKNOWLEDGMENTS

Support for this research was provided by Cotton Incorporated.

LITERATURE CITED

Bibi, A.B., D.M. Oosterhuis, and E.D. Gonias. 2008. Photosynthesis, quantum yield of photosystem II and membrane leakage as affected by high temperatures in cotton genotypes. J. Cotton Sci. 12:150-159.

Burke, J.J., J. Velten and M.J. Oliver. 2004. In vitro analysis of cotton pollen germination. Agron. J. 96: 359-368.

Kakani, V.G., K.R. Reddy, S. Koti, T.P. Wallace, P.V.V. Prasad, V.R. Reddy and D. Zhao. 2005. Differences in in vitro pollen germination and pollen tube growth of cotton cultivars in response to high temperature. Ann. Bot. 96:59-67.

Liu, Z., Y. Yuan, S. Liu, X. Yu, and L. Rao. 2006. Screening for high temperature tolerant cotton cultivars by testing in vitro pollen germination, pollen tube growth and boll retention. J. Integr. Plant Biol. 48:706-714.

Oosterhuis, D.M. 1999. Yield response to environmental extremes in cotton. pp. 30-38. *In*: D.M. Oosterhuis (ed.) 1999 Cotton Research Meeting and Summaries of Research in Progress. Agricultural Experimental Station Research Special Report 193.

Oosterhuis, D.M. 2002. Day or night high temperatures: A major cause of yield variability. Cotton Grower 46:8-9.

Reddy, V.R., D.N. Baker, and H.F. Hodges. 1991. Temperature effect on cotton canopy growth, photosynthesis and respiration. Agron. J. 83:699-704.

Reddy, K.R., V.R. Reddy and H.F. Hodges. 1992. Temperature effects on early season cotton growth and development. Agron. J. 84:229-237.

Reddy, K.R., H.F. Hodges, W.H. McCarty, and J.M. McKinion. 1996. Weather and cotton growth: Present and future. pp. 1-23. *In*: K.H. Remy (ed.) Mississippi State University Bulletin 1061.

Snider, J.L. and D.M. Oosterhuis. 2011. How does timing, duration and severity of heat stress influence pollen-pistil interactions in angiosperms. Plant Signal. Behav. 6:930-933.

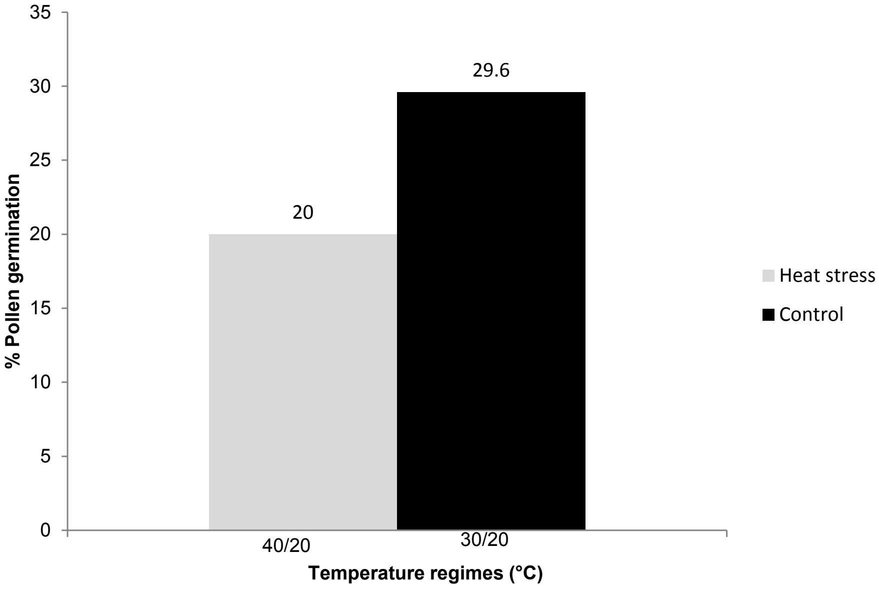


Fig. 1. Percentage pollen germination of the cotton cultivar DP393 measured in a growth chamber. Fayetteville, Ark., 2013.

Fig 2. Cotton pollen germination tubes of the cultivar DP393, grown in a normal temperature regime 30/20 °C (day/night), studied under a compound light microscope (4 × 0.10). Fayetteville Ark., 2013.

Leaf and Ovary Carbohydrate Adjustments During Heat Stress Before, During, and After Anthesis

T.R. FitzSimons and D.M. Oosterhuis[1]

RESEARCH PROBLEM

Cotton grown in the Mississippi Delta often flowers in temperatures that are suboptimal for the species. High-temperature stress leads to a decrease in the photosynthetic efficiency of the plant and hinders proper growth and development. If the efficiency is hindered for a significant period of time, then the plant must repartition resources to facilitate its survival rather than for reproduction. These repartitions include carbohydrate sources used in decreasing water potentials in the plant for water osmotic adjustments. Research is limited in examining the interconnections of carbohydrate and resource partitioning of the ovary that is influenced by heat stress.

BACKGROUND INFORMATION

Plant stress across a field changes the distribution of bolls, favoring less secondary and tertiary boll development thereby reducing yields (Pettigrew, 2004). High-temperature stress has also been shown to reduce the efficiency of plant photosystems (Schrader et al., 2004) while increasing the respiration of the plant (Loka and Oosterhuis, 2010). The carbohydrate production of a plant is directly linked to the enzymatic speed of the Rubisco enzyme (Crafts-Brandner and Salvucci, 2000). High temperature initiates a conformational change in Rubisco structure, denaturing it and reducing or even eliminating carbohydrate production (Allakhverdiev et al., 2008). An increase in heat encourages an increase in evapotranspiration which results in leaves that may be several degrees cooler than the surrounding air (Law and Crafts-Brandner, 1999). Flowers however do not have the same capacity for transpiration as do leaves and thus must rely solely upon the hydraulic architecture of the vascular system and the sugars within the ovary and surrounding tissues to facilitate water movement (Davies et al., 2000). Seeing that the developing boll gleans most of its carbohydrates from its subtending leaf (Ashley, 1972), it makes sense that the developing flower should also change dependent upon how the leaf is able to photo-synthase. It is important to investigate

---

[1] Graduate assistant and distinguished professor, respectively, Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville.

how high-temperature stress may impact the development of the opening flower that may occur in association with the subtending leaf during the three flowering stages of the day before anthesis, the day of, and the day post anthesis.

RESEARCH DESCRIPTION

Cotton (*Gossypium hirsutum* L.) cultivar ST5288 B2RF was grown in two large walk-in growth chambers at the University of Arkansas System Division of Agriculture, Altheimer Laboratory Fayetteville. The chambers were operated with a day/night temperature of 30/20 °C and fourteen hour photoperiods of 500 μmol m^{-2} s^{-1} of photosynthetically active radiation. Once flowering had instigated, temperatures were increased in one chamber to 38/24 °C. Ten sample collections were made daily of candles, open flowers, and day old flowers. These collections also included the corresponding subtending leaf to each sample flower collected. Collections were immediately bagged and placed in an ultra-deep freezer (-80 °C) for later analysis. Carbohydrates were analyzed according to the procedure by Hendrix and Peelen (1987) with modifications.

RESULTS AND DISCUSSION

Trends of sucrose for both heat stressed and control leaves remained virtually identical to each other throughout the temperature study (Fig. 1). Ovary concentrations of the control experienced significantly higher levels of fructose the day before flowering than the remaining two periods. However, the heat-stressed ovaries showed a much higher level of sucrose, about 22%, than in the control before flowering. Levels of sucrose were similar during both the flowering and the day post-flowering stages.

Fructose trends in the leaves were stable at around 0.04 mg/mg dry weight in both the control and of the heat-stressed leaves and were not significantly different from any of the three flowering periods (Fig. 2). Similar to the sucrose results, fructose levels were significantly increased in both the control and the heat stress plants prior to flower opening. However, the level of fructose on the day before flowering was near 25% higher in the stressed plants than was seen in the control. Similar levels of fructose in both the control and the heat-stressed plants were witnessed and were not significantly different from each other.

Glucose levels in the leaves were consistent and had no significance from any flowering period throughout the experiment (Fig. 3). Trends of ovary-related glucose did take on slightly different characteristics when comparing the two temperature regimes. The control trends took on a positive logarithmic shape whereas the heat stress glucose trend levels were more parabolic shaped. The levels of free glucose in the control were both similar the day before flowering and at flowering, but rose significantly post flower. Heat stress ovarian glucose levels were higher than those levels found at flowering, but were similar to the levels found the day after flowering. The lowest levels of free glucose in the heat stress ovaries at flowering were similar to the levels during the same time period as the control.

Levels of starch in the leaves were found to be significantly different for the three flowering stages in both temperature regimes (Fig. 4). Heat-stressed leaf starch concentrations were near 50% higher the day before flowering than was seen in the control. Ovarian levels of starch displayed very different trends during the three flowering collections. Starch at control temperatures exhibited a parabolic trend with no significant difference between the day before or after flowering. The day of flowering had the lowest levels of starch for the control during the period. Heat stress concentrations had a negative linear trend. Levels of starch in plants under stress were similar to the values found in the control the day before flowering; however, levels continued a significant depreciation over the next two flowering periods with the lowest levels occurring the day after flowering.

PRACTICAL APPLICATION

Results indicate that heat stress changes the partitioning of carbohydrates of the ovary without much change in the leaves. This infers that the carbohydrate production within the leaves remains constant, however under heat stress the ovary must utilize the carbohydrate resources differently. These partitioning effects may provide an insight as to why more flower shed is seen in heat-stressed environments than in more optimal conditions even under well-watered conditions. Though many factors ultimately contribute to the final yield of the plant, understanding how carbohydrate partitioning may impact final yield is an area ripe for continued research.

ACKNOWLEDGMENTS

We thank Cotton Incorporated for providing the funding for this research.

LITERATURE CITED

Allakhverdiev, S.I., V.D. Kreslavski, V. V Klimov, D. a Los, R. Carpentier, and P. Mohanty. 2008. Heat stress: an overview of molecular responses in photosynthesis. Photosynth. Res. 98:541-550.

Ashley, D. 1972. 14C-labelled photosynthate translocation and utilization in cotton plants. Crop Sci. 12:69-74.

Crafts-Brandner, S.J. and M.E. Salvucci. 2000. Rubisco activase constrains the photosynthetic potential of leaves at high temperature and CO_2. Proc. Natl. Acad. Sci. U. S. A. 97:13430-13435.

Davies, W.J., M.A. Bacon, D.S. Thompson, W. Sobeih, and L.G. Rodríguez. 2000. Regulation of leaf and fruit growth in plants growing in drying soil: exploitation of the plants' chemical signalling system and hydraulic architecture to increase the efficiency of water use in agriculture. J. Exp. Bot. 51:1617-1626.

Hendrix, D. and K. Peelen. 1987. Artifacts in the analysis of plant tissues for soluble carbohydrates. Crop Sci. 24:710-715.

Law, R. and S. Crafts-Brandner. 1999. Inhibition and acclimation of photosynthesis to heat stress is closely correlated with activation of ribulose-1,5-bisphosphate Carboxylase/Oxygenase. Plant Physiol. 120:173-182.

Loka, D.A.A., and D.M. Oosterhuis. 2010. Effect of high night temperatures on cotton respiration, ATP levels and carbohydrate content. Environ. Exp. Bot. 68:258-263.

Pettigrew, W.T. 2004. Moisture deficit effects on cotton lint yield, yield components, and boll distribution. Agron. J. 96:377-383.

Schrader, S.M., R.R. Wise, W.F. Wacholtz, D.R. Ort, and T.D. Sharkey. 2004. Thylakoid membrane responses to moderately high leaf temperature in Pima cotton. Plant Cell Environ. 27:725-735.

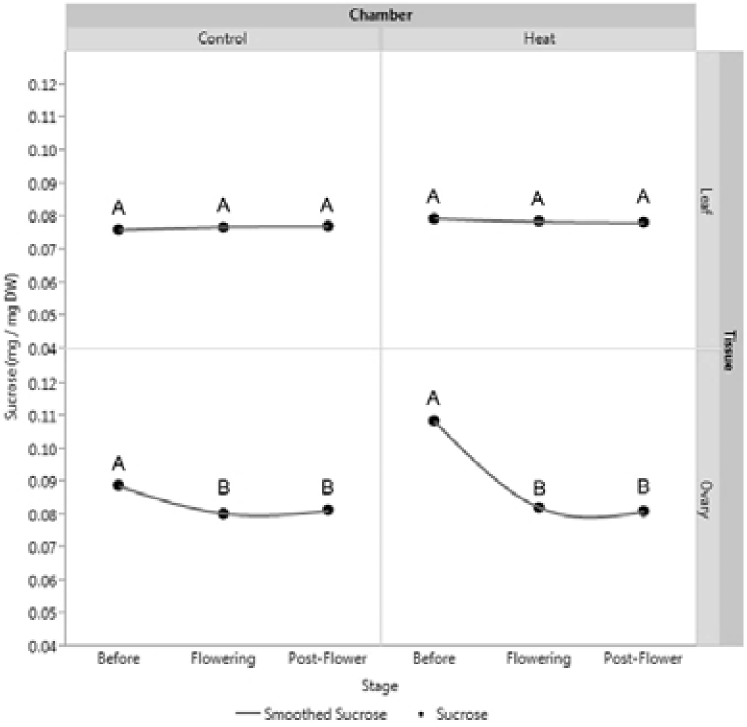


Fig. 1. Sucrose concentrations in control and heat-stressed treatments of three flower stages by tissue and chamber type. Different letters in each combination type represent a significant difference at $P = 0.05$ level.

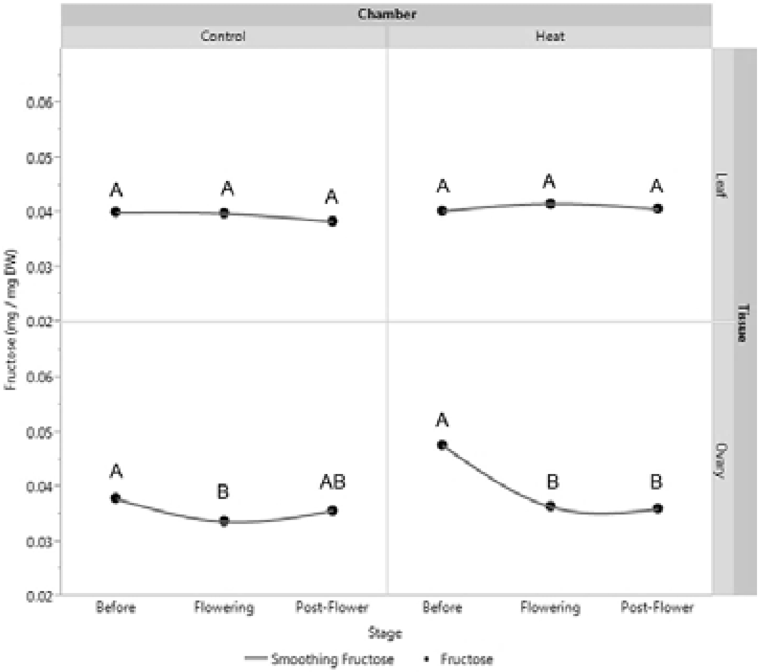


Fig. 2. Fructose concentrations in control and heat-stressed treatments of three flower stages by tissue and chamber type. Different letters in each combination type represent a significant difference at $P = 0.05$ level.

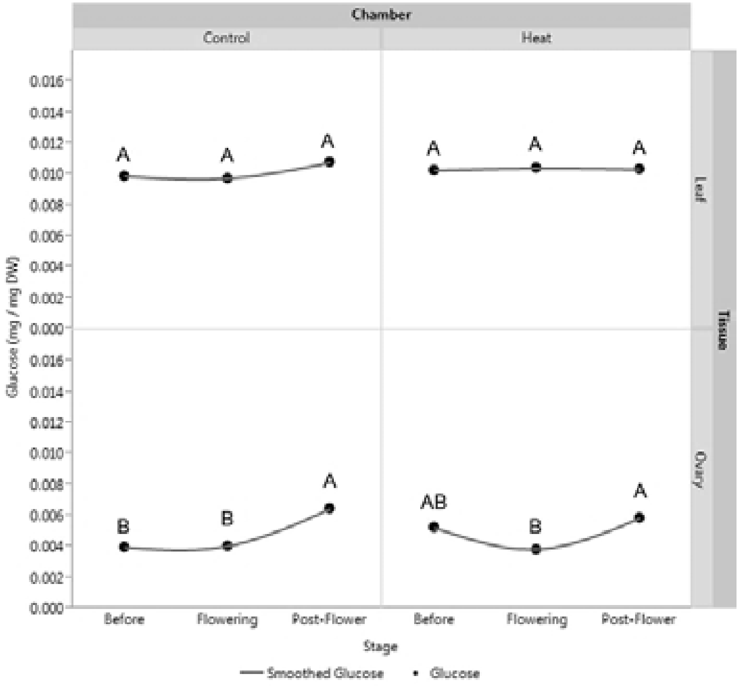


Fig. 3. Glucose concentrations in control and heat-stressed treatments of three flower stages by tissue and chamber type. Different letters in each combination type represent a significant difference at $P = 0.05$ level.

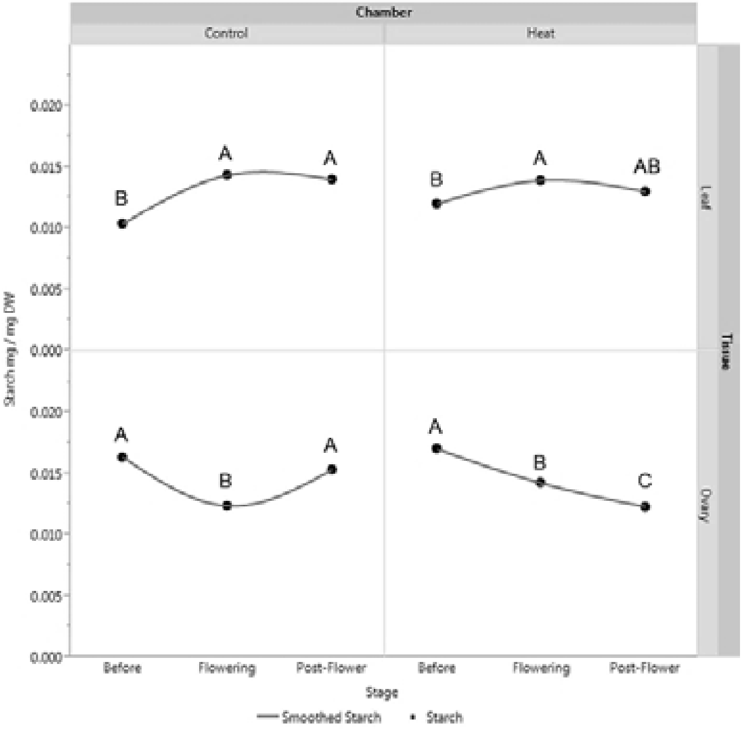


Fig. 4. Starch concentrations in control and heat-stressed treatments of three flower stages by tissue and chamber type. Different letters in each combination type represent a significant difference at $P = 0.05$ level.

Evaluation of 1-Methylcyclopropene to Reduce Ethylene Driven Yield Reductions in Field-Grown Cotton

T.B. Raper, D.M. Oosterhuis, C. Pilon, J.M. Burke, and T. Coomer[1]

RESEARCH PROBLEM

The extreme seasonal variability in lint yields is a major concern of cotton producers (Lewis et al., 2000) and has contributed to a decline in planted acres. Variability in cotton yield is associated with many meteorological parameters and temperature appears to play a major role. High temperatures limit growth and development processes in much of the cotton producing areas (Reddy et al., 2002). Cotton has been shown to be particularly sensitive to high-temperature stress during flowering (Snider et al., 2009). When plants are under stress they increase the production of the plant hormone ethylene, which is a stress hormone known for its role in the regulation of fruit abscission processes (Guinn, 1982). The current project was designed to evaluate the effectiveness of 1-MCP to counteract the effects of stress and maintain fruit and seed numbers for increased yield. As a result, higher and less variable yields could be achieved without undue changes in management and production costs.

BACKGROUND INFORMATION

The plant growth regulator 1-methylcyclopropene (1-MCP) works by occupying the ethylene receptors of plants and thereby inhibiting ethylene from binding and initiating a response such as abscission or senescence (Sisler and Serek, 1997). The affinity of 1-MCP for the ethylene receptor sites is 10 times greater than that of ethylene. The use of 1-MCP in cherry tomatoes and citrus has been shown to prevent and delay fruit abscission (Beno-Mousalem et al., 2004). It has also been reported that a 1-MCP application on field-grown cotton increased the yield (Kawakami et al., 2006). Still, the yield response of field-grown cotton to application of 1-MCP is often inconsistent due to the influence of environmental conditions immediately prior to and following each application. Therefore, the objective of this study was to monitor canopy temperature and multiple meteorological parameters at several 1-MCP application events in order to provide insight into conditions necessary to realize a yield response.

---

[1] Graduate assistant, distinguished professor, graduate assistant, graduate assistant, and graduate assistant, respectively, Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville.

RESEARCH DESCRIPTION

During the 2013 growing season, a field study was conducted at the University of Arkansas System Division of Agriculture, Fayetteville. The field was divided into a 49-plot, Latin Square design with seven replications, and each plot consisting of four 36-inch rows 22.5-feet in length. Treatments included five different application times, one control, and one repeat-application plot which received an application at every application date. Applications were made weekly, beginning roughly two weeks prior to peak flower. The trial was planted with cotton (*Gossypium hirsutum* L.) cultivar Stoneville 4288B2RF on 28 May. Weed and pest populations were managed to remain below University of Arkansas Cooperative Extension Service recommended thresholds. Furrow irrigation water was applied only when substantial leaf wilt was observed mid-afternoon.

Monitored meteorological parameters included ambient air temperature, relative humidity, solar radiation, canopy temperature, soil temperature, and precipitation. Canopy temperature and soil temperature were measured by Apogee SI-121 infra-red canopy temperature sensors (Apogee Instruments, Inc., Logan, Utah) and all data was collected by a Campbell Scientific CR1000 data logger (Campbell Scientific, Inc., Logan, Utah). End of season measurements included boll number, seedcotton weight and lint weight measured from a one meter hand-picked sample and seedcotton weight measured from the mechanically picked center two yield rows of each plot.

RESULTS AND DISCUSSION

Trends of average canopy and ambient temperature, calculated from daily temperatures noted between 11:00 AM and 5:00 PM CST, and 1-MCP application timings are shown in Fig. 1. Prior to July 23, the large division between canopy temperatures and corresponding ambient temperatures were caused by soil within the infrared thermometer field of view. After July 23, substantial canopy cover removed the soil interference. Due to an exceptionally cool August, severe heat stress was not noted during the beginning of the flowering period. Still, two applications of 1-MCP were made during this cool period. As hypothesized, neither of these applications significantly increased lint yields (data not shown). Failure of these applications to increase yields can most likely be attributed to no significant spikes in ethylene production during this time frame and therefore no substantial impact of the anti-ethylene product on seedcotton yield.

Ambient temperatures began to rise to more historically noted levels as the effective flowering period was nearing an end. Two applications of 1-MCP were made during this warmer period. The first application was made on 21 August, as both canopy and air temperatures were increasing at a moderate rate (Fig. 1). Temperatures continued to increase through the last application which was made on 28 August. Within a few days of this last application, average ambient temperature spiked at slightly above 34 °C (Fig. 1). Although both applications made during the warming period were expected to increase seedcotton yields, a significant increase was not associated with the 28 August application (Fig. 2). In contrast, the 21 August application significantly increased seedcotton yields over the untreated control (Fig. 2). These increases were noted in both the one meter handpicked (increase of 253 lb/acre) and plot-length, mechanically picked (increase of 338 lb/acre, data not shown) measurements. In contrast, the treatment receiving repeated applications of 1-MCP was characterized by a significant reduction in yields, indicating that reception of ethylene at some period during the flowering period was required to realize maximum yields.

One possible reason for the increase in seedcotton yields associated with the third application but not associated with the fourth application may be the cool temperatures following the fourth application. Bolls generally require 50-60 days after flowering to reach maturity. Abnormally cool temperatures were experienced within 30 days after the last 1-MCP application (Fig. 1). This cold-stress could have potentially decreased boll development of all young bolls regardless of 1-MCP treatment, and, as a result, masked any yield benefits associated with the last application. In contrast, flowering bodies protected by the third 1-MCP application were fully mature prior to the noted cold-stress period.

PRACTICAL APPLICATIONS

The increases in yield associated with the properly timed application of the anti-ethylene compound 1-MCP suggest this chemical could potentially be applied prior to or immediately following environmental conditions which result in a spike of ethylene to protect yield potential. This chemical has the potential to decrease the extreme seasonal variability noted in cotton yields.

ACKNOWLEDGMENTS

Support for this research was provided by AgroFresh. Special thanks to the staff at the Agricultural Research and Extension Center in Fayetteville, Arkansas, for providing technical support.

LITERATURE CITED

Beno-Mousalem, D., L. Gusev, O. Dvir, E. Pesis, S. Meir, and A. Lichter. 2004. The effects of ethylyne, methyl jasmonate, and 1-MCP an abscission of cherry tomatoes from the bunch and expression of endo-1, 4-β-glucanases. Plant Sci. 167:499-507.

Guinn, G. 1982. Causes of square and boll shedding in cotton. U.S. Department of Agriculture Technical Bulletin No. 1672. USDA-ARS, Washington D.C.

Kawakami, E.M., D.M. Oosterhuis, E.D. Gonias, and A.C. Bibi. 2006. Effect of 1-MCP on the growth and yield of cotton. pp. 58-61. *In*: D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research 2006. Arkansas Agricultural Experiment Station. Research Series 552.

Lewis, H., L. May, and F. Bourland. 2000. Cotton yield components and yield stability. pp. 532-536. In: Proc. Beltwide Cotton Conf., San Antonio, Texas, 4-8 Jan. 2000. Natl. Cotton Council of America, Memphis, Tenn.

Reddy, K.R., P.R. Doma, L.O. Mearns, M.Y.L. Boone, H.F. Hodges, A.G. Richardson, and V.G. Kakani. 2002. Simulating the impacts of climate change on cotton production in the Mississippi delta. Clim Res. 22:271-281.

Sisler, E.C. and M. Serek. 1997. Inhibitors of ethylene responses in plants at the receptor level: Recent developments. Physiol. Planatarum. 100:577-582.

Snider, J.L., D.M. Oosterhuis, B.W. Skulman, and E.M. Kawakami. 2009. Heat stress-induced limitations to reproductive success in *Gossypium hirsutum*. Physiol. Plantarum 137:125-138.

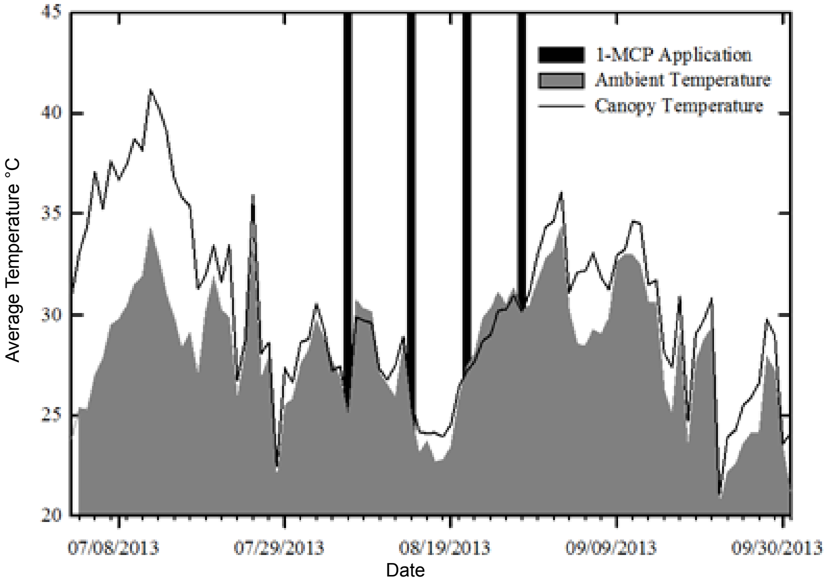


Fig. 1. Average ambient and canopy temperature calculated on a daily interval from temperatures collected between 11:00 AM and 5:00 PM CST. Vertical bars represent dates of 1-methylcyclopropene applications.

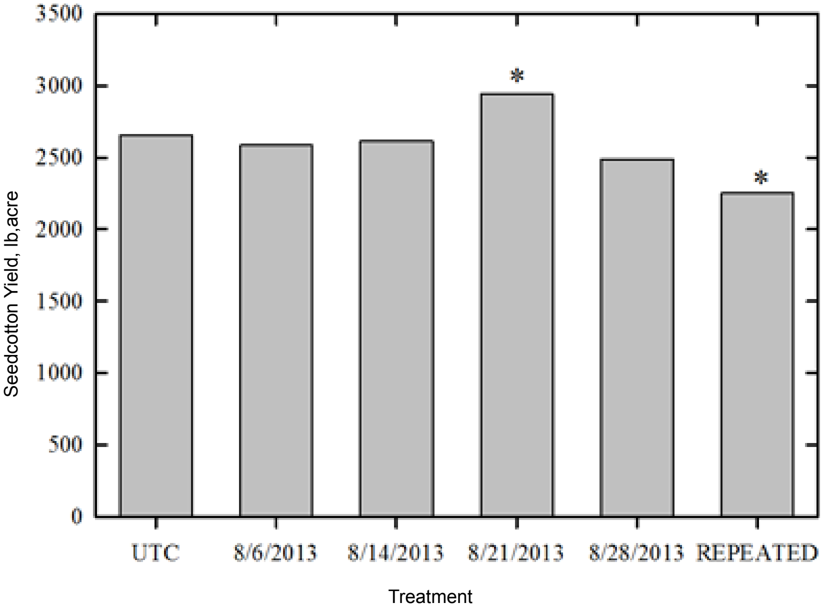


Fig. 2. Average seedcotton yields as measured from one meter hand-picked samples.

An Arkansas Discovery Farm for Cotton: Nutrient and Sediment Losses in Runoff

M. Daniels[1], A. Sharpley[2], C. Henry[3], C. Hallmark[4], J. Hesselbein[4], and S. Hirsh[3]

RESEARCH PROBLEM

Arkansas cotton farmers are under increasing pressure to operate with environmental sustainability. To help agricultural producers take ownership of documenting environmental impact and water-related sustainability, the University of Arkansas System Division of Agriculture in conjunction with many stakeholder groups launched the Arkansas Discovery Farm (ADF) program in 2011 and established a Cotton Discovery Farm in 2013 on the C.B. Stevens farm in Desha County. This program utilizes a unique approach based on agriculture producers, scientists and natural resource managers working jointly to collect economic and environmental data from real, working farms to better define sustainability issues and find solutions that promote agricultural profitability and natural resource protection.

BACKGROUND INFORMATION

Within the Mississippi River drainage basin, large-scale, basin-wide, water quality modeling efforts by the United States Geological Service project agriculture in States along the Mississippi River corridor as the leading source of nitrogen and phosphorus delivery to the Gulf of Mexico where excessive nutrients are thought to be the cause of large hypoxic (waters with low dissolved oxygen) zones within the Gulf. However, little data exists that quantifies edge-of-field losses from agricultural operations and tracks these losses through drainage pathways to streams and rivers. Edge-of-field data is needed to truly determine agriculture's impact on these issues. One objective of the Cotton Discovery Farm was to quantify sediment and nutrient losses in runoff generated from precipitation and irrigation

---

[1] Professor, Extension Water Quality, Department of Crop, Soil, and Environmental Sciences, Little Rock.
[2] Professor, Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville.
[3] Associate professor and program associate, respectively, Rice Research and Extension Center, Stuttgart.
[4] Discovery Farm technician and program technician, Department of Crop, Soil, and Environmental Sciences, Little Rock.

RESEARCH DESCRIPTION

The Arkansas Discovery Farm is located in Desha County near Rowher, Arkansas on the C.B. Stevens farm. Three cotton fields, Shopcot (22 acres), East Weaver (38 acres) and Homeplace (39 acres), were selected for monitoring the quantity and quality of both inflow (precipitation and irrigation) and outflow (runoff). All three fields were planted to cotton in late May. Stale seed bed with minimum tillage was utilized in the Dum2 and Dum3 fields. However due the residue from the cover crop, the middles in the Shopcot were plowed to ensure that water would move freely down the field. On June 13, nitrogen and phosphorus fertilizer was broadcast at the rates of 20 lb/acre of N and 27 lb/acre of P in all fields. On June 17, an additional 89 lb/acre of N as liquid urea was knifed into the soil along the rows.

At the lower end of each field, automated, runoff water quality monitoring stations were established to: (1) measure runoff flow volume, (2) collect water quality samples of runoff for water quality analysis and (3) measure precipitation. The ISCO 6712 automated portable water sampler was utilized to interface and integrate all the components of the flow station. Runoff flow volume (discharge) was collected with a trapezoidal flume especially designed to measure flow in agricultural drainage channels. Discharge data were utilized to trigger flow-paced, automated collection of up to 100, 100-ml subsamples which were composited into a single 10 liter sample.

A subsample of the 10 liter sample was collected, processed in the field for preservation and shipped in insulated shipping vessels to keep samples chilled to meet EPA guidelines for prepping and handling samples. Samples were shipped to the University of Arkansas' Water Resources Laboratory (certified by the Arkansas Department of Environmental Quality) to determine concentration of ortho-Phosphorus, nitrite-nitrate-Nitrogen, total nitrogen, total phosphorus and total solids according to handling, prepping and analytical methods outlined by the US EPA (AWRC, 2014).

RESULTS AND DISCUSSION

Total nitrogen losses in runoff from each field were very low compared to the nitrogen applied as fertilizer (Table 1 and Fig. 1). This study was not designed to do a mass balance of nitrogen applied as change in soil nitrogen levels were not measured; however, losses in runoff were compared to the nitrogen applied as a way to put losses in runoff in perspective in terms of management. Nitrogen loss in the shopcot field was an order of magnitude greater than in the other fields. However, much of this nitrogen loss occurred during rainfall events in May before nitrogen was applied in June. Two possible explanations include the facts that a cover crop was established in Shopcot and that cotton followed corn in this field while cotton followed cotton in the other fields. Nitrogen mineralization from the decaying cover crop may have acted as a source of nitrogen during May or residual soil nitrogen left from the previous corn crop may have been a source. Either way, it appeared that very little of the applied N was lost in runoff.

Total phosphorus losses were also very low in runoff (Fig. 2). Phosphorus losses were also very low compared to the phosphorus applied (Table 2).

PRACTICAL APPLICATION

The data collected during this first year indicates low nutrient losses in runoff to off-farm water bodies, which provides encouragement that our cotton production systems are efficient in terms of nutrient loss to runoff. The results are still preliminary as it is generally accepted by the scientific community that runoff studies should be conducted for a minimum of five years to account for climatic and hydrological response variability.

LITERATURE CITED

AWRC. The Arkansas Water Resources Center. 2014. http://www.uark.edu/depts/awrc/pdf_files/Labpreserveamts.pdf. Acessed 17 March 2014.

Table 1. Seasonal total nitrogen loss as compared to nitrogen applied.

Field	N-applied	N Loss	% Loss	Total
Name (acres)	------------lb/acre------------		%	lbs
Shopcot (22)	108	11.4	10.5	251
Weaver (38)	108	0.7	0.7	27
Homeplace (39)	108	1.8	1.7	70

Table 2. Seasonal total phosphorus loss in runoff compared to phosphorus applied.

Field	P-applied	P Loss	% Loss	Total
Name (acres)	------------lb/acre------------		%	lbs
Shopcot (22)	27	2.2	8.1	48
Weaver (38)	27	0.5	1.9	19
Homeplace (39)	27	0.8	3.0	31

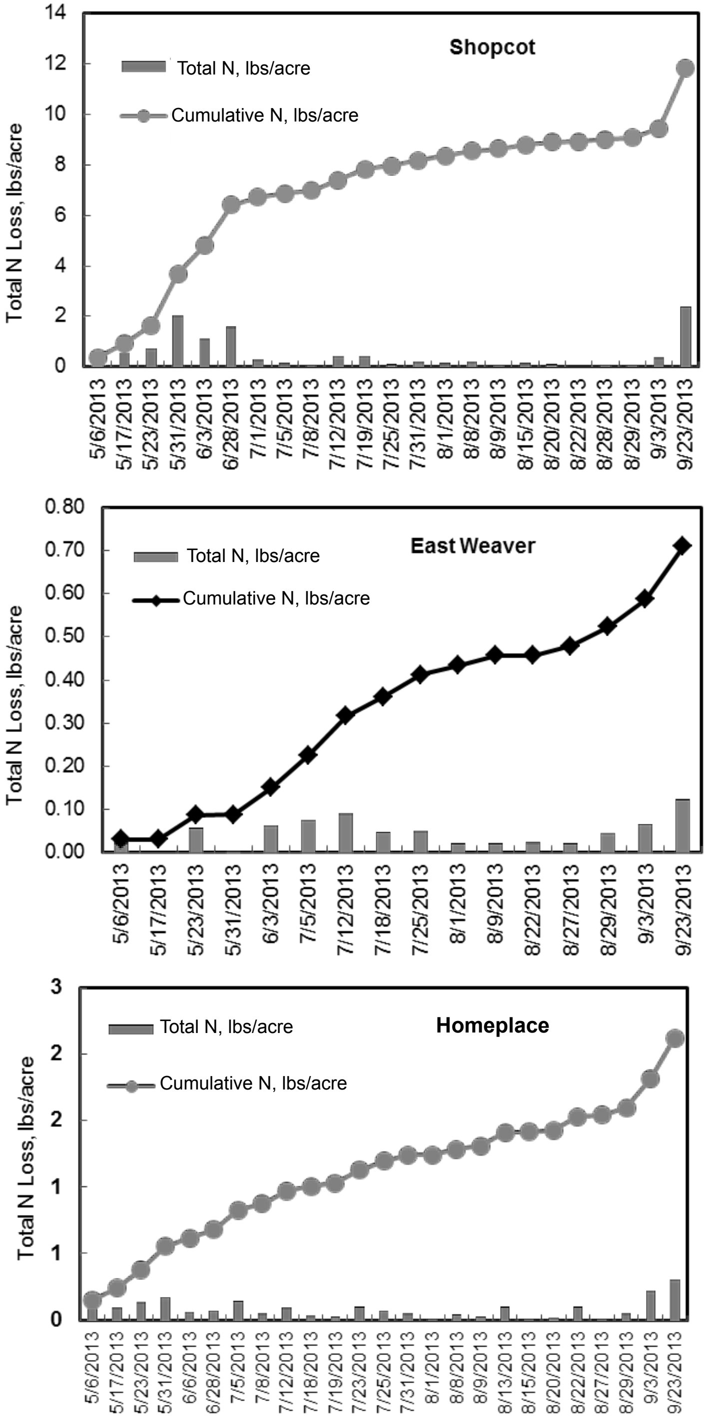


Fig. 1. Total nitrogen losses in runoff from three cotton fields during the 2013 growing season.

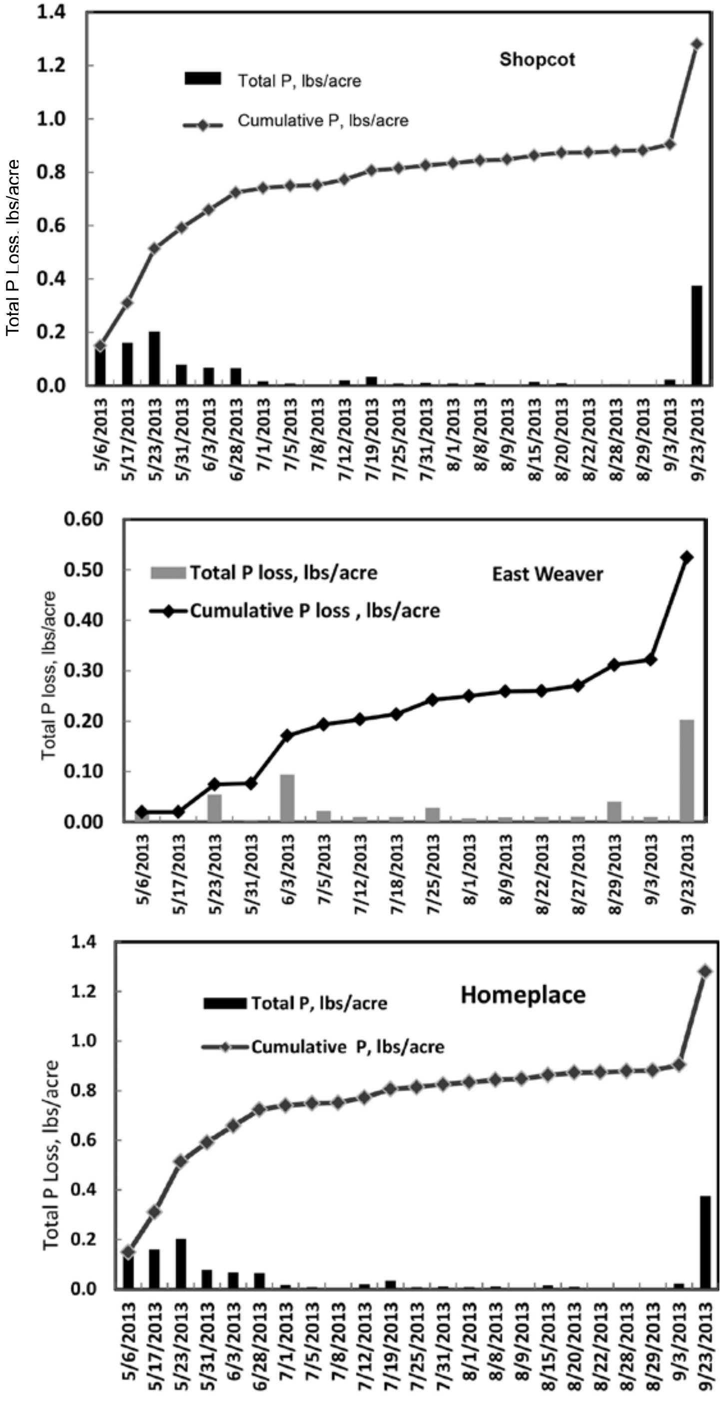


Fig. 2. Total phosphorus losses in runoff from three cotton fields during the 2013 growing season.

An Arkansas Discovery Farm for Cotton: Hydrological Inputs and Runoff

M. Daniels[1], A. Sharpley[2], C. Henry[3], J. Hesselbein[4], C. Hallmark[4], and S. Hirsh[3]

RESEARCH PROBLEM

Cotton production in Arkansas requires irrigation to overcome seasonal droughts during the growing season. In Eastern Arkansas, most cotton farmers utilize groundwater as their irrigation source. Due to declining groundwater levels, the State of Arkansas has declared several row-crop regions as critical groundwater decline areas where withdrawals are not considered sustainable. Agriculture, considered the single largest consumer of groundwater, is facing the possibility of groundwater shortages in the near future. Little data exists on how irrigation water management for cotton relates to tailwater losses via runoff. One objective of the Cotton Discovery Farm was to quantify the relationship between irrigation water management (irrigation and precipitation) and runoff.

BACKGROUND INFORMATION

Arkansas cotton farmers are under increasing pressure to operate with environmental sustainability. To help agricultural producers take ownership of documenting environmental impact and water-related sustainability, the University of Arkansas System Division of Agriculture in conjunction with many stakeholder groups launched the Arkansas Discovery Farm (ADF) program in 2011 and established a Cotton Discovery Farm in 2013 on the C.B. Stevens farm in Desha County. This program utilizes a unique approach based on agriculture producers, scientists and natural resource managers working jointly to collect economic and environmental data from real, working farms to better define sustainability issues and find solutions that promote agricultural profitability and natural resource protection.

RESEARCH DESCRIPTION

The Arkansas Discovery Farm is located in Desha County near Rowher, Arkansas on the C.B. Stevens farm. Three cotton fields, Shopcot (22 acres), East

---

[1] Professor, Extension Water Quality, Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville.

[2] Professor, Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville.

[3] Associate professor and program associate, respectively, Rice Research and Extension Center, Stuttgart.

[4] Discovery program technician and farm technician, respectively, Department of Crop, Soil, and Environmental Sciences, Little Rock.

Weaver (38 acres) and Homeplace (39 acres), were selected for monitoring the quantity and quality of both inflow (precipitation and irrigation) and outflow (runoff) (Table 1). All three fields were planted to cotton in late May. Stale seed bed with minimum tillage was utilized in the East Weaver and Homeplace fields. However due to the residue from the cover crop, the middles in the Shopcot were plowed to ensure that water would move freely down the field. Groundwater was used to furrow-irrigate all fields with polypipe. To ensure equal distribution the computer program PHAUCET (Yazoo Mississippi Delta Joint Water Management District, Stoneville, Miss.) was utilized to determine and vary outlet diameter in the poly-pipe across furrows.

At the lower end of each field, automated, runoff water quality monitoring stations were established to: (1) measure runoff flow volume, (2) to collect water quality samples of runoff for water quality analysis, and (3) measure precipitation. The ISCO 6712 automated portable water sampler (Teledyne Isco, Lincoln, Neb.) was utilized to interface and integrate all the components of the flow station. An ISCO 720 flow module equipped with a submerged pressure transducer was used to measure the hydraulic head (H) at a flow-calibrated measurement point within the trapezoidal flume and was integrated with the automated sampler. Runoff discharge at any given time was estimated from the equation:

$$Q = 1.467\ H^{2.5} + 2.22\ H^{1.5}$$

Where Q = discharge in cubic feet per second, and H = head in feet. Hydraulic head data and runoff discharge data was downloaded into the ISCO Flowlink software where discharge curves integrated over time (hydrographs) were used to calculate total discharge for a single runoff event.

RESULTS AND DISCUSSION

Runoff from precipitation during the growing season ranged from 29% to 63% of the precipitation total received while runoff from irrigation ranged from 23% to 54% of the irrigation total applied. This data indicates that runoff losses and trends from irrigation are similar to those of precipitation, which may indicate that field and soil features exhibit much influence on runoff and infiltration as opposed to the source of input. Cumulative runoff from all three fields exhibit similar trends even though the magnitude of runoff was different (Fig. 1). Cumulative runoff from the East Weaver field increased much slower with time than the cumulative inputs once irrigation commenced in early July (Fig. 2), which most likely reflects the increase in evapotranspiration rate of the rapidly developing cotton biomass.

PRACTICAL APPLICATION

The data collected during this first year indicates typical hydrological variability among fields, runoff events and in time as it relates to cotton development. Studies and data such as this are important to understanding the impact of cotton production on water use and water use efficiency, which are becoming increasingly important considerations for row-crop agriculture in Arkansas in light of declining groundwater levels. However, the results are still preliminary as it is generally accepted by the scientific community that runoff studies should be conducted for a minimum of five years to account for climatic and hydrological response variability.

Table 1. Precipitation, irrigation and runoff from selected cotton fields.

	--------Precipitation--------			----------Irrigation---------			Precipitation + Irrigation		
Field	**Total**	**Runoff**	**% as Runoff**	**Total**	**Runoff**	**% as Runoff**	**Total**	**Runoff**	**% as Runoff**
	------Inches-----		%	------Inches-----		%	------Inches-----		%
Shopcot	12.61	7.91	63	18.45	8.93	48	31.06	16.84	54
East Weaver	12.61	3.66	29	13.59	3.15	23	26.20	6.81	26
Homeplace	12.61	5.17	41	10.64	5.77	54	23.25	10.94	47

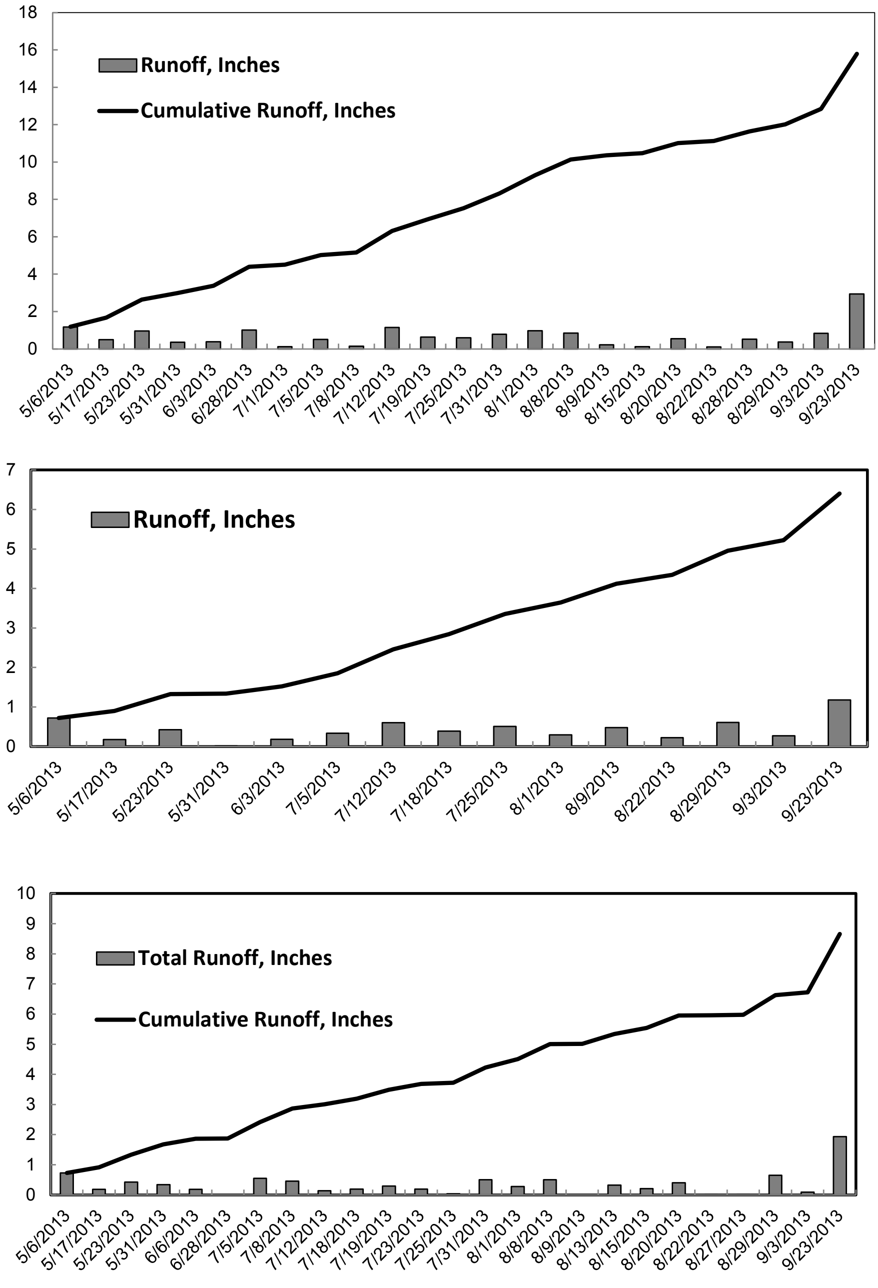
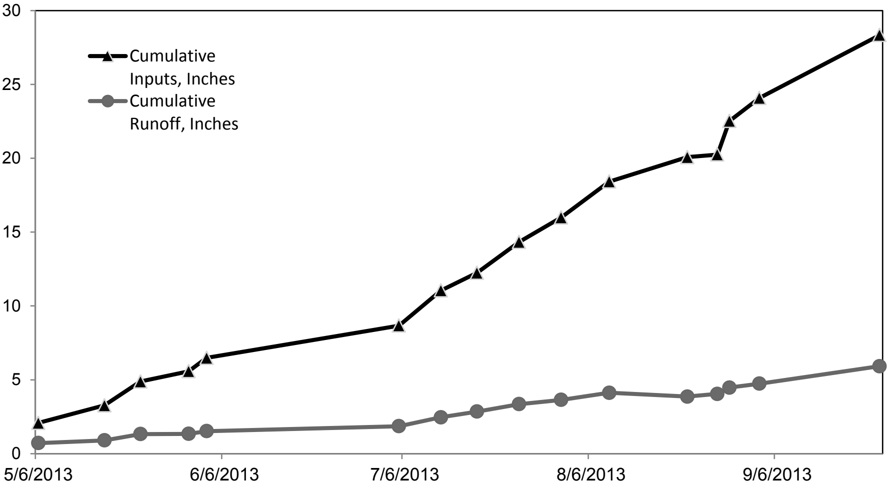


Fig. 1. Cumulative runoff during the growing season from three cotton fields, Shopcot (Top), East Weaver (middle) and Homeplace (bottom), on the Arkansas Cotton Discovery Farm, near Rohwer, Ark.



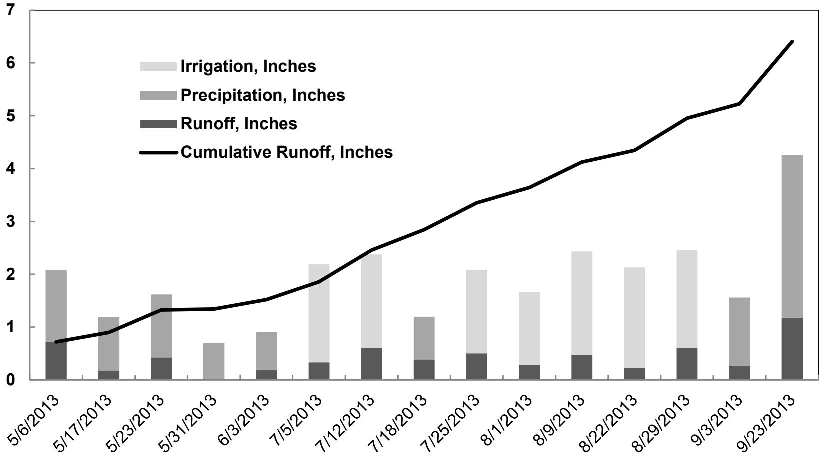


Fig. 2. Cumulative inputs (precipitation and irrigation) and runoff for cotton in East Weaver (top) and precipitation, irrigation and runoff by event (bottom).

Use of Fluridone for Season-Long Palmer amaranth Control

Z. Hill and J. Norsworthy[1]

RESEARCH PROBLEM

Glyphosate-resistant (GR) Palmer amaranth was confirmed in Arkansas in 2006; it infested 87% of the cotton fields in Arkansas by 2011 (Riar et al., 2013). As a result of widespread resistance, weed control programs in most Arkansas cotton fields today consists of 6 to 7 herbicide applications. New herbicide mechanisms with longer residual activity are needed to control GR Palmer amaranth and reduce the risk of resistance evolving to the currently used herbicides. The herbicide fluridone was discovered in the early 1970s, but was never developed and marketed for crop use even though cotton is tolerant to the herbicide when applied preemergence (PRE) (Waldrep and Taylor, 1976). Fluridone is highly persistent in soil, with 25% remaining at 385 days after application (Banks et al., 1979). Research is needed to determine if fluridone use in cotton will provide season-long control of Palmer amaranth.

BACKGROUND INFORMATION

Prior to the release of glyphosate-resistant crop cultivars, weeds were controlled primarily through tillage and various herbicides applied throughout the growing season. In 1997, glyphosate-resistant cotton cultivars were introduced to the market, which allowed for multiple in-crop applications of glyphosate. The extensive use of glyphosate caused several weeds to evolve resistance to glyphosate.

RESEARCH DESCRIPTION

In 2012 and 2013, a cotton research trial was conducted at the Lon Mann Cotton Research Center in Marianna, Ark. Cotton (*Gossypium hirsutum* L.) cultivar Phytogen 375WF was planted in four-row plots in rows spaced 97 cm apart in mid-May both years. This trial was setup as a three (pre-emergence (PRE) herbicides) by three (post-emergence (POST) herbicides) factorial. Factor A consisted of fluridone at 0.24 and 0.336 kg ai/ha, and fluometuron at 1.12 kg ai/ha; and

---

[1] Graduate assistant and professor, respectively, Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville.

factor B consisted of none, glyphosate + prometryn (8- to 10-lf) followed by (fb) MSMA + flumioxazin (layby); glyphosate + S-metolachlor (2-lf) fb glyphosate + S-metolachlor (4- to 5-lf) fb glyphosate + prometryn (8- to 10-lf) fb MSMA + flumioxazin (layby); all herbicides were applied at their labeled rates. Palmer amaranth control ratings were taken weekly through three weeks after the layby application. Collected data from both years were analyzed separately due to differences in rainfall received in each year. Analysis was completed using JMP Pro 10 software (SAS Institute, Inc., Cary, N.C.), and means were separated using Fisher's protected least significant difference method (LSD) $P = 0.05$.

RESULTS AND DISCUSSION

By 12 weeks after initial application (WAIA) in 2012 (dry year), PRE herbicides alone provided less than 25% Palmer amaranth control; while in 2013 (wet year) both fluridone rates provided superior control of Palmer amaranth compared to fluometuron. By 12 WAIA, all PRE treatments followed by four POST herbicide applications were similar, providing 78% to 85% Palmer amaranth control. With only two POST herbicide treatments, Palmer amaranth control decreased to less than 80% in both years. Greater control resulted with both fluridone rates compared to fluometuron when followed by 2 POST applications in 2012, but acceptable control was not obtained with either of these treatments. Greater Palmer amaranth control occurred with fluridone followed by 4 POST applications compared to fluridone followed by two POST herbicide applications (Fig 1).

PRACTICAL APPLICATION

From this study, we can conclude that fluridone does not provide sufficient control of Palmer amaranth to allow for a reduced number of postemergence applications in cotton regardless of the rainfall environment.

ACKNOWLEDGMENTS

The authors thank the SePRO Corporation for funding this research.

LITERATURE CITED

Banks, P.A., M.L. Ketchersid, and M.G. Merkle. 1979. The persistence of fluridone in various soils under field and controlled conditions. Weed Sci. 27:631-633.

Riar, D.S., J.K. Norsworthy, L.E. Steckel, D.O. Stephenson, T.W. Eubanks, and R.C. Scott. 2013. Assessment of weed management practices and problem weeds in the Midsouth United States-soybean: a consultant's perspective. Weed Technol. 27:604-611.

Waldrep, T.W. and H.M. Taylor. 1976. 1-Methyl-3-phenyl-5-[3-(trifluoromethyl) phenyl]-4(1H)-pyridinone, a new herbicide. J. Agric. Food Chem. 24:1250-1251.

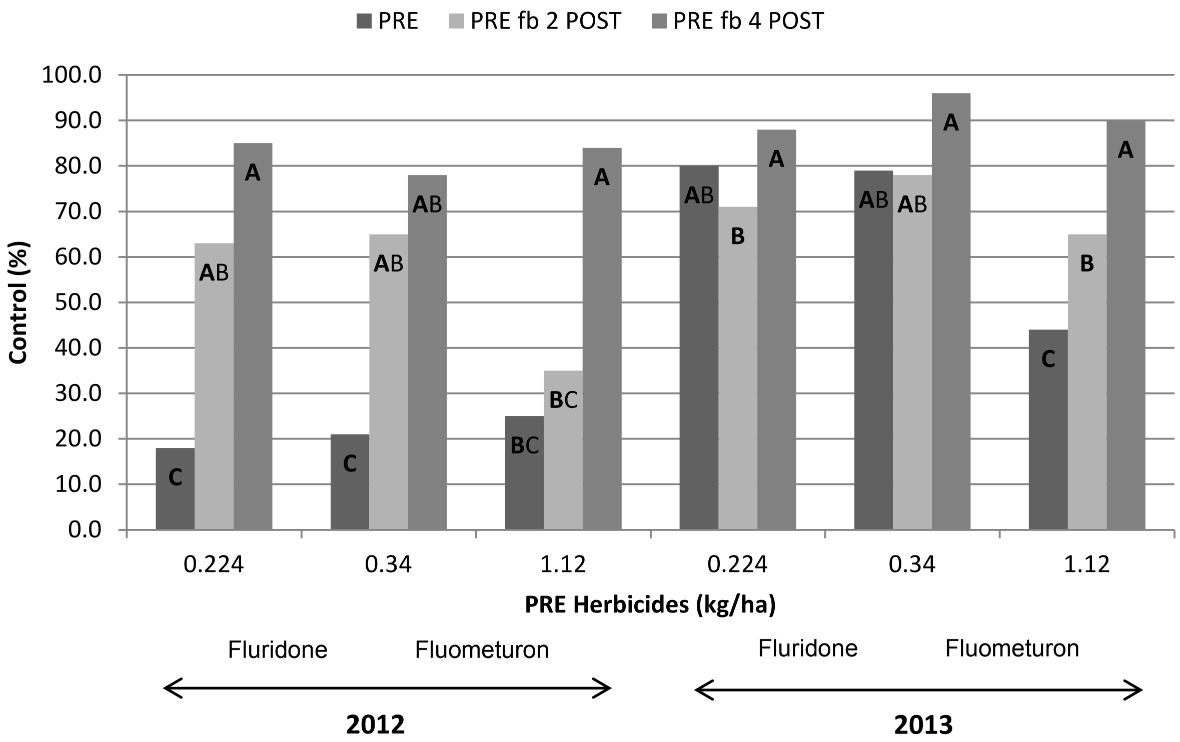


Fig. 1. Palmer amaranth control at 12 weeks after initial application (WAIA) in 2012 and 2013. Dark gray bars are pre-emergence (PRE) herbicides alone. Light gray bars are PRE herbicides followed by (fb) post-emergence (POST) treatments of glyphosate + prometryn (directed) fb MSMA + flumioxazen (directed-layby). Medium gray bars are PRE herbicides fb POST treatments of glyphosate + S-metolachlor fb glyphosate + S-metolachlor fb glyphosate + prometryn (directed) fb MSMA + flumioxazin (directed-layby). Bars topped by different letters within a year indicate significant differences among treatments (*P* = 0.05).

Factors Contributing to Cotton Injury from Soil-Applied Residual Herbicides

B.W. Schrage[1]*, J.K. Norsworthy*[1]*, K.L. Smith*[2]*, D.B. Johnson*[1]*,*
M. Bagavathiannan[1]*, and D. Riar*[1]

RESEARCH PROBLEM

There is narrow selectivity in cotton with regard to soil-applied herbicides, meaning that rates needed for effective weed control can likewise cause cotton injury, especially when environmental conditions are less than optimal for cotton emergence and growth. The objective of this research was to determine the influence of seed size, vigor, and planting depth on cotton injury from soil-applied residual herbicides.

BACKGROUND INFORMATION

Extensive use of glyphosate has led to the evolution of glyphosate-resistant weed species, of which glyphosate-resistant Palmer amaranth is the most notable (Heap, 2012). Glyphosate-resistant Palmer amaranth is the most problematic weed cotton producers throughout the mid-South are facing, with 87% of the cotton acreage in Arkansas infested with this resistant biotype (Norsworthy et al., 2012). Glyphosate resistance has prompted a return to the use of soil-applied residual herbicides. Most often, early-season cotton injury from soil-applied herbicides occurs on under cool, moist conditions (Askew et al., 2002). Conversely, other researchers have reported no or slight cotton injury with residual herbicides in other environments (Faircloth et al., 2001; Riar et al., 2011). For the soil types and production practices common to the mid-South, little research has been conducted to determine the reasons for inconsistent cotton tolerance under different microenvironments. Therefore, an assessment of factors responsible for cotton injury caused by pre-emergence-applied residual herbicides is important.

RESEARCH DESCRIPTION

Field studies were conducted in Fayetteville and Rohwer, Ark. in 2012 and 2013 evaluating the influence of cotton seed size, planting depth, and seed vigor

---

[1] Graduate assistant, professor, graduate assistant, post doctoral research associate, and post doctoral research associate, respectively, Department of Crop, Soil, and Environmental Sciences, University of Arkansas, Fayetteville.

[2] Professor, Southeast Research and Extension Center, Monticello, Ark.

on cotton injury from various soil-applied herbicides (diuron, fomesafen, and fluometuron). In Fayetteville, seed sizes, ranging from 0.33 to 0.46 oz/100 seed were obtained from a red-germplasm variety provided by Fred Bourland of the Northeast Research and Extension Center in Keiser, Arkansas and planted 0.75 in into Taloka silt loam soil. Treatments were applied immediately after planting and included a nontreated control, and diuron applied at 1 and 2 lb ai/acre. In Rohwer and Fayetteville, low- and high-vigor cotton seed was planted at 0.25 and 1.0 in depths in early-April. Low-vigor cotton seed was obtained by subjecting high-vigor seed to an accelerated seed coat aging test. Herbicide treatments were made immediately after planting and included diuron, fomesafen, and fluometuron at 1 and 2× rates. Experiments were irrigated regularly, and estimates of injury to cotton were visually rated at 1, 2, 3, and 4 weeks after treatment (WAT). All above-ground cotton biomass was collected, oven-dried, and weighed. In both experiments, data was subjected to analysis of variance (ANOVA) and means were separated using Fisher's protected least significant difference (LSD) method.

RESULTS AND DISCUSSION

Injury was significantly reduced when soil-applied herbicides were applied to high-vigor cotton plots. The ability of the high-vigor seed to rapidly germinate, freeing itself from the herbicide zone and shortening the window of contact, enabled high-vigor seed to tolerate application more effectively than low-vigor seed. Results from the planting depth study suggest variation among herbicide chemistries. In Fayetteville in 2012 and 2013, low-vigor seed planted deeper than 0.25 inch resulted in greater injury to cotton from fomesafen, diuron, and cotoran. In Rohwer in 2012, greater injury was observed on cotton planted at 1 inch depths that was treated with fomesafen (Fig. 1). In contrast, there was no statistical separation on injury observed from diuron and fluometuron though numeric trends suggest an opposite effect. In 2013, a statistically significant increase in injury was observed when low-vigor cotton planted at 1.0 inch depths was treated with 2× rates compared to normal labeled rates. Additonally, low-vigor seed applied with a 2× rate of diuron exhibited greater injury when planted at deeper depths (Fig. 2). Seed sizes, ranging from 0.33 to 0.46 oz/100 seed, did affect cotton injury from diuron. The four larger seed sizes exhibited no statistical difference though there was a trend for decreased injury with increased seed size in both the 1 and 2× rates. Statistical differences were observed between the smallest seed size (0.33 oz/100 seed) and the largest (0.46 oz/100 seed). An exponential decrease in injury was observed as seed size increased (Fig. 3). Larger seed possesses a greater endosperm and can therefore better survive uptake of herbicides from the preemergence zone. In summary, cotton seed size, seed vigor, and planting depth influenced injury from soil-applied herbicides.

PRACTICAL APPLICATION

The objective of this research was to evaluate genetic and agronomic factors that potentially influence cotton tolerance to soil-applied residual herbicides. By selecting larger seed with high vigor and planting at depths best suited to individual herbicide chemistry, these soil-applied herbicides can be implemented to control problem weeds in cotton while minimizing potential injury.

ACKNOWLEDGMENTS

This research was supported by Cotton Incorporated and the National Cotton Council.

LITERATURE CITED

Askew, S.D., J.W. Wilcut, and J.R. Cranmer. 2002. Cotton (*Gossypium hirsutum*) and weed response to flumioxazin applied preplant and postemergence directed. Weed Technol. 16:184-190.

Faircloth, W. H., M.G. Patterson, C.D. Monks, and W.R. Goodman. 2001. Weed management programs for glyphosate-tolerant cotton (*Gossypium hirsutum*). Weed Technol. 15:544-551.

Heap, I. 2012. The international survey of herbicide resistant weeds. Available: www.weedscience.com. Accessed 12 January 2012.

Norsworthy, J.K., K.L. Smith, R.C. Scott, L E. Steckel, J.A. Bond, T.W. Eubank, D.O. Stephenson, and J. Weirich. 2012. Midsouth weed management survey with emphasis on Palmer amaranth. *In:* Proc. Beltwide Cotton Conf., Orlando, Fla., 3-6 Jan. 2012, p. 1544. National Cotton Council, Memphis, Tenn.

Riar, D.S., J.K Norsworthy, and G.M Griffith. 2011. Herbicide programs for enhanced glyphosate-resistant and glufosinate-resistant cotton (*Gossypium hirsutum*). Weed Technol. 25:526-534.

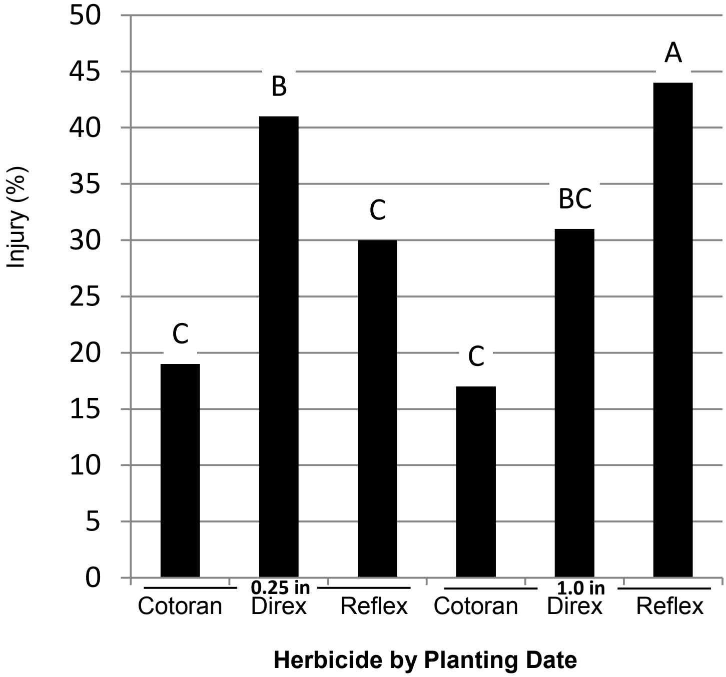


Fig. 1. Cotton injury at 22 days after treatment from soil-applied herbicides at different planting depths in Rohwer, Ark. in 2012.
Note: Cotoran = fluometuron; Direx = diuron; Reflex = fomesafen.

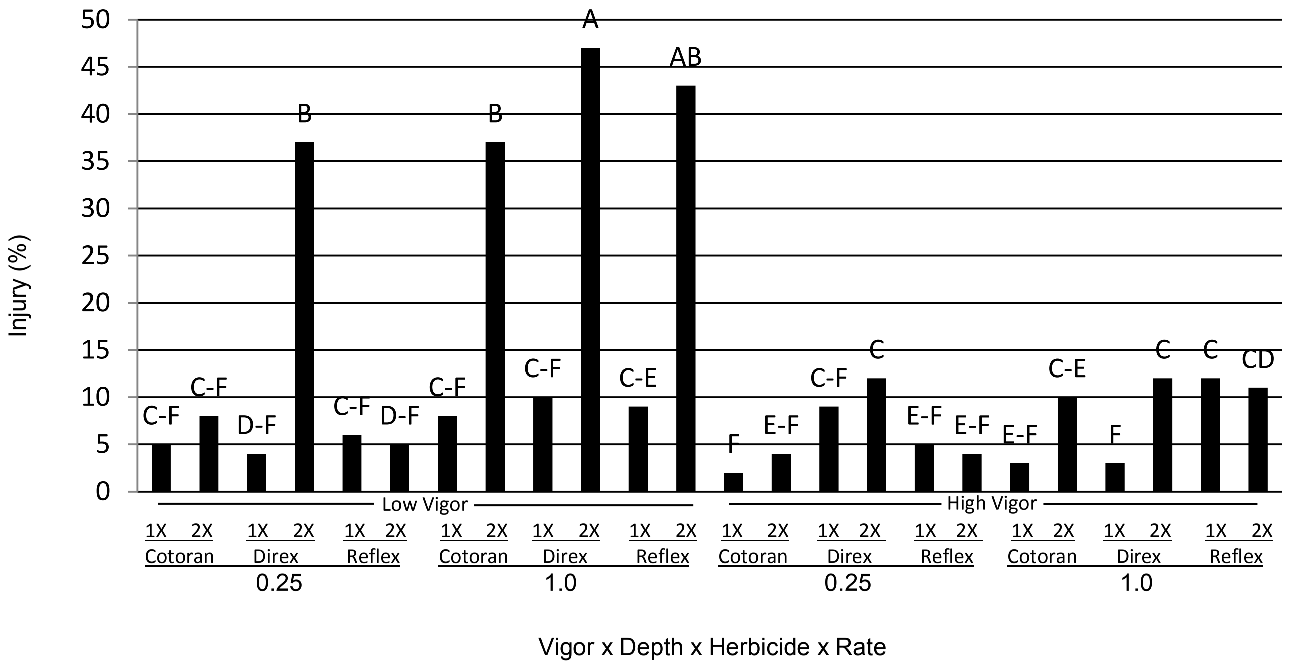


Fig. 2. Injury at 22 days after treatment (DAT) caused by two rates of pre-emergence herbicides applied to cotton planted at 0.25 and 1.0 inch depths at Rohwer, Ark. in 2013.
Note: Cotoran = fluometuron; Direx = diuron; Reflex = fomesafen.

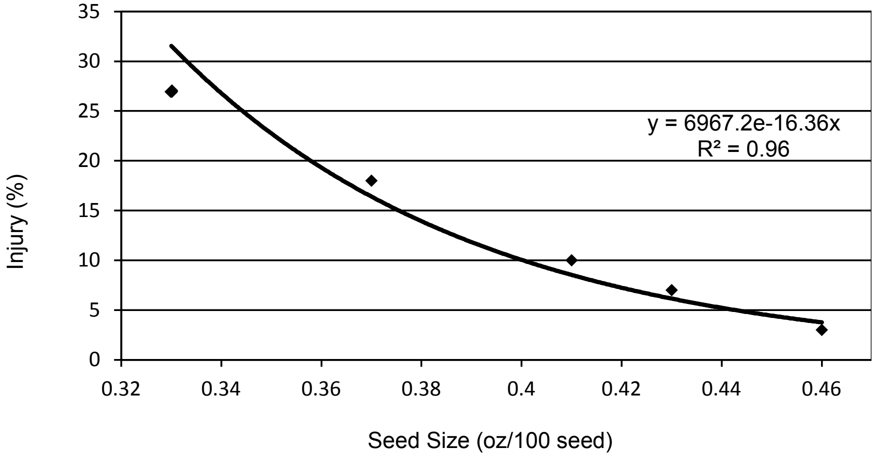


Fig. 3. Injury at 18 days after treatment for various seed sizes within a seed lot in Fayetteville, Ark.

Evaluation of Dual Magnum, Warrant, and Zidua Pre-Emergence in Arkansas Cotton

R. Doherty[1], T. Barber[2], L. Collie[3], and J. Meier[1]

RESEARCH PROBLEM

Cotton (*Gossypium hirsutum L.*) growers in Arkansas are still battling Glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) along with barnyardgrass (*Echinochloa crus-galli*). Multiple control options give growers the ability to increase control of these troublesome weeds. The objective was to evaluate Dual Magnum, Warrant, and Zidua preemergence in Arkansas cotton for crop response and weed control. Each herbicide was evaluated at the ½, ¾, 1, and 2× use rates.

BACKGROUND INFORMATION

Cotton growers have been battling glyphosate-resistant Palmer amaranth since 2007. Currently there is no single herbicide that will control glyphosate-resistant Palmer amaranth after it reaches 4-5 inches in height. Early-season residual control is imperative. More information was needed on Palmer control with Zidua and Warrant.

RESEARCH DESCRIPTION

One trial was established at the Rohwer Research Station, near Rohwer, Ark., in a Hebert silt loam soil in 2012 and 2013 to evaluate crop response, Palmer amaranth, and barnyardgrass control in cotton. In 2012, Fiber Max 1944 GTLL B2 was planted on 10 May and in 2013 Stoneville 4946GL B2 was planted on 28 May. The trial was arranged in a randomized complete block design with four replications. Parameters evaluated were visual ratings of crop injury, Palmer amaranth, and barnyardgrass control and cotton yield.

RESULTS AND DISCUSSION

In 2012, visual cotton injury was not caused by any treatment. In 2013 no occurrence of cotton chlorosis or necrosis was recorded, but stunting did occur.

---

[1] Program technician and program technician, respectively, Southeast Research and Extension Center, Monticello.
[2] Assistant professor, Department of Crop, Soil, and Environmental Sciences. Little Rock.
[3] Program technician, Lonoke Extension Center, Department of Crop, Soil, and Environmental Sciences, Lonoke.

Zidua was the only herbicide that caused visual stunting. Zidua at 4 oz/acre or 2× rate caused the most injury at 16% plant height reduction (Fig. 1).

In 2012, twenty-five days after application (DAA) barnyardgrass control was above 76% with all herbicides and rates. Warrant provided less barnyardgrass control than Dual Magnum or Zidua at all rates. In 2013 20 DAT the same trend occurred with Warrant being the weaker product on barnyardgrass control (Figs. 2 and 3).

Palmer amaranth control 25 DAT in 2012 was above 81% with all herbicides and rates. In 2013, 20 DAT Warrant at 48 oz/acre, Dual Magnum at 16 oz/acre, and Zidua at 2 oz/acre provided 55%, 68%, and 98% control of Palmer amaranth respectively. Zidua provide the most consistent Palmer amaranth control across rates and across years (Fig. 4).

In 2012, all treatments provided equal yields to that of the weed-free check except for Zidua at 2 oz/acre which provided less (Fig 5). In 2013, all treatments provided cotton yield greater than the untreated check and equal to the weed-free check. In 2012, the highest yield numerically (3086 lb/acre) was provided by Warrant at 96 oz/acre. In 2013, the highest yield numerically (4134 lb/acre) was provided by Dual Magnum at 32 oz/acre (Figs. 4 and 6).

PRACTICAL APPLICATION

Early-season Palmer amaranth control is necessary in Arkansas cotton. The herbicides tested in this trial provide early–season control options, although some provided better control than others. The information from this trial will be used to make Palmer amaranth control recommendations throughout the state.

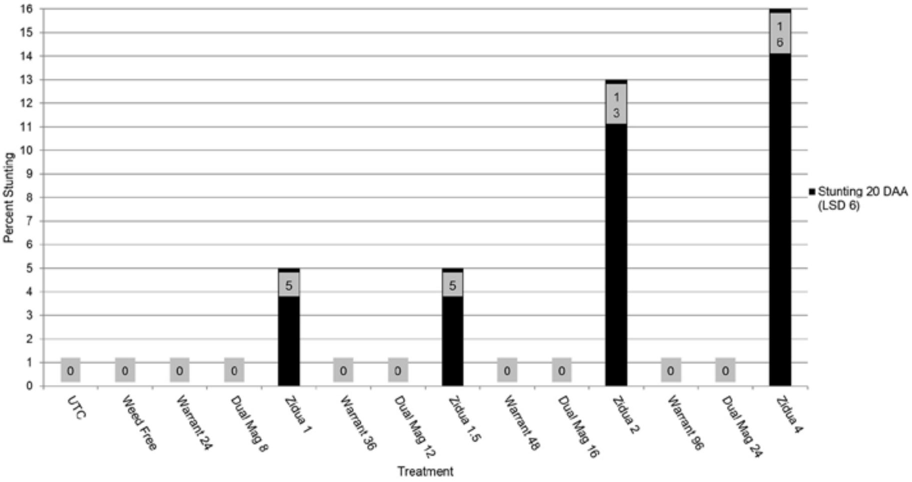


Fig. 1. Effect of herbicide treatment on cotton stunting 2013 at the Rohwer Research Station, near Rohwer, Ark. UTC - untreated check, DAA - days after application.

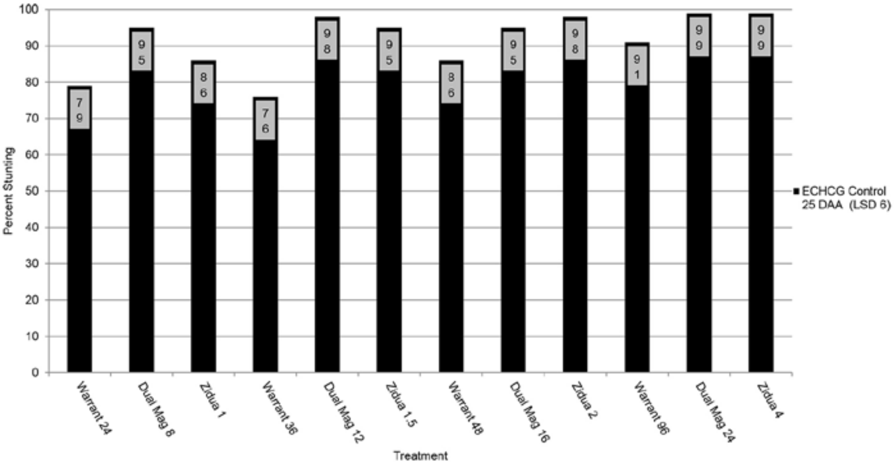


Fig. 2. Effect of herbicide treatment on Barnyardgrass control 2012 at the Rohwer Research Station, near Rohwer, Ark. UTC - untreated check, DAA - days after application.

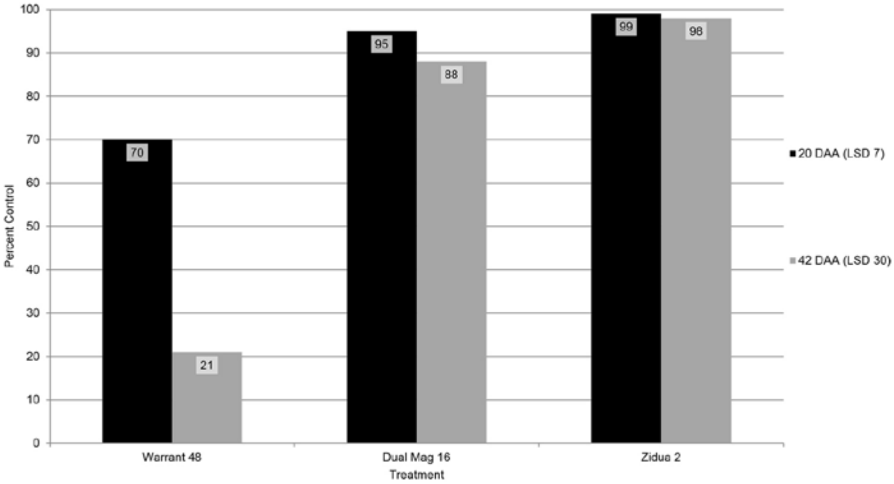


Fig. 3. Effect of herbicide treatment on Barnyardgrass control 2013 1 X at the Rohwer Research Station, near Rohwer, Ark. UTC - untreated check, DAA - days after application.

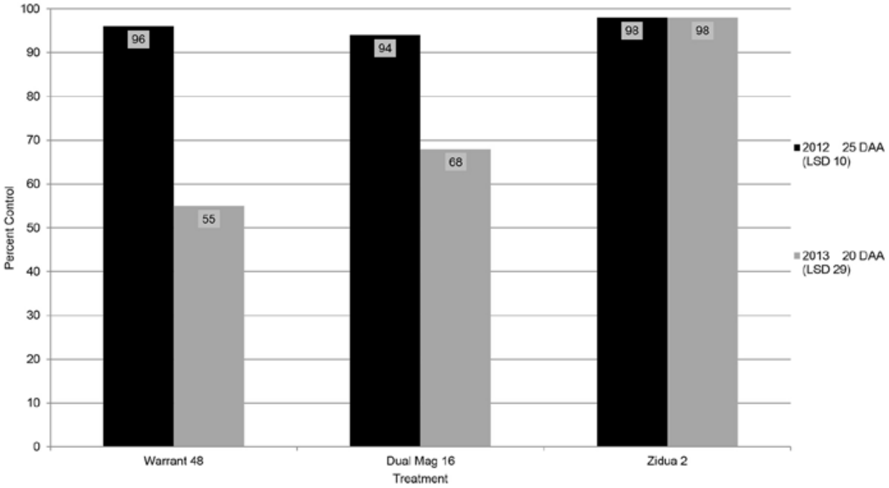


Fig. 4. Effect of herbicide treatment on Palmer amaranth control 1 X at the Rohwer Research Station, near Rohwer, Ark. UTC - untreated check, DAA - days after application.

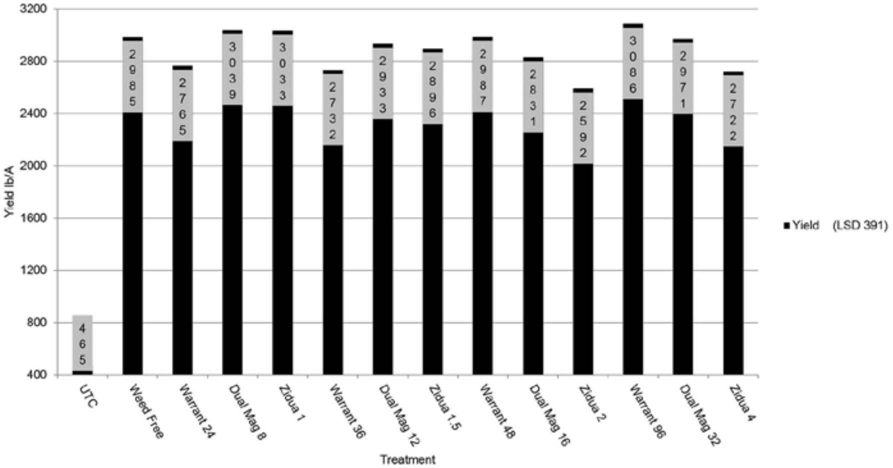


Fig. 5. Cotton yield in herbicide treatments 2012 at the Rohwer Research Station, near Rohwer, Ark. UTC - untreated check, LSD - least significant difference.

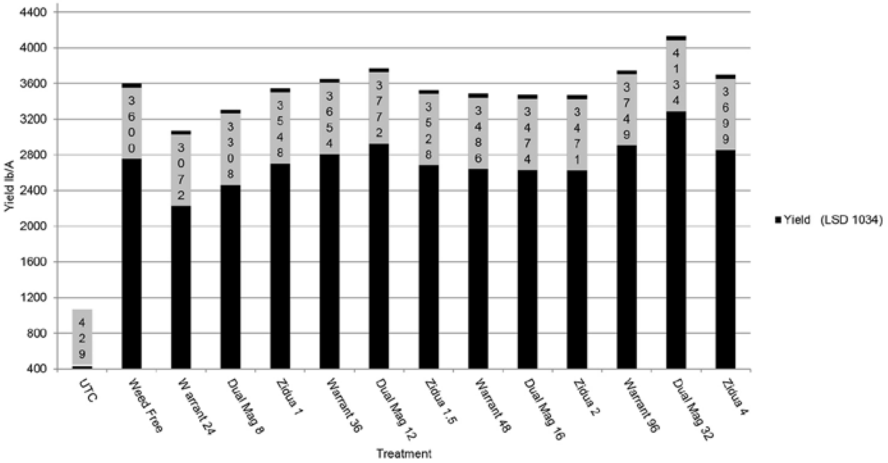


Fig. 6. Cotton yield in herbicide treatments 2013 at the Rohwer Research Station, near Rohwer, Ark. UTC - untreated check, LSD - least significant difference.

Comparison of Herbicides Acetochlor, Metolachlor, and Pyroxasulfone Applied Post-Emergence to Cotton

L. Collie[1], T. Barber[2], R. Doherty[3], and J. Meier[3]

RESEARCH PROBLEM

Arkansas cotton (*Gossypium hirsutum* L.) growers are currently relying on residual herbicides to control glyphosate-resistant Palmer amaranth (*Amaranthis palmeri* L.). Current recommendations for resistant pigweed control involve overlapping residual herbicides to prevent pigweed emergence. In this trial, the objective was to evaluate weed control and compare crop injury with currently labeled and potential herbicides.

BACKGROUND INFORMATION

Though Dual Magnum (metolachor) and Warrant (acetochlor) are both labeled for use in cotton there have been reports of crop injury when these products are tank mixed with Liberty (glufosinate). More information was needed on damage caused with the combination of these products.

RESEARCH DESCRIPTION

This trial was conducted at the Lon Mann Cotton Station, in Marianna, Ark., during the 2013 season. Applications were made in a Liberty Link system Stoneville cultivar 4946 GLB2. The trial was arranged in a randomized complete block design with four replications. Each block was 30ft by 4 rows. Dual Magnum, Warrant, and Zidua were applied post-emergence (Post) at ½×, ¾×, 1× and 2× rates, and each rate was applied at the 1-2 and 4-6 leaf growth stage.

Crop injury, weed control, and cotton yield were evaluated 7, 14, 21, and 28 days after the applications. Palmer amaranth (*Amaranthis palmeri* L.), pitted morningglory (*Ipomoea lacunose* L.), barnyardgrass (*Echinochloa crus-galli* L.), and broadleaf signalgrass (*Brachiaria platyphylla* Nash) were over seeded at planting to provide a consistent weed population. Also, at planting, an application of Cotoran (fluometeron) was applied at 1 lb ai/acre across all treatments. Liberty was added to each application at 29 oz/acre.

---

[1] Program technician, Department of Crop, Soil, and Environmental Sciences, Lonoke.
[2] Assistant professor, Department of Crop, Soil, and Environmental Sciences. Little Rock.
[3] Program technician and program technician, respectively, Southeast Research and Extension Center, Monticello.

RESULTS AND DISCUSSION

Crop injury was present with higher rates of all residual herbicides at both 1-2 leaf and 4-6 leaf applications. The Warrant tank mixtures of 2.3 lb ai/acre provided 18% injury at 14 days after the 1-2 leaf application and 26% at 7 days after the 4-6 leaf application (Fig. 1). Cotton recovered at 21 days with either application. Dual Magnum at 1.9 lb ai/acre produced 25% damage at 14 days after the 1-2 leaf application, by 21 days there was no visual damage. There was 13% injury present with 2 pt/acre Dual Magnum 7 days after the 4-6 leaf applications (Fig. 2), but by 14 days the plants recovered and there was no visible injury present. Zidua produced significant damage at high rates at both 1-2 leaf and 4-6 leaf applications. At 14 days after the 4-6 leaf treatment, there was 44% damage noted; but only the highest rate (0.21 lb ai/acre) of Zidua produced significant damage at 21 days after application (Fig. 3). Though significant injury was observed, there was no substantial yield reduction. Also, there were no notable differences in weed efficacy.

PRACTICAL APPLICATION

Post-emergence Palmer amaranth control is necessary in Arkansas cotton. The residual herbicides tested in this trial provide post-emergence control options. Based on information received from this trial we believe that Zidua (pyroxasulfone) will have a better fit post directed or as a layby application. The information from this trial will be used to make recommendations throughout the state.

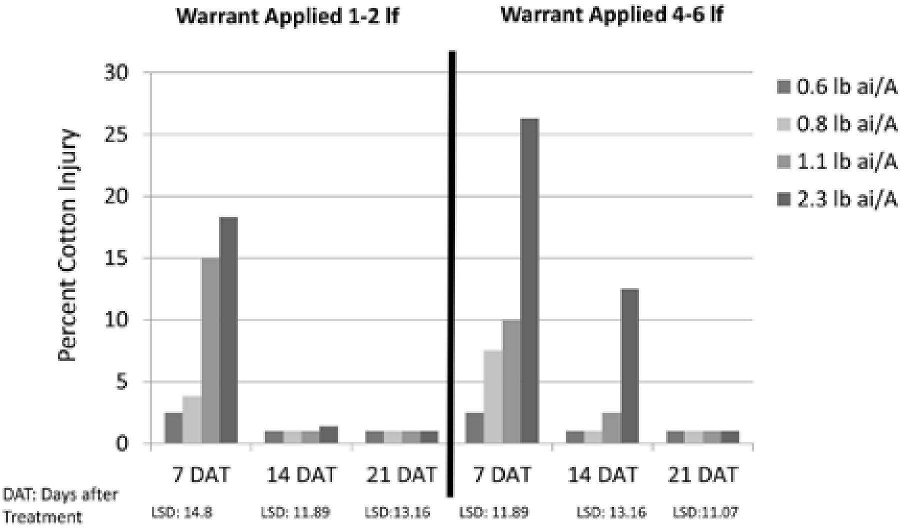


Fig. 1. Injury from Warrant applied on 1-2 and 4-6 leaf cotton. LSD - least significant difference.

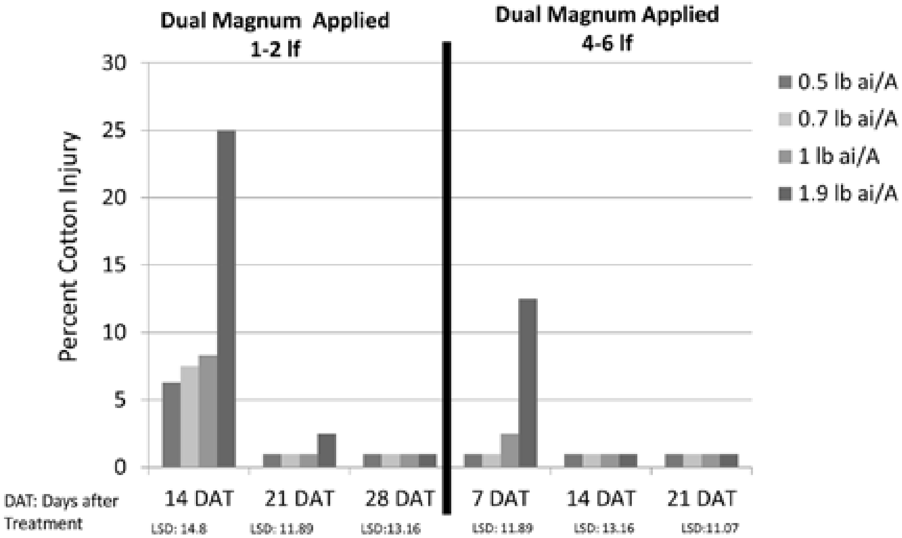


Fig. 2. Injury from Dual applied on 1-2 and 4-6 leaf cotton. LSD - least significant difference.

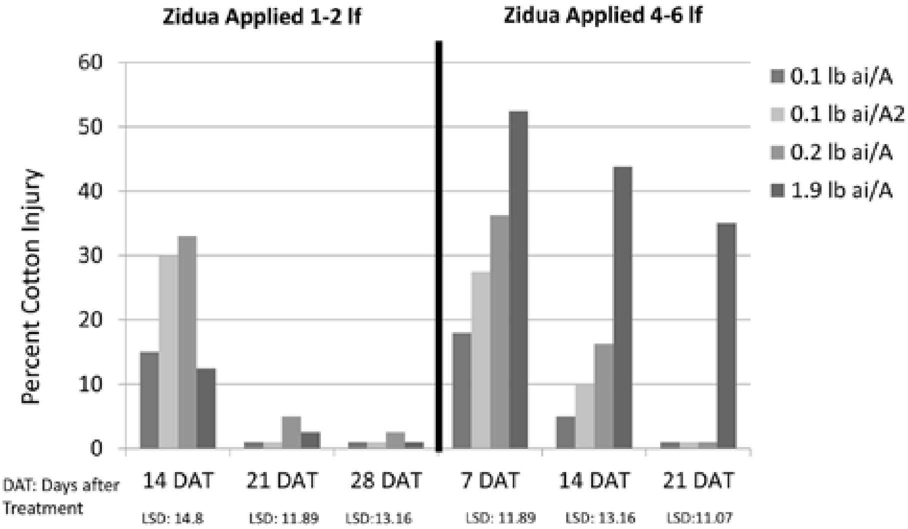


Fig. 3. Injury from Zidua applied on 1-2 and 4-6 leaf cotton. LSD - least significant difference.

Determining Relative Rainfastness of Insecticides Used For Control of Tarnished Plant Bug in Cotton

G.M. Lorenz III[1], G. Studebaker[2], N.M. Taillon[1], H.M. Chaney[1], D.L. Clarkson[3], B.C. Thrash[3], L.R. Orellana Jiminez[3], and M.E. Everett[3]

RESEARCH PROBLEM

The problem of controlling tarnished plant bug (TPB) is exacerbated with the situation of "pop up" rain events that often occur in the mid-South that can cause wash off of insecticide applications that can occur at any time after application. Also, many growers that have overhead irrigation may need to irrigate their crop to meet water demand of the crop as soon as possible behind insecticide applications. Labels do not provide adequate information on rainfastness, or the amount of time that is needed after an application before a rainfall event or overhead irrigation event can take place for the insecticide to still provide an acceptable level of control. Overestimating wash-off can cause unwarranted re-applications of insecticide applications, while underestimating wash-off may result in inadequate crop protection. Studies were conducted in both the greenhouse and field to evaluate the rainfastness of selected insecticides currently recommended for control of TPB in Arkansas and the mid-South.

BACKGROUND INFORMATION

In 2008 and 2009, we experienced unusually wet years across the crop landscape in Arkansas. Of the many questions posed to Extension entomologists across the state, among the most common were related to efficacy and/or longevity of insecticides when applied prior to a rainfall event (Lorenz and Studebaker, pers. comm.). A number of growers delayed insecticide treatments until the chance of precipitation decreased, while others received unexpected rainfall hours after application. Knowing how long a given insecticide must remain rain-free in order to be effective is important, particularly during a "wet year". Additionally, knowing which insecticides are more rainfast than others can help decision-makers choose which insecticide to use should unpredictable rainfall patterns set in. Furthermore,

---

[1] Associate department head, program technician, and program associate, Department of Entomology, Lonoke Extension Center, Lonoke.

[2] Entomologist, Northeast Research and Extension Center, Keiser.

[3] Graduate assistant, program technician, graduate assistant, and graduate assistant, respectively, Department of Entomology, University of Arkansas, Fayetteville.

growers can potentially save money by planning insecticide applications around rainfall events and/or weather forecasts once greater knowledge of these insecticides is attained. Many labels provide no specific information on rainfastness. The objectives of this research were to (1) quantify how long each insecticide needs to be rain-free to be effective enough to not need repeat application, and (2) compare relative rainfastness of selected insecticides commonly used for tarnished plant bug management.

RESEARCH DESCRIPTION

Greenhouse trials were conducted at the Lonoke Extension Center, Lonoke, Ark. Field trials were conducted at the Northeast Research and Extension Center, Keiser, Ark. Plot design was a 4 × 5 × 7 factorial design utilizing 4 insecticides, 5 adjuvants and 7 rain periods with 4 replications. Insecticides included Centric, Transform, Orthene and Bidrin. Adjuvants included crop oil concentrate, non-ionic surfactant, organosilicone, and methylated seed oil. Rain periods were 0, 1, 3, 6, 12 and 24 h post application and a no rain event.

RESULTS AND DISCUSSION

Efficacy for all insecticides improved as rain timing increased from application for all insecticides (Fig. 1). Crop oil concentrate, methylated seed oil and non-ionic surfactant had significantly higher mortality compared to no surfactant and organosilicone surfactant (Fig. 2). Bidrin had the highest mortality of all insecticides tested (Fig. 3).

PRACTICAL APPLICATION

Results of this study will assist entomologists in giving recommendations to cotton growers who are making key integrated pest management (IPM) decisions about which insecticide to use when there is a "chance" of rain, and whether or not to re-spray if rain occurs after an insecticide application is made, as well as determine what period of time needs to pass before he should use overhead irrigation.

ACKNOWLEDGMENTS

We would like to thank Cotton Incorporated and the Arkansas Cotton State Support Committee for funding this research. We would also like to thank Helena Seed Company for their support.

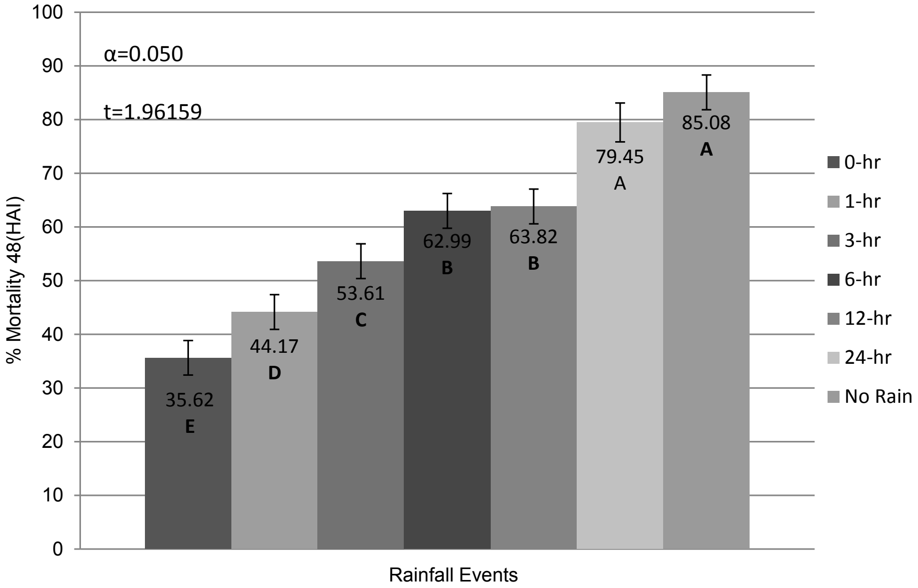


Fig. 1. Percentage mortality for all insecticides at selected rainfall events.

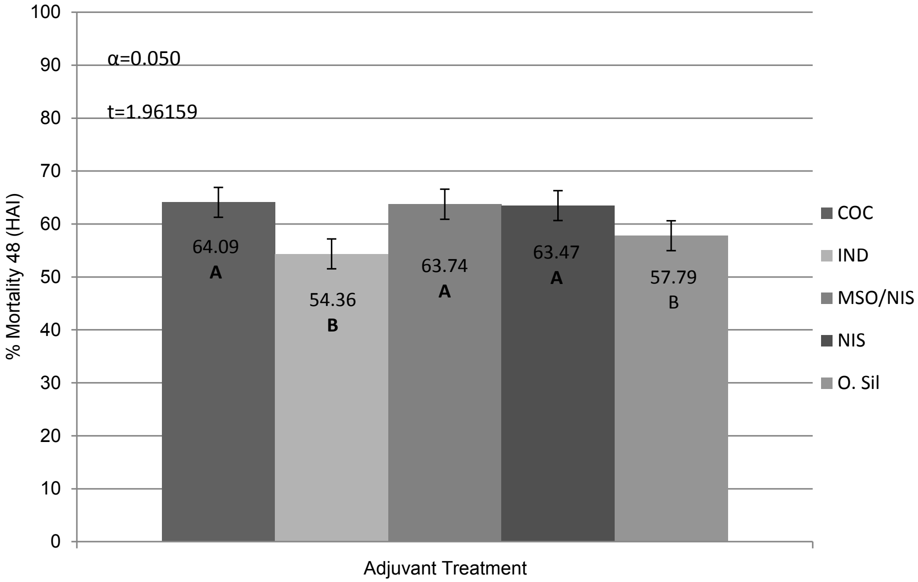


Fig. 2. Percent mortality for each of selected surfactants.

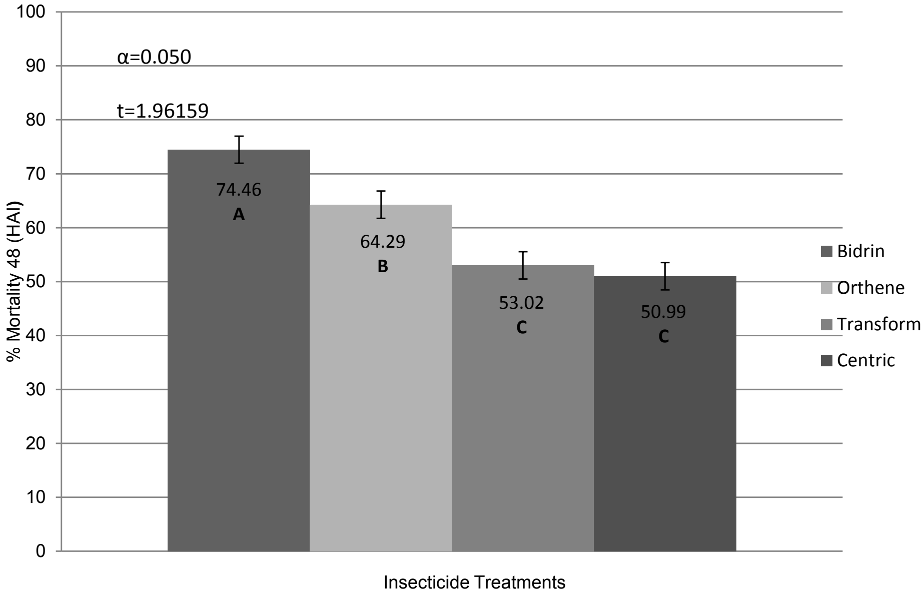


Fig. 3. Percent mortality for each of selected insecticides.

Effect of Timing and Duration of Two-Spotted Spider Mites Infestation on Cotton Growth and Yield

L.R. Orellana Jimenez[1], G.M. Lorenz III[2], N.M. Taillon[2], W.A. Plummer[2],
B.C. Thrash[1], D.L. Clarkson[2], and M.E. Everett[1]

RESEARCH PROBLEM

Arkansas cotton acreage treated for spider mites has more than doubled since 2005. Most of the increase can be attributed to early season infestations (Gore et al., 2013). Continued research is needed to understand how outbreaks of spider mites at different stages of cotton development and duration of infestations will affect growth and yield.

BACKGROUND INFORMATION

Two-spotted spider mites have become more of a long-season problem, causing injury to cotton in early vegetative stages (Catchot et al., 2006). Spider mites have stylet-like sucking mouth parts that, when everted, form a hollow piercing probe. Spider mites feed mostly on the underside of leaves, damaging important photosynthetic sites. Prolonged feeding periods on leaves can result in large lesions of irregular light yellow or grayish spots. Damage can turn into necrotic areas on leaves and stems and can even cause defoliation and ultimately yield loss (Jeppson et al., 1975).

RESEARCH DESCRIPTION

Research plots were located in Lee County, Arkansas, during 2012 and 2013 crop seasons. Early-maturing cotton varieties used were DP 0912 B2RF and ST 4946 GLB2 during 2012 and 2013, respectively. Each year, groups of three cotton plots were infested at three different times: fourth, sixth and ninth true leaf and cotyledon, fourth and sixth (or ninth) true leaf during 2012 and 2013 respectively. Within each infestation time, a plot was assigned to each of three different spider

---

[1] Graduate assistant, program technician and graduate assistant, respectively, Department of Entomology, University of Arkansas, Fayetteville.

[2] Associate department head, program technician, program technician, and program associate, respectively, Department of Entomology, Lonoke Extension Center, Lonoke.

mite infestation durations: short (3-6 d), medium (9-10 d) and long (14-36 d). Mite densities and leaf damage were assessed between three to five days after infestation and continued until mite elimination. Plant response to mite infestation was assessed through measurements of plant heights, total plant nodes, nodes to first square, nodes above white flower and yield.

RESULTS AND DISCUSSION

In 2012, rain did not allow the establishment of spider mites infestation on early planted cotton plots. Even so, late planted cotton where spider mites were successfully established did not have differences in plant response measured (i.e. nodes to first square, plant heights, total plant nodes, and nodes above white flower). However seed cotton yields (Table 1) had statistical differences when analyzed by infestation length (Table 2). Contrasts were used to determine differences in yield between control and each one of the long infestation durations at fourth, sixth and ninth true leaf (Table 3). The contrast suggested that higher mite densities led to significant yield loss, as occurred in the treatments with infestations at fourth (28 d) and sixth true leaf (14 d), where yield loss was estimated to be 15.1% and 12.5%, respectively.

In 2013, late planted cotton was significantly taller (17.77–28.30 cm) (Table 4) and had more nodes (2-3 nodes) than early planted cotton. However, this cannot be explained as an effect of mite infestations since nodes to first square, nodes above white flower, and yield were not statistically different between planting dates. Cotton is known to be sensitive to fluctuations in temperature and light intensity (Baker, 1965). Hence it is presumed that environmental conditions favored faster growth in the late planted cotton.

In 2012, environmental conditions (Table 5) favored spider mite infestations, where higher densities were recorded on the longest infestation duration at fourth true leaf and spider mites reached a peak density of 12.68 mites/cm^2. In 2013, the infestation that started at cotyledon with longest duration reached a mite density of 1.86 mites/cm^2, and it was the highest mite density recorded during 2013. This mite density difference between years can be attributed to warmer, dryer weather observed during 2012 than in 2013.

PRACTICAL APPLICATION

Under these experimental conditions, we concluded that spider mites can reduce yield when environmental conditions favor sustained densities for intervals greater than 14 days. Conversely, spider mites will not cause significant yield loss if environmental conditions do not favor spider mite development for extended periods of time.

LITERATURE CITED

Baker, D.N. 1965. Effects of certain environmental factors on net assimilation in cotton. Crop Sci. 5:53-56.

Catchot, A., J.F. Smith, J. Gore, F. Musser, S. Stewart, G. Lorenz, R. Bagwell, and R. Leonard. 2006. Spider mites: a persistent problem in mid-south cotton, pp. 1407-1408. *In*:Proceedings, Beltwide Cotton Conferences, San Antonio, Texas, 3-6 January, 2006 . National Cotton Council, Memphis, Tenn.

Gore, J., D.R. Cook, A. Catchot, F. Musser, W.S. Scott, B.R. Leonard, G. Lorenz, G. Studebaker, D.S. Akin, K.V. Tindall, and R.E. Jackson. 2013. Impact of twospotted spider mite (Acari: Tetranychidae) infestation timing on cotton yields. J. Cotton Sci. 17:34-39.

Jeppson, L.R., H.H. Keifer, and E.W. Baker. 1975. Mites injurious to economic plants. University of California Press, Berkeley, California. 614 pp.

Table 1. 2012 yield means ± SEM results by treatment (infestation timing and infestation duration) during 2012.

Treatment	Yield Means ± SEM
Control	3197.85 ± 114.84
Fourth true leaf short	3040.81 ± 198.91
Sixth true leaf short	3571.88 ± 198.91
Ninth true leaf short	3383.41 ± 198.91
Fourth true leaf long	2715.31 ± 198.91
Sixth true leaf long	2796.69 ± 140.65
Ninth true leaf long	3066.51 ± 198.91

Table 2. Yield main factors (infestation time and infestation duration) and their interaction.

Measurements	df	F Ratio	Prob > F
Infestation time (IT)	2	1.6406	0.208
Infestation length (IL)	1	8.0708	0.0074*
Interaction IT× IL	2	0.9107	0.4113

*= significant, α= 0.05, df = degrees of freedom.

Table 3. Yield contrasts between control and infestation duration at fourth true leaf, sixth true leaf, ninth true leaf, and all infestation times during 2012.

Contrast Between Control and	df	F Ratio	Prob > F	Yield ± SEM Kg/Ha
Fourth true leaf	1	4.4137	0.0404*	482.53 ± 229.68
Sixth true leaf	1	4.8809	0.03155*	401.16 ± 181.58
Ninth true leaf	1	0.3270	0.5698	131.34 ± 229.68
All long Durations	3	4.7346	0.0340*	338.34 ± 155.49

*= significant, α = 0.05, df = degrees of freedom.

Table 4. Least squares means comparison of plant response early planted vs. late planted differences for plant nodes and plant heights during 2013.

Measurements	F Ratio	Prob > F	Early Planted (SE)	Late Planted (SE)
Plant Nodes				
Squaring	292.22	<.0001	8.05 ± 0.14b[†]	11.54 ± 0.15a
Bloom	82.96	<.0001	10.83 ± 0.13b	12.54 ± 0.14a
Cutout	72.18	<.0001	15.98 ± 0.25b	19.10 ± 0.27a
Plant Heights				
Squaring	641.42	<.0001	32.78 ± 0.74b	60.55 ± 0.81a
Bloom	223.99	<.0001	71.00 ± 0.80b	84.54 ± 0.87a
Cutout	326.7437	<.0001	91.51 ± 1.06b	119.90 ± 1.16a

[†] Means followed by the same letter are not significantly different, α= 0.05.

Table 5. Monthly averages of high/low temperatures (C°) and precipitation (mm) during 2012, 2013, and 30 year average at Lon Mann Cotton Research Station, Marianna, Arkansas.

	2012			2013			30 Year Average		
Month	Avg high	Avg low	Total Precipn	Avg high	Avg low	Total Precipn	Avg high	Avg low	Total Precipn
January	13.4	1.9	48.8	10.9	1.9	216.2	8.9	-1.0	99.1
February	13.6	4.0	100.6	12.0	1.9	122.7	11.6	1.2	108.5
March	23.6	11.9	138.2	21.0	9.9	142.5	16.6	5.6	122.9
April	25.1	12.4	28.4	21.0	9.9	142.5	22.1	10.4	127.8
May	30.4	17.8	38.1	25.9	15.4	188.5	26.9	15.8	129.5
June	31.8	19.4	19.8	32.0	20.6	18.8	31.2	20.1	100.1
July	34.3	22.9	64.8	31.0	20.5	70.9	32.7	21.7	95.3
August	34.3	22.9	64.8	31.7	20.9	47.8	32.6	20.7	67.1
September	29.6	17.7	123.4	31.2	18.2	111.3	29.2	16.5	64.0
October	21.8	9.9	114.6	23.0	12.0	68.3	23.3	10.3	104.6
November	16.9	4.4	101.3	14.9	3.6	99.6	16.5	5.6	125.2
December	13.3	4.6	90.4	9.8	1.3	180.1	10.3	0.6	140.2

Tillage Effects on Abundance of Arthropods in Arkansas Cotton Fields: Pitfall Trap Studies

S. Kathiar[1,2], J. Lanza[1], T.G. Teague[3], and K. Neeley[3]

RESEARCH PROBLEM

Incorporation of conservation tillage as a best management practice has been an important step toward reducing soil loss and nutrient runoff, while maintaining crop productivity in Arkansas cotton. Conservation tillage has become a standard practice for most producers. In addition, winter cover crops of wheat or rye often are planted in row middles in Northeast Arkansas to reduce damage associated with wind and blowing sand. One concern among producers and their crop advisors is the potential for outbreaks of pest insects in low-till systems because of increased availability of plant hosts in spring, and the "low-spray" environments in the post-boll weevil era. Tillage practices may affect other arthropods, including beneficial natural enemies. The purpose of this study was to evaluate the effects of the three different tillage systems (conventional tillage, cover crop, and no-till) on abundance of soil-surface arthropods during two production seasons.

BACKGROUND INFORMATION

Tillage sometimes is recommended to eliminate pests from fields before they emerge from their winter habitat in the soil (Leonard et al., 2000). The greater availability of crop residue in conservation tillage systems compared to fields with conventional tillage might increase food supplies for pests (Holland, 2004). As use of conservation tillage systems has increased, more research has evaluated arthropod populations in different tillage regimes. Stinner and House (1990) reviewed 45 studies that documented the effects of different tillage systems on crop damage, and they reported that, from 51 arthropod pest species, 28% of the arthropod pests increased in abundance with decreasing tillage and 43% of the pests decreased. In Georgia, cotton aphid populations were higher under conservation tillage than conventional tillage (Marti and Olson, 2007). However, in Turkey, four different tillage systems did not affect the three cotton pests studied (Gencsoylu and Yalcin, 2004). Numerous studies have reported that no-till fields have

---

[1] Graduate assistant and professor, respectively, Department of Biology, Little Rock.

[2] Graduate assistant, Department of Biology, University of Baghdad, Baghdad, Iraq.

[3] Professor and program technician, Arkansas State University, University of Arkansas System Agricultural Experiment Station, Jonesboro.

significantly more beneficial natural enemies than conventional fields (House and Parmalee, 1985). For example, more ground predators were observed in plots with conservation tillage than in those with conventional tillage in Texas cotton fields (Sansone and Minzenmayer, 2005).

RESEARCH DESCRIPTION

The study site was located at the Judd Hill Cotton Research Station in Truman, Ark. in a long-term tillage field trial. Three tillage treatments (conventional, wheat winter cover crop, and no-till) were arranged in a randomized complete block design with three replications. These tillage strips have been maintained since 2007. Plots were 16 rows wide and 150 m long. Cotton cultivar Stoneville 4554 B2F was planted 7 May 2010, and cultivar DPL 0912 B2RF was planted 11 May 2011 in a soil mapped as Dundee silt loam. Production practices were similar across all tillage treatments with the following exceptions. In conventional main plots each spring, beds were reshaped and then flattened prior to planting with a DO-ALL fitted with incorporation baskets. No post-planting cultivation was used in any tillage regime. Plots were furrow irrigated. We used pitfall traps to sample soil-surface arthropods. Six pitfall traps were located in row 6 at ~20 m intervals through each plot. All traps were checked weekly from 7 May to 26 July 2010 and from 23 March to 15 August 2011. Arthropods were identified to family. Repeated measures analysis of variance were used for statistical analyses.

RESULTS AND DISCUSSION

Fourteen families of herbivores and five families of predators were collected. In both seasons, herbivore and predator abundances under different tillage systems changed over time. In 2010 (Fig. 1), tillage systems did not affect herbivore (A) or predator (B) numbers. In 2011 (Fig. 2), conservation tillage plots had more herbivores before planting (A) and significantly more predators than plots with conventional tillage (B). Ground beetles (carabids) were important potential predators (Fig. 3). In 2010 no-till plots had significantly more carabids than did plots with cover crop or conventional tillage (A). However, in 2011 tillage treatments did not significantly affect the number of carabids (B). Spiders were the most abundant predator (Fig. 4). Tillage treatment did not affect spider abundance in 2010 (A), but conventional tillage treatment plots contained fewer spiders than plots of either conservation tillage treatment in 2011 (B).

PRACTICAL APPLICATION

In concurrent evaluations associated with this field study, results from weekly plant and insect pest monitoring on plants indicated low levels of insect pests, including heliothines and tarnished plant bugs, in both years. There were no significant arthropod pest-related effects on yield in either year. Integrated pest management (IPM) is a key component in a sustainable cotton system, and regardless of tillage system, producers should include crop monitoring and scouting for decision making regarding arthropod pest control.

ACKNOWLEDGMENTS

The authors thank the Ministry of Higher Education and Scientific Research of Iraq for their funding. Cotton Incorporated and the Judd Hill Foundation are also acknowledged for their support.

LITERATURE CITED

Gencsoylu, I. and I. Yalcin. 2004. The effect of different tillage systems on cotton pests and predators in cotton fields. Asian J. Plant Sci. 3:39-44.

Holland, J.M. 2004. The environmental consequences of adopting conservation tillage in Europe: reviewing the evidence. Agr. Ecosyst. Environ. 103:1-25.

House, G.J., and R.W. Parmalee. 1985. Comparison of soil arthropods and earthworms from conventional and no-tillage agroecosystems. Soil Till. Res. 5:351-360.

Leonard, B., K. Torrey, and R.L. Hutchinson. 2000. Influence of conservation tillage on cotton insect pest ecology: A case study with cotton aphid, *Aphis gossypii* Glover. pp. 43-44. *In:* Proc. 23rd Annual Southern Conservation Tillage Conference for Sustainable Agriculture. Monroe, La., 19-21 Jun.

Marti, O.G., and D.M. Olson. 2007. Effect of tillage on cotton aphids (Homoptera: Aphididae), pathogenic fungi, and predators in South Central Georgia cotton field. J. Entomol. Sci. 42:354-367.

Sansone, C.G., and R.R. Minzenmayer. 2005. The impact of different tillage practices on arthropods in cotton in the southern rolling plains of Texas. pp. 1164-1170. *In:* Proc. Beltwide Cotton Conf., Orlando, Fla., 4-7 Jan. 2005. National Cotton Council, Memphis, Tenn.

Stinner, B.R., and G.J. House. 1990. Arthropods and other invertebrates in conservation-tillage agriculture. Ann. Rev. Entomol. 35:299-318.

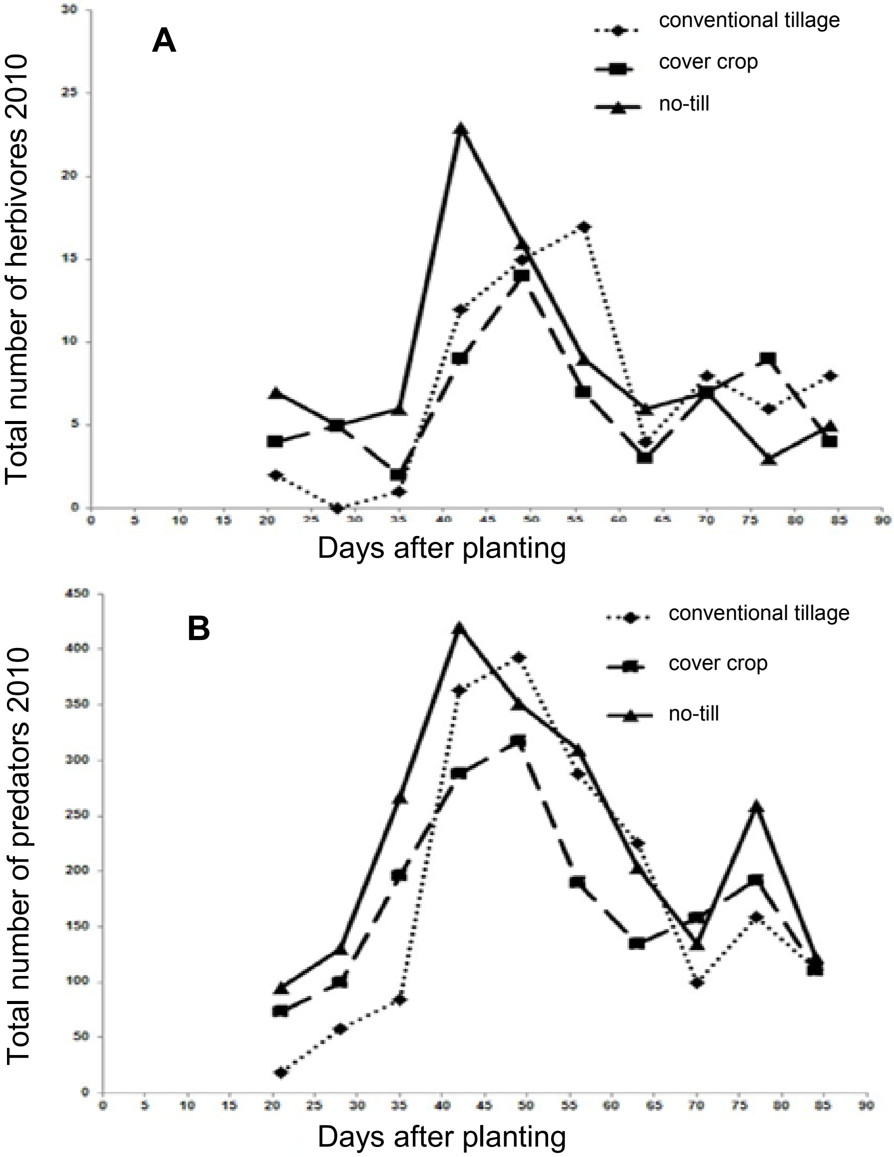


Fig. 1. In 2010, the number of herbivores (A) and predators (B) were counted in plots with conventional tillage, wheat cover crop, and no-till treatments. Tillage treatments did not significantly affect the number of herbivores ($P = 0.16$) or predators ($P = 0.15$). Days after planting had a significant effect ($P < 0.0001$).

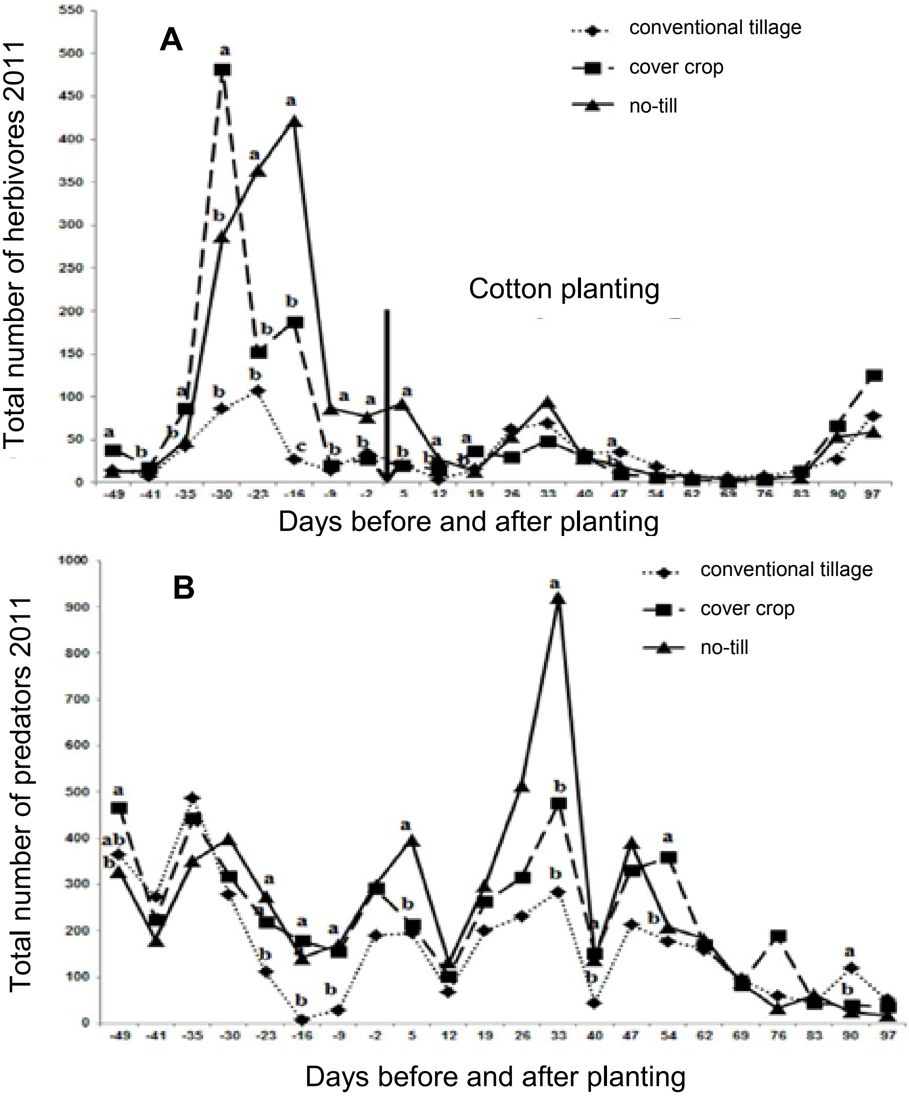


Fig. 2. In 2011, the number of herbivores (A) and predators (B) were counted in plots with conventional tillage, wheat cover crop, and no-till treatments. Conservation tillage plots had significantly more herbivores (*P* = 0.0001) and more predators (*P* = 0.009) than did plots with conventional tillage. Days before and after planting had a significant effect (*P* = 0.0001). Different letters indicate dates when curves differed significantly (*P* < 0.05) as determined by Tukey tests.

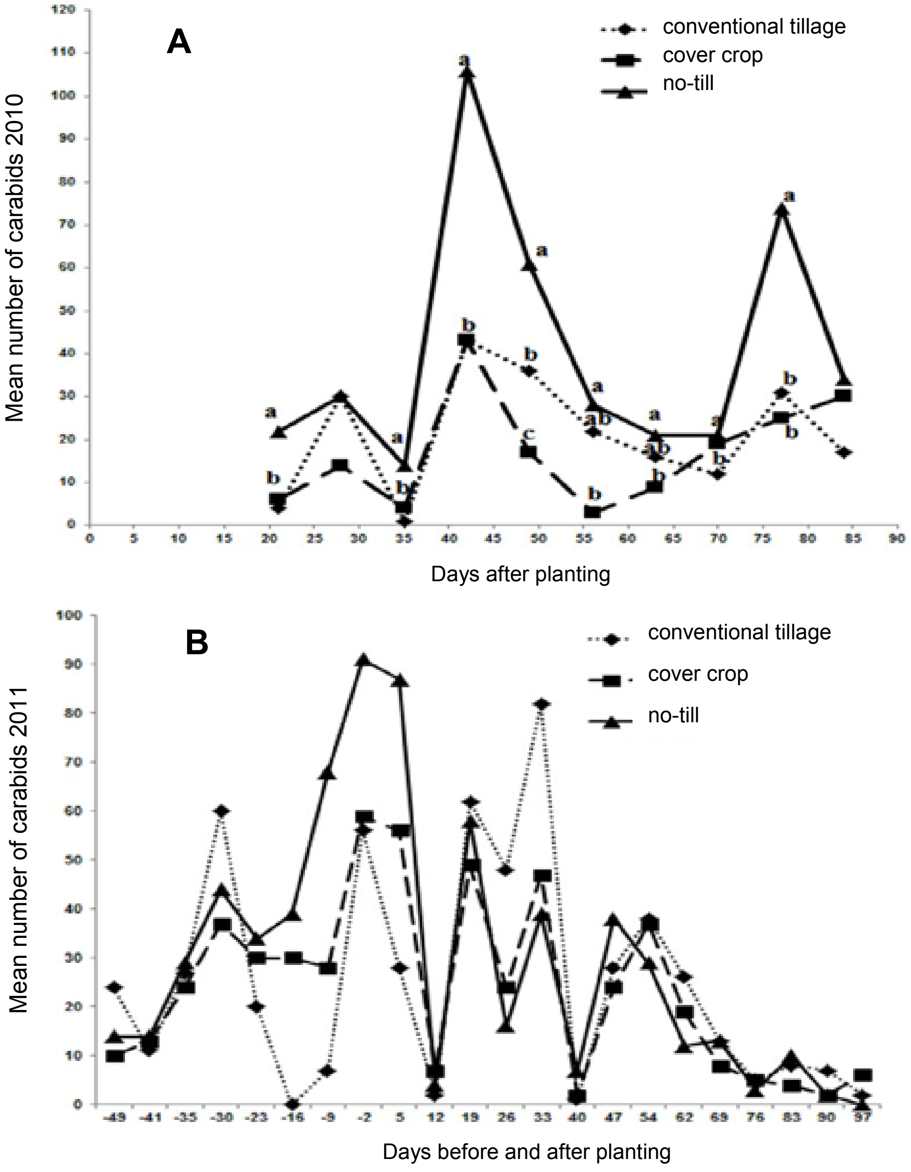


Fig. 3. The mean number of carabid beetles in plots with conventional tillage, wheat cover crop, and no-till treatments. In 2010, no-till plots had significantly more carabids than did plots with cover crop or conventional tillage in 2010 (A, $P < 0.0001$) but in 2011 tillage treatments did not significantly affect the number of carabids in 2011 (B, $P = 0.203$). Days after planting had a significant effect ($P = 0.0001$) and days before and after planting had a significant effect in 2011 ($P = 0.0001$). Different letters indicate dates when curves differed significantly ($P < 0.05$) as determined by Tukey tests.

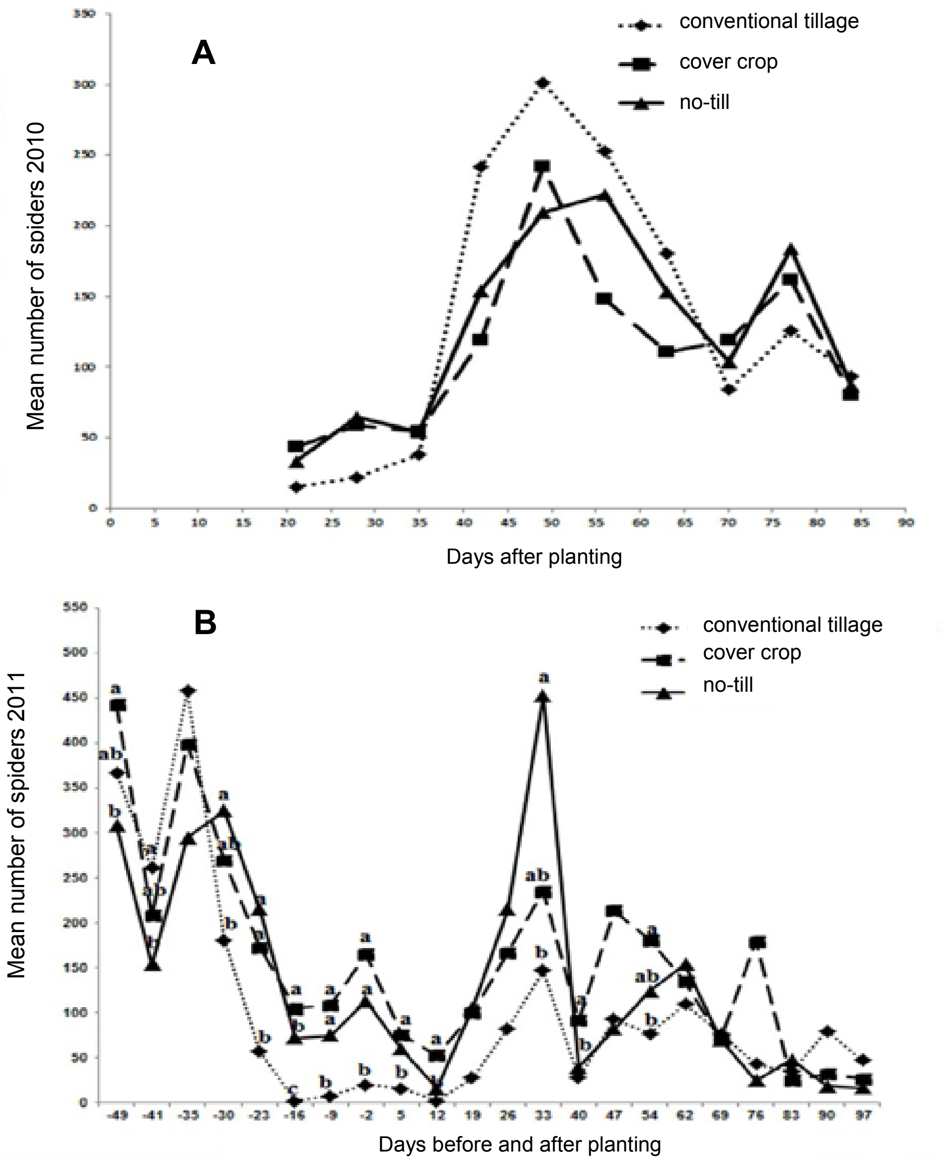


Fig. 4. The number of spiders in plots with conventional tillage, wheat cover crop, and no-till treatments. In 2010, tillage treatments did not affect the number of spiders (A, *P* = 0.63) but in 2011 conservation tillage plots had significantly more spiders (B, *P* = 0.0012) than did plots with conventional tillage. Days after planting had a significant effect in 2010 (*P* = 0.0001) and days before and after planting had a significant effect in 2011 (*P* = 0.0001). Different letters indicate dates when curves differed significantly (*P* < 0.05) as determined by Tukey tests.

Impact of Pre-Emergence Herbicide Application on Cotton with Selected Insecticide Seed Treatments

D.L. Clarkson[1], G.M. Lorenz[1], L.T. Barber[2], N.M. Taillon[3], B.C. Thrash[1], W.A. Plummer[3], M.E. Everett[4], and L.R. Orellana Jiminez[4]

RESEARCH PROBLEM

Within the last three years (2010-2012), a new potential has developed for the interaction of insecticide seed treatments (IST) and pre-emergence (PRE) herbicides. This potential interaction has led to the hypothesis that PRE herbicides are slowing cotton growth by causing stress to the plant. Much like stressing due to colder temperature, the herbicide stressed plant then gives the potential for thrips to cause more damage. The objective of this study is to determine if there is an interaction between PRE herbicides and ISTs where the herbicide slows cotton growth and therefore decreases efficacy of the IST.

BACKGROUND INFORMATION

Thrips (Thysanoptera: Thripidae) are one of the most important pest families during the early growing season of mid-South U.S. cotton (*Gossypium hirsutum* L.). Currently thrips control in cotton is achieved through the use of ISTs. However, from 2010-2013 more than 70% of cotton acreage in Arkansas was treated with a supplemental foliar insecticide application for thrips control, independent of ISTs (Williams, 2012). During this time period a major shift in weed control practices has also occurred, due to glyphosate resistant Palmer amaranth. Pre-emergence (PRE) herbicides are now recommended for all Arkansas cotton acres (Scott, 2010).

RESEARCH DESCRIPTION

Field trials were conducted in 2013 at the University of Arkansas Lon Mann Cotton Research Station near Marianna, Ark. and repeated at the Rohwer Re-

---

[1] Graduate assistant, associate department head, and program technician, respectively, Department of Entomology, Little Rock.
[2] Assocaite professor, Department of Crop, Soil, and Environmental Sciences, Lonoke.
[3] Program associate and program technician, respectively, Department of Entomology, Lonoke
[4] Graduate assistant and graduate assistant, respectively, Department of Entomology, University of Arkansas, Fayetteville.

search Station, near Rohwer, Ark. Treatments included a 3 × 4 factorial arrangement of IST and pre-emergence (PRE) herbicides (Table 1). Plots were 40 feet long and 4 rows wide, arranged in a randomized complete block design with four replications. Pre-emergence herbicide applications were made directly after seed was planted. Measurements of thrips populations were recorded three times (10, 18, and 25 days after planting). Pre-emergence herbicide injury ratings were visually estimated 7-10 after emergence. Plant heights were taken weekly from the time of emergence until first flower. Changes in maturity were determined by taking nodes above white flower counts. Yield was estimated by the use of a machine harvester, picking the center two rows of each plot.

RESULTS AND DISCUSSION

Visual differences in plant appearance among treatments approximately 60 days after emergence were observed. Plots with Aeris treated seed contained the healthiest more vigorous plants followed by Avicta treated seed and then untreated seed. No significant differences were observed in stand counts, chlorosis damage, and nodes above white flower (NAWF). Thrips populations were significantly effected by insecticide seed treatments alone. However, no differences were observed for thrips numbers by PRE herbicides or the interaction between PRE herbicides and ISTs. Avicta (thiamethoxam) reduced thrips numbers compared to an untreated seed and Aeris (imidacloprid) had fewer than Avicta (Fig. 1). All thrips populations were based on the sum of three collection periods. Plant heights were also significantly effected by IST alone, but were not influenced by pre-emergence herbicides or the interaction effect, each having no statistical separation. As seen in (Fig. 2) Aeris treatments showed taller plants at 15 days after emergence but only separated statistically from the untreated check. Both seed treatments separated with taller plants than the untreated check approximately 45 days after emergence but the two seed treatments did not separate among themselves. Comparatively, pre-emergence herbicides showed no separation in plant heights at both 15 and 45 days after emergence. After the event of a foliar application of Ignite (45 days after emergence) plants showed signs of necrosis damage. Necrosis damage was highest at 50% in the untreated check while less damage was observed in Avicta treatments (25%). Aeris treatments had the least necrosis damage at 9% (Fig. 3). Pre-emergence herbicides exhibited no significant impact on necrosis damage.

PRACTICAL APPLICATION

The results from this study suggest that thrips populations are impacted only by IST and the hypothesis that PRE herbicides may impact IST efficacy is not correct. In 2013, preliminary studies were conducted testing populations of thrips throughout the south for resistance to neonicotinoids. Results indicated reduced control of thrips with thiamethoxam. This data and preliminary studies suggest that reduced efficacy of IST is not through the interaction of IST and PRE herbicides, but may actually be the loss of control of IST. Data collected in this trial supports this hypothesis. More data will need to be collected in order to determine if this resistance trait is heritable.

ACKNOWLEDGMENTS

The authors thank Cotton®, Cotton State Support Committee, Syngenta, Bayer Crop Science, and the seasonal crew at the University of Arkansas System Division of Agriculture Experiment Station in Lonoke, Arkansas for making this project possible.

LITERATURE CITED

Scott, B.S. 2010. Prevention and Control of Glyphosate Resistant Pigweed in Soybean and Cotton. University of Arkansas Cooperative Extension, FSA2152, 4.

Williams, M.R. 2012. At planting insecticide applications. (ed. by MSU Extension), http://www.entomology.msstate.edu/resources/croplosses/2012loss.asp.

Table 1. Insecticide and herbicide treatments in 2013.

Treatment #	Insecticide Seed Treatment	PRE Herbicide
1	Control	Control
2	Control	Cotoran 1 qt/acre
3	Control	Diuron 1 pt/acre
4	Control	Reflex 1 pt/acre
5	Aeris 0.75 mg AI/seed	Control
6	Aeris 0.75 mg AI/seed	Cotoran 1 qt/acre
7	Aeris 0.75 mg AI/seed	Diuron 1 pt/acre
8	Aeris 0.75 mg AI/seed	Reflex 1 pt/acre
9	Avicta Duo 0.525 mg AI/seed	Control
10	Avicta Duo 0.525 mg AI/seed	Cotoran 1 qt/acre
11	Avicta Duo 0.525 mg AI/seed	Diuron 1 pt/acre
12	Avicta Duo 0.525 mg AI/seed	Reflex 1 pt/acre

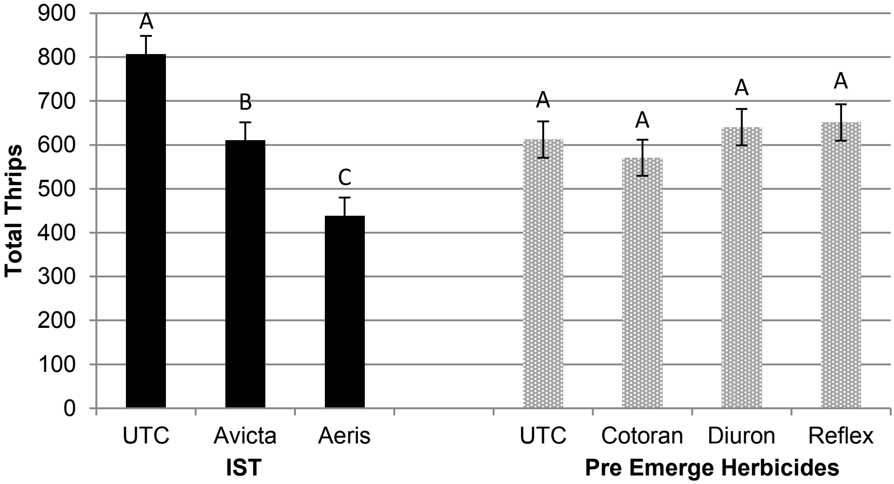


Fig. 1. Thrips vs. insecticide seed treatments (IST) and pre-emergence (PRE) herbicides. UTC = untreated check.

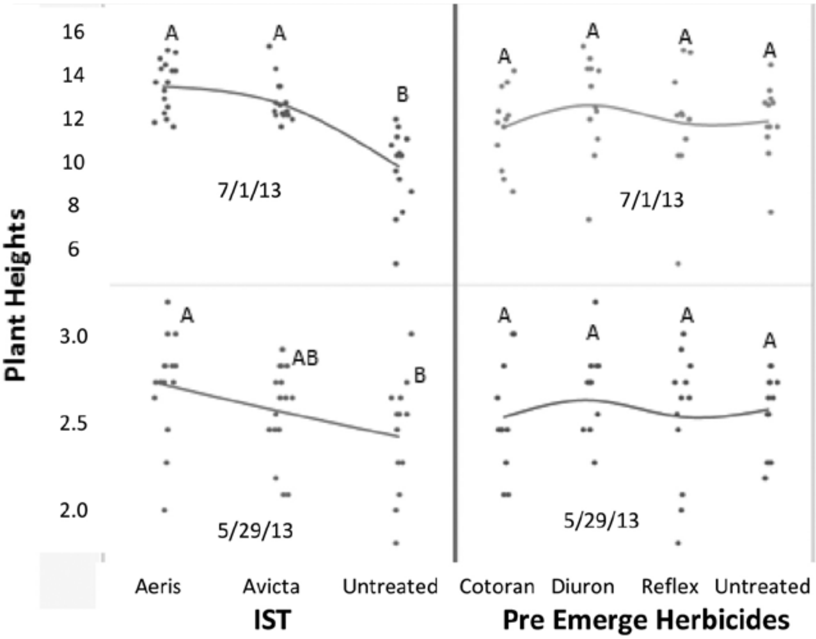


Fig. 2. Average plant heights vs. insecticide seed treatments (IST) and pre-emergence (PRE) herbicides.

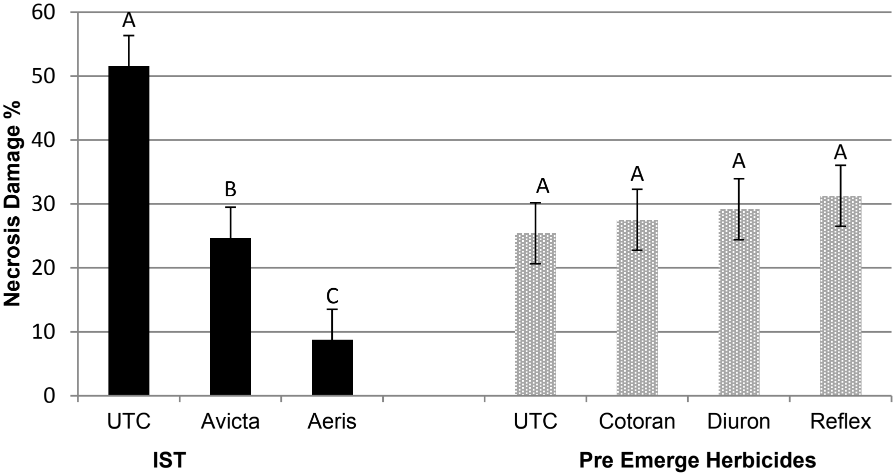


Fig. 3. Necrosis damage % for insecticide seed treatments (IST) and pre-emergence (PRE) herbicides. UTC = untreated check.

Efficacy of Dual Gene *Bacillus thuringiensis* (*Bt*) Cotton for Control of Bollworm, *Helicoverpa Zea* (Boddie)

N.M. Taillon[1], G. Lorenz[1], A. Plummer[1], M. Chaney[1], B.C. Thrash[2], D.L. Clarkson[1], L. Orellana Jiminez[2], and M. Everett[2]

RESEARCH PROBLEM

In years when bollworm populations are high in cotton, dual gene *Bacillus thuringiensis* (*Bt*) cotton may not provide adequate protection to maintain potential yield. In those situations, supplemental foliar applications may be required to provide additional yield protection. Trials were conducted in 2011-2013 to evaluate the impact and efficacy of foliar oversprays on conventional and dual-gene cottons, specifically Bollgard II and WideStrike, for control of cotton bollworm, *Helicoverpa zea.* In 2011, a trial was conducted to evaluate the performance of insecticide applications for bollworm/budworm on conventional cotton compared to non-sprayed *Bt* cotton to evaluate protection of insecticides to the *Bt* technologies currently used in production. In 2012 and 2013, foliar applications were also applied on WideStrike and Bollgard II cultivars to determine the impact of foliar oversprays on dual-gene cottons for control of Heliothines, primarily cotton bollworm.

BACKGROUND INFORMATION

Since the introduction of Bollgard in 1996, economic evaluations have been conducted by a number of researchers which indicate that in Arkansas, the most economical cultivar is the one that is highest yielding, regardless of technology associated with the cultivar (Bryant et al., 1997). Most studies show the efficacy of control advantage to single and dual gene technology but when compared economically, high yielding cultivars are the most economical in Arkansas (Bryant et al., 2004). Recently, DuPont has developed Coragen (Rynaxypyr) and Bayer Crop Sciences has developed Belt (flubendiamide), these new insecticides are very effective for control of caterpillar pests. They have a similar mode of action that cause disruption of the calcium balance within insect muscle cells, leading to a rapid cessation in feeding as well as paralysis of target pests (Bayer Crop Science and DuPont technical fact sheet, 2009). Both new insecticides have

---

[1] Program technician, associate department head, program technician, program associate, and program associate, respectively, Department of Entomology, Cooperative Extension Center, Lonoke.

[2] Program technician, graduate assistant, and program associate, respectively, Department of Entomology, Fayetteville.

broad spectrum caterpillar pest control and both have very good residual activity (Hardke et al., 2008). Cotton bollworm and tobacco budworms accounted for only 0.27% reduction in yield in 2009; however, with the high populations encountered in Arkansas during the 2010 growing season, damage levels rose to 2.67%, this equated to cost of control plus loss of yield of over $14 million (Williams, 2009, 2010). While plant bugs are considered the number one pest in Arkansas cotton, caterpillar pests can be equally or even more devastating to the bottom line for our producers. Many of the acres planted with dual gene *Bt* cultivars in 2009 and 2010 required supplemental foliar applications for bollworms. Applications targeting bollworm/budworms have increased from 0.6 applications per acre in 2008 to 1.7 applications per acre in 2010 (Williams, 2008-2010). A similar trend was seen with the single gene Bollgard cultivars as well. Bollgard I increased from 0.5 applications per acre to 1.2 applications per acre before Dual gene cotton was forced into the marketplace in 2004 (Williams, 2001-2005). The objective of this study was to evaluate supplemental foliar applications on Bollgard II and WideStrike cotton to ascertain the benefit of these products in each type of cotton.

RESEARCH DESCRIPTION

All trials were conducted at Hooker Farms in Jefferson County, Ark., 2011-2013. Treatments were applied with a Mud Master fitted TXVS-6 hollow cone nozzles. Spray volume was 10 gallons per acre (GPA) at 40 psi. Plot sizes were 12.5 ft (4 rows) by 50 ft. All trials were sprayed for other pests such as plant bugs, aphids, etc. as needed. Damage assessment and larval numbers were based on counts made on 25 plants per plot. Plant structures assessed were: terminals, squares, blooms, and bolls. Harvest was taken for all trials. Data were processed using analysis of variance, and Duncan's New Multiple Range Test (P = 0.10) to separate means using Agriculture Research Manager Version 8 (2011-12) or Version 9 (2013) (Gylling Data Management, Inc., Brookings, S.D.).

In 2011, treatments for conventional cotton included an untreated control, Prevathon at 20 oz/acre, Prevathon at 27 oz/acre, Belt at 2 oz/acre, Belt 3 oz/acre, and a tank-mix of Tracer 2 oz/acre and Bifenthrin 5.12 oz/acre, an unsprayed Bollgard II cultivar (DP0912), and an unsprayed WideStrike cultivar (PHY 375). Insecticide treatments were made 5 July 5 and 23 July and scouting was accomplished on 3, 8, and 16 days after the first application; 3, 6, and 11 days after the second application.

In 2012, cultivars planted were a conventional (DP174), a Bollgard II (ST5288), and a WideStrike (PHY375). Each cultivar included an untreated control, Prevathon 14 oz/acre, Prevathon 20 oz/acre and Belt 3 oz/acre. Insecticide treatments were made 10 July and scouting was accomplished on 7, 14, 21, and 27 days after application.

In 2013, cultivars planted were a Bollgard II (DP0912) and a WideStrike (PHY375). Treatments in each cultivar included an untreated control, Prevathon at 20 oz/acre, Belt at 3 oz/acre and Tracer at 3.5 oz/acre. Insecticide treatments were made 8 August and scouting was accomplished 6 and 12 days after application.

RESULTS AND DISCUSSION

In 2011, all treatments reduced larval numbers compared to the untreated control (UTC) (Table 1). All treatments reduced damage compared to the untreated control while Prevathon at 20 and 27 oz/acre, and BGII and WS cultivars reduced damage compared to all other treatments. All treatments yielded higher than the untreated control, all other treatments except for WideStrike and BGII yielded higher than Belt at 3 oz/acre and Tracer 2 oz/acre + Bifenthrin 5 oz/acre. In 2012, all treatments reduced larvae and damage when compared to the conventional untreated control (Table 2). BGII and WideStrike reduced larvae and damage compared conventional cotton across all treatments. In conventional cotton, all treatments reduced damage compared to the untreated control while Prevathon at 14 and 20 oz/acre reduced damage compared to Belt 3 oz/acre. In WideStrike cotton, all treatments reduced damage compared to the unsprayed WideStrike but did not separate among treatments. When comparing yield, all BGII cotton with foliar applications and WideStrike cotton treated with Prevathon at 14 and 20 oz/acre had higher yield than all other treatments. In conventional cotton, Prevathon at 14 and 20 oz/acre had higher yield than both untreated control and Belt 3 oz/acre and Prevathon at 20 oz/acre yielded higher than at 14 oz/acre. In BGII cotton, Prevathon 20 oz/acre and Belt 3 oz/acre yielded higher than BGII with no spray. In WideStrike cotton, Prevathon at 14 and 20 oz/acre yielded higher than Belt 3 oz/acre and WideStrike with no spray. BGII and WideStrike with no foliar application as well as WideStrike with Belt 3 oz/acre did not yield more than conventional cotton treated with Prevathon at 14 or 20 oz/acre. In 2013, BGII that was treated with Prevathon 20 oz/acre, Belt 3 oz/acre, and Tracer 3.5 oz/acre reduced larvae compared to WideStrike cotton across all treatments (Table 3). When comparing yield, all BGII treatments yielded higher than WideStrike treated with Belt 3 oz/acre and Tracer 3.5 oz/acre.

PRACTICAL APPLICATION

These studies suggest that when a conventional cultivar is sprayed with insecticides it can yield similarly to current *Bt* cultivars. *Bt* cotton can also benefit from an insecticide application in years when cotton fields are under high bollworm pressure

ACKNOWLEDGMENTS

We thank Cotton Incorporated and the Arkansas Cotton State Support Committee for funding this research as well as DuPont, Bayer, and Dow for their support.

LITERATURE CITED

Bryant, K.J., W.C. Robertson, and G. M. Lorenz. 1997. Economic evaluation of Bollgard cotton in Arkansas. pp. 358-360. *In:* Proc. Beltwide Cotton Conf., New Orleans, La., 6-10 Jan. 1997. National Cotton Council, Memphis, Tenn.

Bryant, K.J., J. Greene, G. Lorenz, R. Robertson, and G. Studebaker. 2004. BT cotton performance in Arkansas 2003: An economic evaluation. pp. 1700-1702. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 5-9 Jan. 2004. National Cotton Council, Memphis, Tenn.

Hardke, J., Lorenz, G., Colwell, K., Shelton, C., and Edmund, R. 2008. A novel insecticide for control of Heliothines in conventional and Bollgard cotton. pp. 1431- 1438. *In*: Proc. Beltwide Cotton Conf., New Orleans, La., 9-12 Jan. 2007. National Cotton Council, Memphis, Tenn.

Williams, M.R. 2002. 2001 Insect losses. *In:* Proc. Beltwide Cotton Conf., Atlanta, Ga., 8-12 Jan. 2002. National Cotton Council, Memphis, Tenn.

Williams, M.R. 2003. 2002 Insect losses. pp. 1208-1216. *In:* Proc. Beltwide Cotton Conf., Nashville, Tenn., 6-10 Jan., 2003. National Cotton Council, Memphis, Tenn.

Williams, M.R. 2004. 2003 Insect Losses. pp. 1249-1257. *In:* Proc. Beltwide Cotton Conf., San Antonio, Texas, 5-9 Jan. 2004. National Cotton Council, Memphis, Tenn.

Williams, M.R. 2005. 2004 Insect Losses. pp. 1828-1843. *In:* Proc. Beltwide Cotton Conf., New Orleans, La., 4-7 Jan. 2004. National Cotton Council, Memphis, Tenn.

Williams, M.R. 2006. 2005 Insect Losses. pp. 1151-1204. *In:* Proc. Beltwide Cotton Conf., San Antonio, Texas, 3-6 Jan. 2006. National Cotton Council, Memphis, Tenn.

Williams, M.R. 2009. 2008 Insect losses. pp. 897-940. *In:* Proc. Beltwide Cotton Conf., San Antonio, Texas, 6-8 Jan. 2009. National Cotton Council, Memphis, Tenn.

Williams, M.R. 2010. 2009 Insect losses. pp. 1029-1073. *In:* Proc. Beltwide Cotton Conf., New Orleans, La., 5-7 Jan. 2010. National Cotton Council, Memphis, Tenn.

Williams, M.R. 2011. 2010 Insect losses. pp. 896-940. *In:* Proc. Beltwide Cotton Conf., Atlanta, Ga., 4-7 Jan. 2011. National Cotton Council, Memphis, Tenn.

Table 1. 2011 treatment means for season total larvae, season total damage and seed cotton yield.

Treatment	Season Total Larvae	Total Season Damage	Yield
UTC	39.3 a[†]	228.9 a	431.5 d
Prevathon SC 20 oz/acre	3.8 c	44.3 c	1965.9 ab
Prevathon SC 27 oz/acre	3.0 c	41.3 c	2112.3 a
Belt 2 oz/acre	6.8 bc	75.5 b	1551.8 c
Belt 3 oz/acre	7.3 bc	68.8 b	1998.9 ab
Tracer 2 oz/acre + Bifenthrin 5.12 oz/acre	11.0 b	80.3 b	1489.7 c
BGII DP0912	2.8 c	25.0 c	1796.2 abc
WS PHY375	7.0 bc	39.5 c	1598.4 bc

[†] Means followed by same letter do not significantly differ (α = 0.10).

Table 2. 2012 treatment means of season total larvae, season total damage and seed cotton yield.

Treatment		Season Total Larvae	Total Season Damage	Seed Cotton Yield (lb/a)
Cultivar	Insecticide Rate			
Conventional DP174	UTC	34 a[†]	146 a	1662.0 e
Conventional DP174	Prevathon 14 oz/acre	24.7 b	64.8 c	2025.2 d
Conventional DP174	Prevathon 20 oz/acre	21.3 b	55.3 c	2237.1 c
Conventional DP174	Belt 3 oz/acre	21 b	85.8 b	1604.5 e
Bollgard II DP9012	UTC	5.3 cd	20 ef	2361.5 bc
Bollgard II DP9012	Prevathon 14 oz/acre	1.3 d	8 f	2560.3 ab
Bollgard II DP9012	Prevathon 20 oz/acre	0.5 d	10.8 ef	2679.6. a
Bollgard II DP9012	Belt 3 oz/acre	3.5 cd	12 ef	2744.6 a
WideStrike PHY 375	UTC	9.3 c	35.8 d	2162.3 cd
WideStrike PHY 375	Prevathon 14 oz/acre	3 cd	17.5 ef	2697.8 a
WideStrike PHY 375	Prevathon 20 oz/acre	3 cd	17.3 ef	2725.2 a
WideStrike PHY 375	Belt 3 oz/acre	4 cd	24.5 de	2380.3 bc

[†] Means followed by same letter do not significantly differ (α = 0.10).

Table 3. 2013 treatments means of season total larvae, season total damage and seed cotton yield.

Treatments		Season Total Larvae	Season Total Damage	Seed Cotton Yield (lb/a)
Cultivar	Insecticide Rate			
Bollgard II DP0912	UTC	14.0 abc[†]	20.3 a	3024.4 ab
Bollgard II DP0912	Prevathon 20 oz/acre	8.5 c	6.9 a	2941.9 ab
Bollgard II DP0912	Belt 3 oz/acre	10.8 bc	4.3 a	2892.6 ab
Bollgard II DP0912	Tracer 3.5 oz/acre	10.5 bc	11.9 a	3146.1 a.
WideStrike PHY499	UTC	17.8 ab	15.8 a	2383.6 c
WideStrike PHY499	Prevathon 20 oz/acre	19.8 a	14.9 a	2617.9 bc
WideStrikePHY499	Belt 3 oz/acre	19.0 a	18.4 a	2865.5 ab
WideStrike PHY499	Tracer 3.5 oz/acre	17.5 ab	12.2 a	2761.7 abc

[†] Means followed by same letter do not significantly differ (α = 0.10).

Efficacy of Selected Insecticide Seed Treatments for Control of Thrips in Arkansas, 2011-2013

W.A. Plummer[1], G.M. Lorenz III[1], N.M. Taillon[1], H.M. Chaney[1], D.L. Clarkson[1],
B.C. Thrash[2], L.R. Orellana Jiminez[2], and M.E. Everett[2]

RESEARCH PROBLEM

Seed treatments have been the standard for growers in Arkansas for thrips control. Recently there has been concern over thrips control with insecticide seed treatments and the need for additional foliar applications to achieve adequate control. Efficacy data on new and currently labeled products will help in proper selection of seed treatments for consultants and producers. Trials were conducted in the 2011, 2012, and 2013 growing seasons to evaluate the efficacy of insecticide seed treatments for thrips management in cotton.

BACKGROUND INFORMATION

Thrips are early-season cotton pests that have the potential to cause delayed maturity and yield loss in cotton. Typical symptoms of thrips damage on young cotton include ragged crinkled leaves that curl upward, “burnt” edges, and a silvery appearance. Thrips damage usually occurs on cotton seedlings and severe damage may stunt cotton growth and reduce yields. The level of damage varies from year-to-year based on severity of the thrips infestation (Hopkins et. al., 2001). Thrips affected 100% of all Arkansas cotton acreage in the 2011 and 2012 growing seasons (Williams 2012; 2013). The cost of control and economic loss caused by thrips was more than $4.9 million for Arkansas cotton producers in the 2011 growing season. This number more than doubled at over $10.9 million in 2012. Efficacy data on new and currently labeled products will help in proper selection of seed treatments for consultants and producers.

RESEARCH DESCRIPTION

Trials were conducted at the Lon Mann Cotton Research Station in Marianna, Ark., to evaluate the efficacy of insecticide seed treatments (IST) for thrips man-

---

[1] Program technician, associate department head, program technician, program associate, and program associate, respectively, Department of Entomology, Lonoke Extension Center, Lonoke.

[2] Program technician, graduate assistant, and graduate assistant, respectively, Department of Entomology, University of Arkansas, Fayetteville.

agement in cotton. Plot size was 12.5 ft by 40 ft in a randomized complete block with 4 replications. Samples were taken when plants reached 1-2 leaf stage and 3-4 leaf stage. Insect density was determined by collecting 5 plants per plot and placing in jars with a 70/30 alcohol solution. Plants were washed and filtered in the laboratory at the Lonoke Extension Center, Lonoke, Ark., and thrips counted using a dissecting scope. In 2011, all seed was treated with a base fungicide package; treatments included a fungicide only treatment (UTC), Aeris 21.3 oz/acre or Avicta 17.2 oz/acre. Foliar applications were Acephate 0.2 lbs ai/acre that were applied with a Mud Master ground applicator. The spray boom was fitted with TX6 cone jet nozzles at 19-inch nozzle spacing. Spray volume was 10 gallons per acre (GPA) at 40 psi. In 2012, seed treatments alone were compared to mixing multiple treatments, fungicide only and black seed (no insecticide seed treatment and no fungicide package). In 2012 and 2013, a supplemental IST representing storage grain protection rates were applied to test for any residual benefit for controlling thrips. Damage ratings were taken by rating plots on a 1-5 scale. (1 = no damage, 5 = plant loss). Data were processed using analysis of variance, and Duncan's New Multiple Range Test (*P* = 0.10) to separate means using Agriculture Research Manager Version 8 (2011-12) or Version 9 (2013) (Gylling Data Management, Inc., Brookings, S.D.).

RESULTS AND DISCUSSION

In 2011, all treatments reduced thrips numbers below the fungicide-only treatment (no spray) (Fig. 1). However, the fungicide-only treatment sprayed at (1-2 leaf), (3-4 leaf), (1-2 + 3-4 leaf), Aeris (no spray) and Avicta (3-4 leaf) did not separate from the fungicide-only (no spray). Avicta (1-2 + 3-4 leaf) reduced thrips populations below all other treatments, although no differences were seen from the other seed treatments whether a foliar application was applied or not. However, it did significantly reduce thrips numbers below the fungicide-only seed treatments. Optimum control was achieved with a foliar application at the 1-2 leaf stage.

In the 2012 trial, all insecticide seed treatments reduced the number of thrips below the naked black seed as well as the fungicide-only (Fig. 2). Aeris (3.8 oz/cwt) + Imidacloprid (3.1 oz/cwt) reduced thrips numbers below all the other treatments; although Gaucho (8.6 oz/cwt) was the only IST where statistical differences were seen. Yield data indicated that all IST except Aeris (3.8 oz/cwt) + Imidacloprid (3.1 oz/cwt) had a yield increase over the UTC and fungicide-only (Fig. 3). Gaucho (8.6 oz/cwt) increased yields higher than all other treatments and averaged around 300 lb/acre higher than the UTC.

In the 2012 late-season trial, all treatments reduced thrips populations below the UTC (Fig. 4). However, Gaucho (8.6 oz/cwt and 11.6 oz/cwt) reduced thrips numbers below the other treatments but separated only from Cruiser (8.3 oz/cwt).

In the 2013 seed treatment trial, damage assessment ratings were taken (1 = no damage, 5 = plant loss). All treatments reduced damage compared to the untreated control except for Cruiser 10.8 oz/acre (Table 1). Yield data indicated that all treatments except for Cruiser 10.8 oz/acre and Avicta Duo 17.2 oz/cwt had a yield increase over the UTC.

PRACTICAL APPLICATION

With the loss of Temik, growers have become increasingly dependent on insecticide seed treatments for thrips control in early season cotton. Our observations indicate we may be experiencing a loss of efficacy which has resulted in the need for foliar applications to achieve adequate control resulting in higher costs for producers. Recent studies indicated that tolerance/resistance maybe developing to Thiamethoxam in the mid-South.

ACKNOWLEDGMENTS

Appreciation is expressed to the Lon Mann Cotton Branch Experiment Station. We acknowledge Bayer and Syngenta for their support.

LITERATURE CITED

Hopkins, J.D., J.D Reaper, III, D.R. Johnson, and G.M. Lorenz, III. 2001. Thrips Management in Arkansas Cotton. pp 216-223. Arkansas Agricultural Experiment Station Research Series 497.

Williams, M.R. 2012. Cotton Insect Losses 2011. pp. 1013-1057. *In*: Proc. Beltwide Cotton Conf.,Orlando, Fla., 3-6 Jan. 2012. National Cotton Council, Memphis, Tenn.

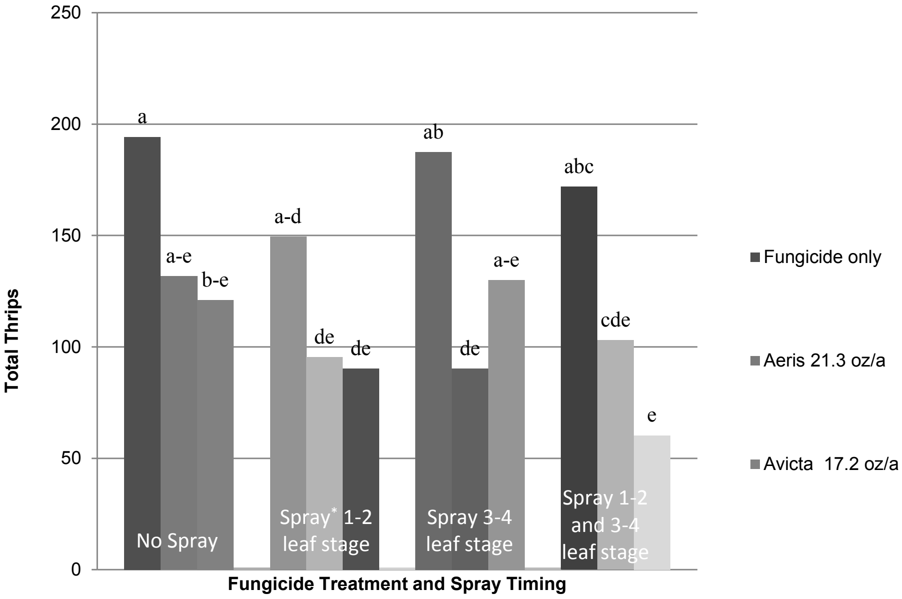
Williams, M.R. 2013. Cotton Insect Losses 2012. pp. 546-586. *In*: Proc. Beltwide Cotton Conf., 2013. San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Table 1. Cotton Insecticide Seed Treatment Trial, 2013.

Treatment[†]		Damage Rating Scale 1(best) - 5(worst) 7/1/2013	Seed Cotton Yield lb/acre 11/5/2013
UTC		3.8 a[‡]	1104.8 ef
UTC			
Cruiser 10.8 oz/cwt	A	3.3 ab	984.3 f
Cruiser 0.4 oz/cwt	B		
Avicta Duo 17.2 oz/cwt	A	2.5 bc	1234.8 def
Gaucho 600 FS 3.8 oz/cwt	B		
Aeris 21.3 oz/cwt	A	2.5 bc	1839.4 ab
Cruiser 0.4 oz/cwt	B		
Gaucho 600 FS 10.7 oz/cwt	A	2.8 bc	2074.7 a
Untreated	B		
Gaucho 600 FS 10.7 oz/cwt	A	2.3 c	1690.6 bc
Gaucho 600 FS 3.8oz/cwt	B		
Aeris 21.3 oz/cwt	A	2.3 c	1580.3 bcd
Untreated	B		

[†] A = thrips treatment, B = stored grain treatment.

[‡] Number in columns followed by the same letter are not significantly different (*P* = 0.10).



*spray applications - Acephate 0.2 lbs ai/a

Fig. 1. Efficacy of foliar insecticide timing on selected insecticide seed treatments, 2011.

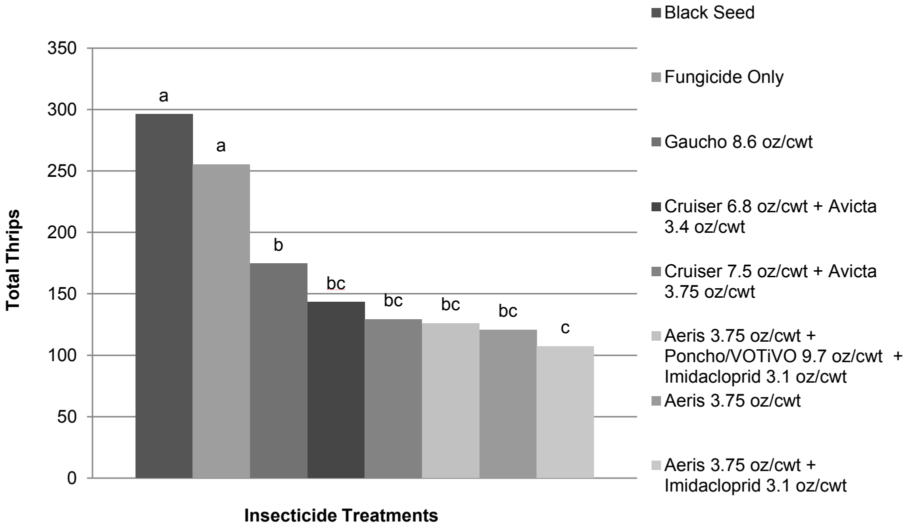


Fig. 2. Efficacy of selected insecticide seed treatments, 2012.

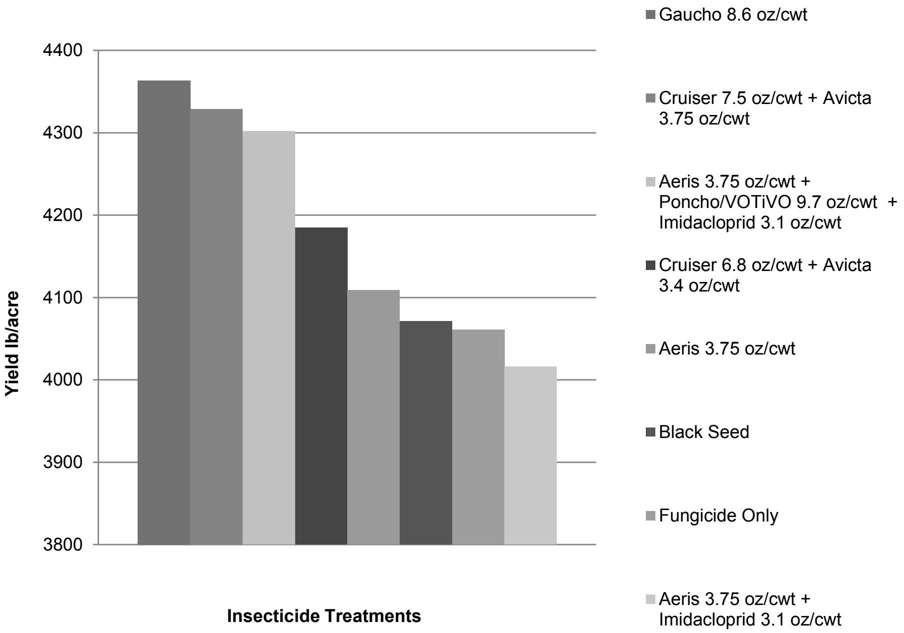


Fig. 3. Efficacy of selected insecticide seed treatments, 2012 harvest.

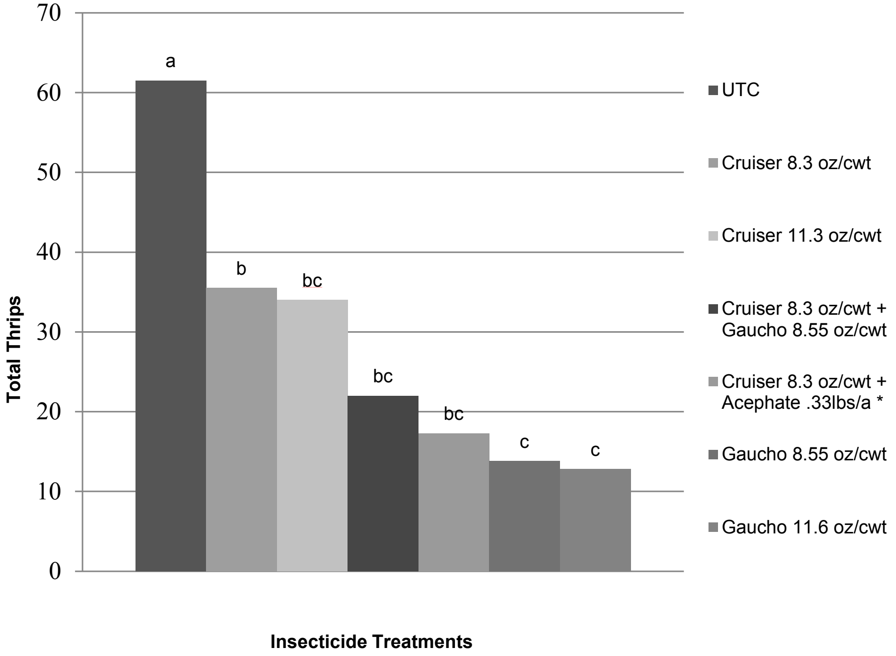


Fig. 4. Late season efficacy of selected insecticides for control of thrips, 2012. UTC = untreated check.

Using Insecticide Mixes to Improve Tarnished Plant Bug Control

B.C. Thrash[1], G.M. Lorenz III[2], N.M. Taillon[2], W.A. Plummer[2], H.M. Chaney Jr.[2],
D.L Clarkson[2], M.E. Everett[1], and L. Orellana Jiminez[1]

RESEARCH PROBLEM

The tarnished plant bug (TPB), *Lygus lineolaris,* is the most important insect pest of cotton in Arkansas and the mid-South. It is imperative for growers to have tools available to them to combat this pest and maintain the upper hand before increasing populations grow beyond their control. In order to inform growers of which tools are the most effective, it is crucial that trials are conducted to make that determination.

BACKGROUND INFORMATION

From 2003 to 2009, tarnished plant bug caused more yield loss than any other pest averaging a loss of over 50,000 bales in Arkansas (Williams, 2010). Plant bug populations in the past several years have been extremely high and currently labeled insecticides are not providing the level of control needed to reduce plant bug numbers below economic threshold with one application (Colwell et al., 2010). To make matters worse, resistance to multiple insecticides has been found across the mid-South (Snodgrass, 1996; Snodgrass et al., 2009). Uses of insecticide premixes and tank-mixes have been shown as an effective way to increase control of tarnished plant bug. A total of 42 trials from the 2009-2013 growing seasons were used to evaluate the control of insecticide mixes compared to single products.

RESEARCH DESCRIPTION

Trials were conducted during the 2009-2013 growing seasons in Lee County, Arkansas at the Lon Mann Cotton Research Station and grower fields. Treatments were applied with a Mud Master fitted with TXVS-6 hollow cone nozzles. Spray volume was 10 gallons per acre (GPA) at 40 psi. Plot sizes were 12.5 ft (4 rows) by 50 ft. Insect numbers were determined by using a 2.5-ft drop cloth and taking 2 samples per plot (10 row ft). Data were processed using Agriculture Research

---

[1] Program technician, graduate assistant, and graduate assistant, respectively, Department of Entomology, University of Arkansas, Fayetteville.
[2] Associate department head, program technician, program technician, program associate, and program associate, Department of Entomology, Lonoke Extension Center, Lonoke.

Manager, (Gylling Data Management, Inc., Brookings, S.D.) Version 8, Analysis of Variance, and Duncan's New Multiple Range Test ($P = 0.10$) to separate means. Data was compared between tests by converting each treatments' season total plant bug numbers to their respective untreated controls season total to provide a percent control. The number of data sets for each insecticide ranged from 1–13.

RESULTS AND DISCUSSION

Insecticide mixes generally increased TPB control when compared to single products. All treatments showed an increase in efficacy when single products were mixed with bifenthrin (Fig. 1). An average efficacy increase of 12.25% was observed when selected insecticides were combined with bifenthrin. All selected insecticides showed an increase in efficacy when novaluron (6 oz/acre) was mixed with single products (Fig. 2). Tank-mixes containing novaluron (6 oz/acre) showed an average increase of 16.6% when compared to single products. When novaluron (6 oz/acre) was mixed with Transform (2.125 oz/acre), control was increased only 7% over Transform alone (Fig. 3). When selected insecticides were mixed with Transform (1.5 oz/acre), control was increased an average of only 4%; and in the case of Bidrin (8 oz/acre), control was actually decreased. The small increase in control provided with Transform mixes is probably not enough to warrant the extra cost. Transform (2.5 oz/acre) provided the greatest control in the High Pressure Plant Bug trial though no insecticide or mix provided significantly better control than any other (Fig. 4). The trial FMC Plus 2013 indicates the lack of control some pyrethroids (Hero, Mustang Max) are providing and that mixing two insecticides together does not guarantee increased control (Fig. 5). Transform (1.5 oz/acre, 2 oz/acre) in this study provided better control than all other treatments. Carbine (2.3 oz/acre, 2.8 oz/acre) alone provided better control than when mixed with Mustang Max or Hero. This may be because Carbine is relatively "soft" on beneficial insects and mixing an ineffective pyrethroid could be killing beneficial insects, resulting in lowered plant bug control. Cost is a major factor in choosing which insecticides to use. Many of the insecticides mixes mentioned perform very well, but may not be a viable option because of price and others can provide similar control at lower costs (Table 1).

Tank-mixes that included novaluron regularly provided increased control. Transform provided excellent control when compared to all other single products. The results of these studies show insecticide mixes can be an effective and economical way to increase control of tarnished plant bug with existing products.

ACKNOWLEDGMENTS

We thank Cotton Incorporated and the Arkansas Cotton State Support Committee for funding this research, as well as the Lon Mann Cotton Research Station for their help in plot maintenance and the growers of Arkansas for their support.

LITERATURE CITED

Colwell, C.K., G.M. Lorenz III, J. Fortner, N. Taillon, and B. VonKanel. 2010. Efficacy of Selected Insecticides for Control of Plant Bugs in Arkansas, 2010. pp. 149-54. *In*: D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research 2010. Agricultural Experiment Station Research Series 589.

Snodgrass, G.L. 1996. Insecticide Resistance in Field Populations of the Tarnished Plant Bug (Heteroptera: Miridae) in Cotton in the Mississippi Delta. J. Econ. Entomol. 89:783-790.

Snodgrass, G.L., J. Gore, C.A. Abel, and R. Jackson. 2009. Acephate Resistance in Populations of the Tarnished Plant Bug (Heteroptera: Miridae) from the Mississippi River Delta. J. Econ. Entomol. 102: 699-707.

Williams, M. 2010. Cotton Insect Losses, 2009. pp. 1029-1073. *In*: Proc. Beltwide Cotton Conf., New Orleans, La., 5-7 Jan. 2010. National Cotton Council, Memphis, Tenn.

Table 1. Insecticide costs and control.

Insecticide	Control (%)	Cost ($)
Novaluron 6 oz/acre + Transform 2.125 oz/acre	90%	22
Novaluron 6 oz/acre + Centric 2.5 oz/acre	84%	17.25
Novaluron 6 oz/acre + Transform 1.5 oz/acre	83%	18
Transform 2.125 oz/acre	83%	16
Novaluron 6 oz/acre + Acephate 0.75 lb ai/acre	81%	9
Bifenthrin 6 oz/acre + Transform 1.5 oz/acre	81%	15
Acephate 1 lb/acre	80%	4
Bifenthrin 4.12 oz/acre + Imidacloprid 2 oz/acre	80%	4
Novaluron 6 oz/acre + Bidrin 6 oz/acre	79%	
Novaluron 6 oz/acre + Bifenthrin 6 oz/acre	78%	9
Transform 1.5 oz/acre	77%	12

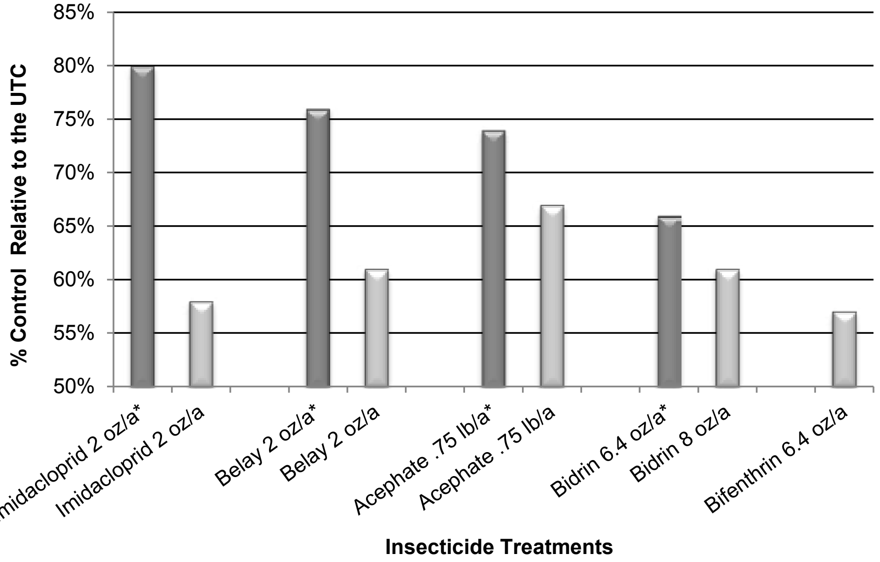


Fig. 1. Tarnished plant bug control with mixes of bifenthrin. UTC = untreated check.

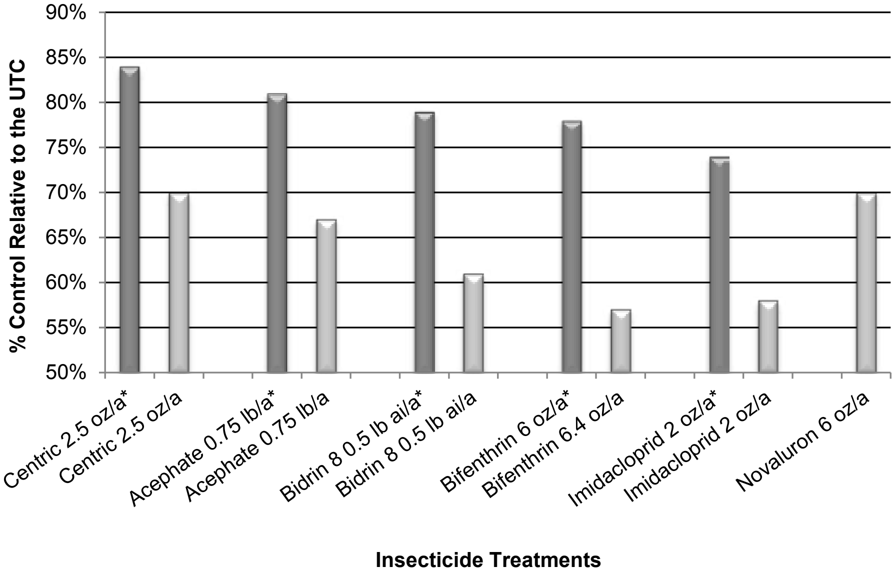


Fig. 2. Tarnished plant bug control with mixes of Novaluron. UTC = untreated check.

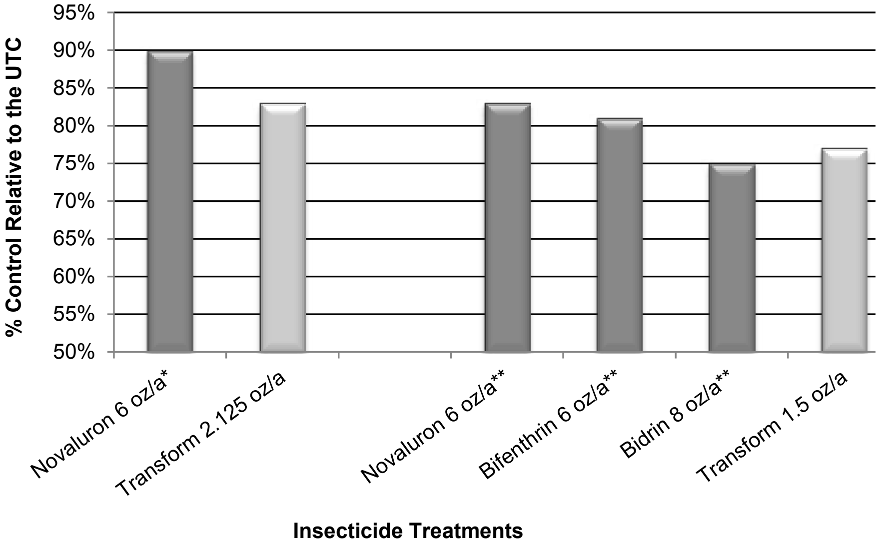


Fig. 3. Tarnished plant bug control with mixes of Transform. UTC = untreated check.

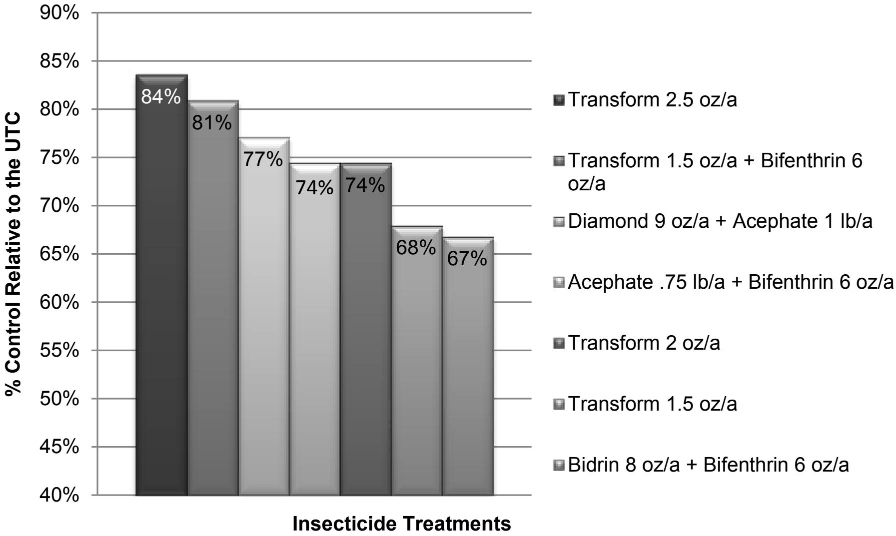


Fig. 4. High pressure plant bug trial, 2012. UTC = untreated check.

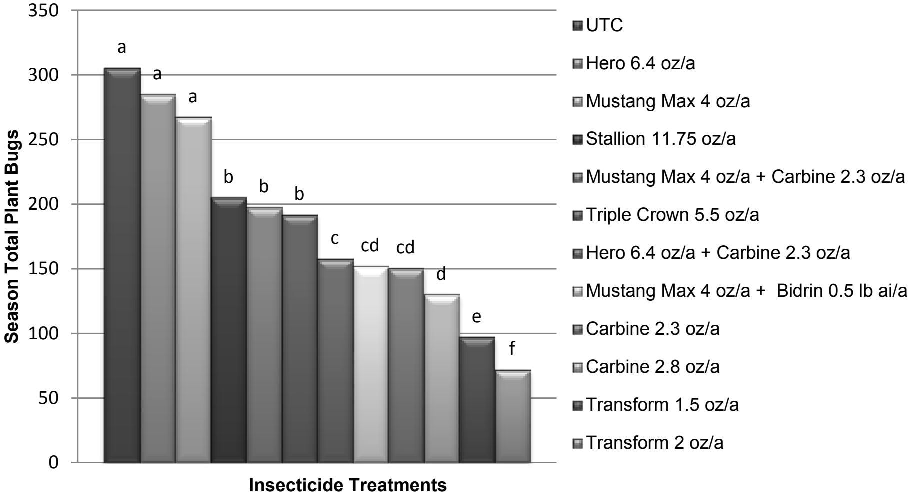


Fig. 5. FMC Plus trial, 2013. UTC = untreated check.

Managing Tarnished Plant Bug Populations in Cotton in Arkansas

L. Towles and G. Studebaker[1]

RESEARCH PROBLEM

The tarnished plant bug is a major pest of cotton in the mid-Southern United States. Increasing levels of insecticide resistance has been measured in this important pest. It is important to evaluate possible methods of delaying resistance development, such as combining and/or rotating different classes of insecticide chemistries and their efficacy against this insect.

BACKGROUND INFORMATION

The tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), is one of the most important pests of cotton in Arkansas and the mid-Southern United States (Williams, 2013). Applying recommended insecticides when bugs reach treatment level is the most commonly used option to control this pest (Studebaker, 2013). However, increasing levels of resistance to insecticides are beginning to make some chemistry less effective (Hollingsworth et al., 1997; Holloway et al., 1998; Snodgrass and Scott, 1988; Snodgrass and Elzen, 1995; Snodgrass, 2006). Therefore, it is important to evaluate commonly used insecticides and combinations of these insecticides for their efficacy in controlling tarnished plant bugs. Two efficacy trials were conducted in 2012 and 2013 in northeast Arkansas against tarnished plant bug. In both trials, tank-mixes of various chemistries and rotations of different chemistries were evaluated.

RESEARCH DESCRIPTION

Both trials were conducted at the Northeast Research and Extension Center, Keiser, Ark. Trial 1 was conducted in 2012 and Trial 2 was conducted in 2013. Plots were 8-rows wide by 50-ft long. Treatments were replicated 4 times arranged in a randomized complete block design. Treatments were applied with a high clearance sprayer calibrated to deliver 10 gallons per acre (GPA) through 2 hollow cone nozzles per row. Plots were sprayed when tarnished plant bug num-

---

[1] Program technician and entomologist, respectively, Northeast Research and Extension Center, Keiser.

bers reached 3 per 5 row feet. Plant bug numbers were estimated by taking 2 shake sheet samples per plot at 3, 6, 7, and 11 days after application. When treatments reached threshold again, applications were repeated. A total of 3 applications were applied in trial 1, and 2 applications in trial 2. All plots were taken to yield by harvesting the center 4 rows of each plot. All data were analyzed using Agriculture Research Manager (ARM) version 8 software (Gylling Data Management, Inc., Brookings, S.D.). Means were separated at $P = 0.05$ level.

RESULTS AND DISCUSSION

In 2012, all treatments significantly reduced tarnished plant bug numbers by 3 and 6 days after treatment (DAT; Table 1). Numbers did rebound above treatment level by 6 DAT 2 (Table 1). There did not appear to be any benefit to tank mixes or rotation of chemistries. All treatments did significantly increase yield (Table 1).

In 2013 there was unusually high rainfall during the month of July when tarnished plant bug numbers were high, making it difficult to make timely applications and evaluations. The excessive rainfall also adversely affected yields (Table 2). There was a rainfall event within 24 hours of the first application which did seem to affect the Transform applications more than the other treatments (Table 2). In general, it appears that those treatments in combination with Diamond seemed to fare better under the adverse conditions experienced in this trial.

ACKNOWLEDGMENTS

We would like to thank AMVAC Chemical Company for funding the research conducted in this project.

LITERATURE CITED

Hollingsworth, R.G., D.C. Steinkraus, and N.P. Tugwell. 1997. Response of Arkansas populations of tarnished plant bugs (Heteroptera: Miridae) to insecticides, and tolerance differences between nymphs and adults. J. Econ. Entomol. 90:21-26.

Holloway, J.W., B.R. Leonard, J.A. Ottea, J.H. Pankey, J.B. Graves and G. Snodgrass. 1998. Insecticide resistance and synergism of pyrethroid toxicity in the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), pp. 947-949. *In*: Proc. Beltwide Cotton Conf., San Diego, Calif., 5-9 Jan. 1998. National Cotton Council, Memphis, Tenn.

Snodgrass, G.L. and W.P. Scott. 1988. Tolerance of the tarnished plant bug to dimethoate and acephate in different areas of the Mississippi Delta. pp. 294-295. *In*: Proc. Beltwide Cotton Conf., New Orleans, La., 5-8 Jan. 1988. National Cotton Council, Memphis, Tenn.

Snodgrass, G.L. and G.W. Elzen. 1995. Insecticide resistance in a tarnished plant bug population in cotton in the Mississippi Delta. Southwestern Entomol. 20:317-323.

Snodgrass, G.L. 2006. Status of resistance in tarnished plant bug, pp. 1633-1638. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 3-6 Jan. 2006. National Cotton Council, Memphis, Tenn.

Studebaker, G.E. 2013. Cotton insect control, pp. 66-76. Insecticide recommendations for Arkansas. University of Arkansas System Cooperataive Extension Publication MP144.

Williams, M.R. 2013. Cotton insect losses 2012. p. 546–586. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Table 1. Tarnished plant bug (TPB) counts and yields from Trial 1.

		-------------Number TPB (nymphs + adults)/10 row feet-------------						Seed Cotton Yield
Treatment	**Rate oz/acre**	**3 DAT-A**	**6 DAT-A**	**3 DAT-B**	**6 DAT-B**	**7 DAT-C**	**11 DAT-C**	**lb/acre**
Untreated		14.1 a[†]	17.4 a	12.1 a	17.5 a	15.5 a	9.9 a	1414 b
Bidrin 8 EC alt. w/Transform 50WG	8.0 1.5	5.7 b	4.3 b	2.8 b	9.8 b	5.8 b	2.0 bcd	2335 a
Acephate 97 S alt. w/Transform 50WG	16.0 1.5	5.7 b	6.5 b	0.7 b	9.5 b	5.5 b	1.5 cd	2352 a
Bidrin 8 EC + Diamond 4 EC alt. w/Transform 50WG	8.0 6.0 1.5	8.5 b	6.0 b	0.5 b	7.3 b	5.8 b	0.4 d	1970 a
Acephate 97S + Diamond 4 EC alt. w/Transform 50WG	16.0 6.0 1.5	8.8 b	5.6 b	1.1 b	8.5 b	4.8 b	2.2 bcd	2205 a
Centric 40 WG + Diamond 4 EC alt. w/Transform 50WG	2.5 6.0 1.5	5.9 b	8.3 b	0.6 b	10.3 b	7.3 b	3.8 bc	2200 a
Transform 50 WG alt. w/Bidrin 8 EC	1.5 8.0	5.9 b	3.0 b	0.4 b	7.0 b	8.8 b	6.1 bc	2168 a
Bidrin 8 EC +Transform 50 WG alt. w/Acephate 97S	8.0 1.5 16.0	5.9 b	4.2 b	1.2 b	11.5 b	6.8 b	4.1 bc	2310 a
Acephate 97S	16.0	5.9 b	4.8 b	1.2 b	12.8 b	5.8 b	5.0 bc	2212 a

---

[†] Means within a column followed by the same letter do not significantly differ ($P = 0.05$, Fisher's protected least significant difference test).

Table 2. Tarnished plant bug (TPB) counts per 10 row feet and yields from Trial 2.

Treatment	Rate oz/acre	4 DAT-A	7 DAT-A	5 DAT-B	11 DAT-B	Seasonal Total	Seed Cotton lbs/acre
Untreated		12.5 a[†]	11.8 a	11.5 a	15.5 a	51.5 a	433.6 b
Bidrin 8 EC alt. w/Transform 50WG	8 1.5	5.0 bc	3.3 d	5.8 bc	11.5 ab	25.4 bc	830.5 a
Bidrin 8EC + Diamond 4 EC alt. w/ Transform 50 WG	8 16 1.5	5.4 bc	3.5 d	4.0 bc	10.8 b	23.0 bc	761.9 a
Bidrin 8 EC + Diamond 4 EC alt. w/Transform 50WG + Diamond 4 EC	8 6 1.5 6	4.5 bc	5.5 cd	3.8 bc	8.3 bc	22.2 bc	715.4 a
Transform 50 WG + Bidrin 8 EC	1.5 8	2.9 bc	10.3 ab	8.0 ab	8.3 bc	29.9 b	808.5 a
Transfor 50 WG alt. w/ Bidrin 8 EC + Diamond 4 EC	1.5 8 6	7.0ab	8.0 abc	3.0 c	4.5 cd	22.2 bc	886.9 a
Transform 50 WG + Diamond 4 EC alt. w/ Bidrin 8 EC + Diamond 4 EC	1.5 6 8 6	2.8 c	5.5 cd	5.8 bc	7.3 bcd	21.1 bc	774.2 a
Centric 40 WG alt. w/ Transform 50 WG + Bidrin 8 EC	2.5 1.5 8	4.9 bc	6.8 bcd	4.5 bc	73.5 d	19.2 c	759.5 a
P > F		<0.01	0.01	<0.01	<0.01	<0.01	<0.01

[†] Means within a column followed by the same letter do not significantly differ ($P = 0.05$, Fisher's protected least significant difference test).

Host-Plant Resistance to Tarnished Plant Bug in Arkansas: A Seven Year Summary

G.E. Studebaker and F.M. Bourland[1]

RESEARCH PROBLEM

The tarnished plant bug is a major pest of cotton in Arkansas. Growers routinely make 3-6 insecticide applications each year to control this pest in cotton. Resistance to insecticides has become a major issue with the tarnished plant bug. Therefore, information on possible host-plant resistance is important to growers as well as decision makers. It is important to evaluate possible resistant cultivars in larger plots to verify their level of resistance to tarnished plant bugs.

BACKGROUND INFORMATION

The tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois) is a major pest of cotton in the mid-Southern United States (Williams, 2013). It is not uncommon for growers to make 3-6 applications of insecticide to control this pest in a normal growing season while some may make as many as 15 applications in situations of heavy pest pressure. Insecticides have been the primary line of defense against this pest in the past. However, the tarnished plant bug is developing resistance to many of the insecticides commonly used for control of this important pest (Hollingsworth et al., 1997; Holloway et al. 1998; Snodgrass and Scott 1988; Snodgrass and Elzen 1995; Snodgrass 2006). Host-plant resistance to a pest is an important component of integrated pest management (IPM) and should not be overlooked. Some cotton cultivars appear to exhibit a high level of resistance to tarnished plant bugs in ultra-small plots. However, data from small 1 or 2 row plots may imply that the insect merely prefers one variety over another instead of the variety being truly resistant. The objective of this study was to take cotton cultivars exhibiting a high level of resistance to the tarnished plant bug in small research plots and verify that resistance in much larger research plots.

RESEARCH DESCRIPTION

Cultivars that exhibited resistance as well as several that were highly susceptible in small plot research trials were planted into large plots at the Northeast

---

[1] Entomologist and director/professor, respectively, Northeast Research and Extension Center, Keiser.

Research and Extension Center, Keiser, Ark. during the growing seasons of 2007-2013. Cultivars used are reported in Table 1. Plot size varied from year to year from 16 to 24 rows in width by 75-100 ft in length. Plots were randomized and arranged in a split-plot design with both treated and untreated for tarnished plant bugs within each variety. Treated plots were sprayed with acephate at 0.75 lbs/acre when tarnished plant bugs reached the recommended treatment threshold of 3 plant bugs per 5 row-ft. Tarnished plant bug numbers were determined by taking 2 shake sheet samples from the center of each plot on a weekly basis throughout the growing season until cotton reached cutout (nodes above white flower (NAWF) = 5) plus 250 accumulated heat units. Heat units were determined on a degree day 60 (DD60) heat unit scale. Plots were taken to yield by harvesting the center rows in each plot with a small plot cotton picker.

In 2011-2012, resistant cultivars were monitored in grower fields to determine the level of plant bug populations in each. A nearby field with a susceptible variety was also monitored at each location. Ten pairs of grower fields were monitored and compared in both years.

RESULTS AND DISCUSSION

Tarnished plant bug populations varied from year to year and only the data from representative selective years is reported. Results in Figs. 1 and 2 are typical of those found throughout the course of this study. Tarnished plant bug numbers are reported in levels per 10 row-ft, therefore the economic threshold in each figure would be 6 as is shown by the red horizontal line in Fig. 1. In 2010 the susceptible cultivars reached treatment threshold during the 2nd and 3rd week of flowering while the resistant cultivars did not reach threshold until the 4th and 5th week of flowering (Fig. 1). In 2012 four cultivars were tested, two resistant and two susceptible. The 2 susceptible cultivars reached threshold on the first week of flowering while the resistant cultivars did not reach threshold until the third week (Fig. 2). In 2013, tarnished plant bug numbers were extremely high and all cultivars reached treatment level at the same time regardless of resistance level (Fig. 3). In all years with the exception of 2013, resistant cultivars reached treatment threshold from one to three weeks after the susceptible cultivars. Susceptible cultivars often required twice as many insecticide applications to control tarnished plant bugs as the resistant cultivars (Fig. 4). This also translated at the grower level as can be seen from the grower fields monitored in 2011 and 2012 (Fig. 5).

PRACTICAL APPLICATION

Resistance measured in small plots does appear to translate to large plots as well as to grower fields. On average, resistant cultivars required half as many insecticide applications for tarnished plant bugs and often did not require treatments until later in the season. In some years, resistant cultivars did not require a treatment until the last week of flowering just as plots reached cutout resulting in very little yield loss from tarnished plant bugs. By utilizing resistant cultivars, growers should be able to maximize yield and reduce costs associated with tarnished plant bugs. An added benefit is the possible delay of insecticide resistance development in this insect by reducing the number of insecticide applications.

ACKNOWLEDGMENTS

The authors would like to thank Cotton Incorporated for funding the research conducted in this project.

LITERATURE CITED

Hollingsworth, R.G., D.C. Steinkraus and N.P. Tugwell. 1997. Response of Arkansas populations of tarnished plant bugs (Heteroptera: Miridae) to insecticides, and tolerance differences between nymphs and adults. J. Econ. Entomol. 90:21-26.

Holloway, J.W., B.R. Leonard, J.A. Ottea, J.H. Pankey, J.B. Graves and G. Snodgrass. 1998. Insecticide resistance and synergism of pyrethroid toxicity in the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), pp. 947-949. *In*: Proc. Beltwide Cotton Conf., San Diego, Calif., 5-9 Jan. 1998. National Cotton Council, Memphis, Tenn.

Snodgrass, G.L. and W.P. Scott. 1988. Tolerance of the tarnished plant bug to dimethoate and acephate in different areas of the Mississippi Delta, pp. 294-295. *In*: Proc. Beltwide Cotton Conf., New Orleans, La., 5-8 Jan. 1988. National Cotton Council, Memphis, Tenn.

Snodgrass, G.L. and G.W. Elzen. 1995. Insecticide resistance in a tarnished plant bug population in cotton in the Mississippi Delta. Southwestern Entomol. 20:317-323.

Snodgrass, G.L. 2006. Status of resistance in tarnished plant bug, pp. 1633-1638. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 3-6 Jan. 2006. National Cotton Council, Memphis, Tenn.

Williams, M.R. 2013. Cotton insect losses 2012. p. 546–586. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2012. National Cotton Council, Memphis, Tenn.

Table 1. Cotton cultivars tested in large plots from 2007-2013.

Cultivar	Resistant	Susceptible
AM UA48		X
SGS UA222	X	
ST 5288B2F	X	
PHY 375WRF		X
DP 0935B2RF	X	
ST 4498B2RF	X	
ST 4554B2RF	X	
FM 1740B2RF		X
TX-Frego		X
SG 105	X	

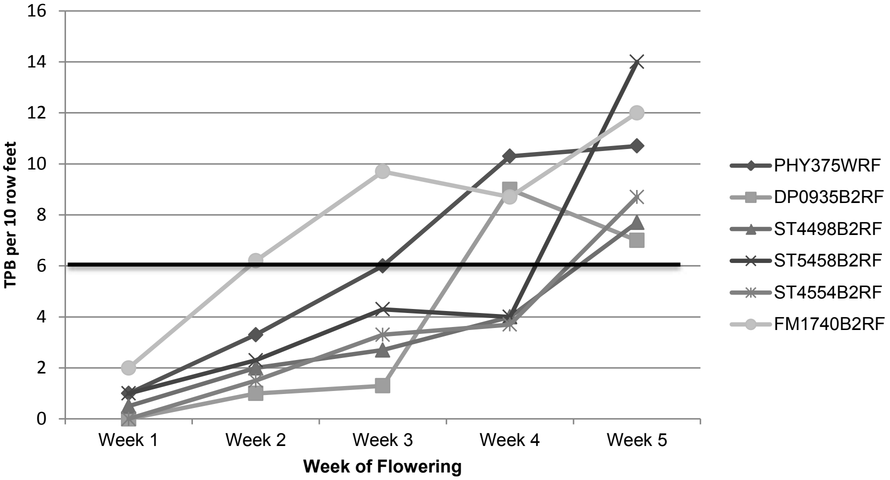


Fig. 1. Tarnished plant bug (TPB) density in untreated plots in 2010

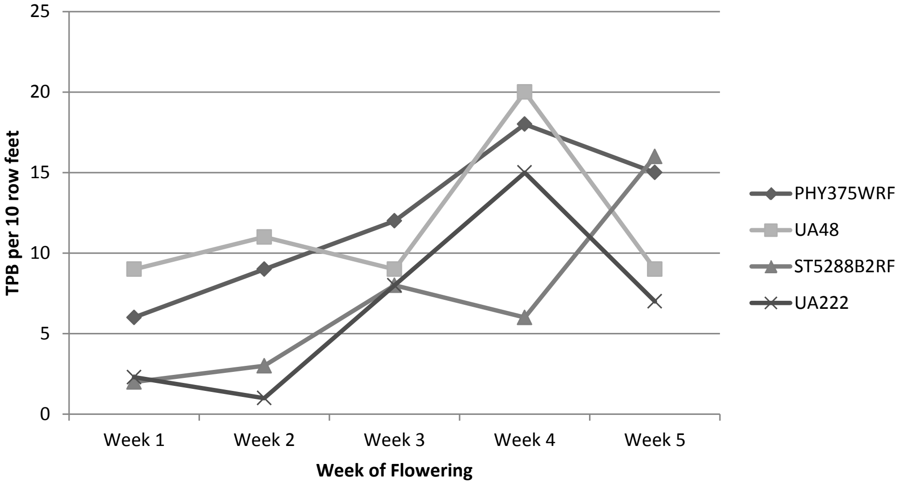


Fig. 2. Tarnished plant bug (TPB) density in untreated plots in 2012.

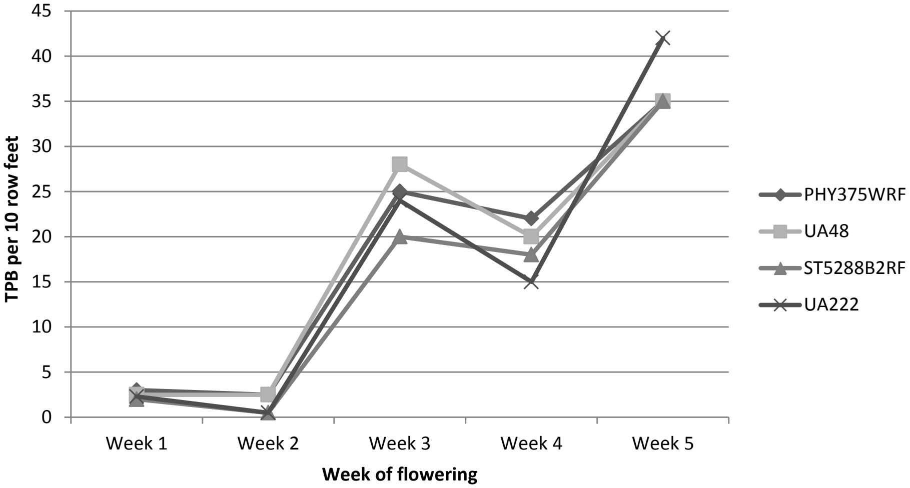


Fig. 3. Tarnished plant bug (TPB) density in untreated plots in 2013

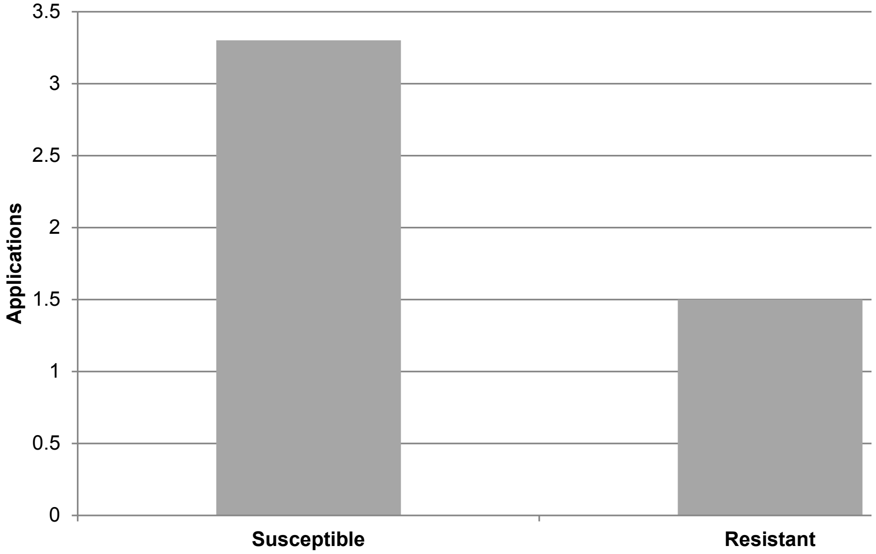


Fig. 4. Average number of insecticide applications for tarnished plant bugs (TPB) on susceptible versus resistant cultivars in large plots from 2007-2013.

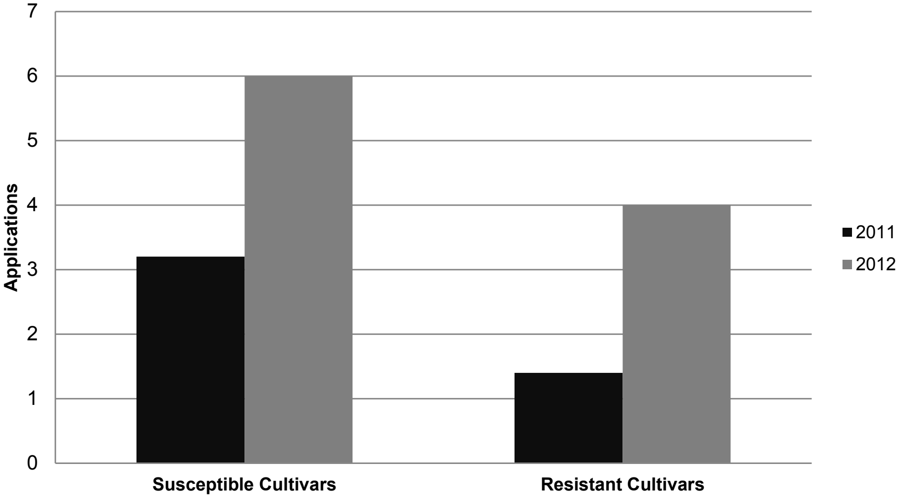


Fig. 5. Average number of insecticide applications for tarnished plant bugs (TPB) on commercial fields in 2011 and 2012.

Stocks-to-Use Response for Acreage Allocation of Arkansas Field Crops

A. Flanders[1]

RESEARCH PROBLEM

Commodity programs for agriculture have a dual challenge of addressing public policy objectives of farm income stability and maintaining desirable efficiencies that derive from market-based outcomes. Economic theories and historical experience suggest potential conflicts with simultaneous motivations of distributional equity and allocation efficiencies. Theories of public finance and social welfare analysis allow for achieving acceptable levels of distributional equity with public policies that minimize inefficiencies which are inevitable with deviations from market-based absolutism. One measure of economic efficiency is producer response to market signals. A measure of distributional equity is the level of income support relative to costs of production. The objective of this research is to quantify Arkansas field crop acreage response to signals conveyed by supply and demand equilibrium conditions

BACKGROUND INFORMATION

Agricultural programs for field crops in the U.S. have a national scope as opposed to having specific policies directed at unique regional production characteristics. Empirical analysis at a state level indicates effects for a region with unique production characteristics operating under public policy with national objectives. Economically efficient responses are state acreage increases as producers follow national signals of decreasing supply relative to demand and state acreage decreases as national supply is increasing relative to demand.

RESEARCH DESCRIPTION

Producers make crop acreage decisions with information about prevailing supply and demand conditions. Expected prices reflect market conditions so that production adjusts to maintain an optimal stocks-to-use ratio, K/D (K = stocks, D = use). In general, market equilibrium is achieved with acreage allocations, $A_{t,}$ that

---

[1] Assistant professor, Northeast Research and Extension Center, Keiser.

equate supply and demand of production. Agricultural management practices often entail a degree of inertia in acreage allocations. Optimal management follows crop rotations that limit continuous cropping, and producers do not completely switch out of one crop into another based on current market conditions. Market conditions are incentives to make marginal adjustments in crop allocations, and the marginal transitions may continue over more than one year in correspondence to prevailing market conditions. Also, some crops have specialized equipment requirements that limit annual acreage changes. Circumstances in which changes in market conditions are prevalent for an extended period may necessitate more than one year for producers to fully respond. Thus, a lagged acreage variable, A_{t-1}, is included to account for allocations following *K/D* that require more than one period for equilibrium adjustment. A transitional variable for other acreage, OA_t, is the sum of other field crop acreage in period *t* divided by the sum of other acreage in period *t-1*.

Crop acreage for the study is annual data reported for 1981-2012 by the National Agricultural Statistics Service (USDA, NASS, 2013). Annual U.S. stocks-to-use are calculated as the ratio of 1980-2011 ending stocks to the sum of total domestic consumption and marketing year exports (USDA, FAS, 2013). A complete econometric model representing the correlation of crop acreage planted and the stocks-to-use ratio is:

$$A_t = \beta_0 + \beta_1 + \beta_2 T_t + \beta_3 OA_t + \beta_4 A_{t-1} + \varepsilon_t, \qquad \text{Eq. (1)}$$
$$t = 1980 \ldots 2012,$$

where *T* is a time trend, and ε is a random disturbance term that has 0 mean and is assumed uncorrelated with the independent variables. Occurrences such as droughts represent shocks to equilibrium relationships and are captured by the random error term. Ordinary Least Squares (OLS) is applied for parameter estimates of β_0, β_1, β_2, β_3, and β_4 in Eq. (1). A potential violation of OLS assumptions is that the random disturbance term is serially correlated, in which case OLS parameter estimates are unbiased, but may overstate the statistical significance (Gujarati and Porter, 2009). Serial correlation is evaluated by Durbin-Watson statistics and, if present, appropriate Yule-Walker estimates are reported (SAS, Institute, Inc., Cary, N.C.).

RESULTS AND DISCUSSION

Parameter estimates for Eq. (1) are presented in Table 1. Stocks-to-use has a negative correlation with planted acreage for all crops, and is statistically significant for all crops except grain sorghum. Although statistically significant, the stocks-to-use parameter estimate for soybeans is relatively low compared to other crops. Arkansas has much crop acreage that is characterized as a heavy clay soil type. This acreage is most suited for a crop rotation of soybeans and rice, and not optimal for corn or cotton. Soybean acreage serves as a complimentary crop for rice production, which is much less suited for continuous cropping than is soybean production.

The trend variable is statistically significant for corn, soybeans, and wheat. Corn acreage is trending with a positive parameter estimate of 0.0234, but soybeans with -0.0052 and wheat with -0.0331 have negative trends. The long-term trend for corn acreage is mostly attributable to increased irrigation in Arkansas with acreage increases since 2006 being impacted by relative increases in corn prices. Soybeans with a wheat double-crop are suitable for non-irrigated production, but corn as an alternative becomes more preferable as producers add irrigated acreage to their operations. Corn is an earlier planted crop, and the conclusion of its production period can limit irrigation pumping demands for farms needing water to flood rice and irrigate later planted soybeans. Corn production enables producers to spread water demand over an extended period of the crop year. The parameter estimate for other acreage is negative and statistically significant only for corn.

The lagged dependent variable is positive and statistically significant for cotton and rice. This indicates that it takes more than one period for cotton and rice acreage to respond to market conditions entailed in the current stocks-to-use ratio. Cotton has specialized harvesting equipment that causes difficulties in adding acreage when market conditions are favorable. Likewise, operations that are adequately invested in cotton harvesting equipment may have financial constraints to add additional harvesting equipment for increased acreage of other crops. Also, not entailed in market conditions expressed by the stocks-to-use ratio, the residual value of cottonseed revenue returned after ginning may be an inducement for producers to produce cotton. Rice has some specialized agronomic characteristics that could lead to acreage adjustments extending over more than one crop year. Optimal rice yield is limited by continuous cropping, and producers are encouraged to change fields for their production regularly, but changing total rice acreage is limited by agronomic considerations.

PRACTICAL APPLICATION

Results of this analysis indicate that stocks-to-use is a significant determinant of acreage decisions in Arkansas. Changes in stocks-to-use are associated with acreage changes in responses that maintain equilibrium of U.S. supply and demand. Wheat acreage is highly optional as an alternative in Arkansas cropping decisions, and it is the most responsive to changes in stock-to-use ratios. Soybeans are more fundamental in Arkansas crop production, especially due to the significant acreage of heavy clay soils in the state, and it is the least responsive to changes in the stocks-to-use ratio. Corn acreage is highly responsive to changes in the stocks-to-use ratio, but acreage is increasing with a significant trend as total irrigated crop acreage is increasing. Cotton and rice are responsive to changes in stocks-to-use, and the effects are extended over more than one production year.

LITERATURE CITED

Gujarati, D. and D. Porter. (eds.) 2009. Basic Econometrics. McGraw-Hill Education, 5th ed., Columbus, Ohio. 922 pp. ISBN 0071276254.

USDA, FAS. 2013. U.S. Department of Agriculture, Foreign Agricultural Service. "Production, Supply, and Distribution Online." Internet Site: http://www.fas.usda.gov/psdonline/psdQuery.aspx. Accessed August 2013.

USDA, NASS. 2013. U.S. Department of Agriculture, National Agricultural Statistics Service. "Quick Stats U.S. & All States Data – Crops." Internet Site: http://www.nass.usda.gov:8080/QuickStats/Create_Federal_All.jsp. Accessed August 2013.

Table 1. Ordinary least squares[a] results for Arkansas acreage response, 1981-2012.

Explanatory Variable	Corn	Cotton[a]	Grain Sorghum[a]	Rice	Soybean[a]	Wheat[a]
Intercept	1.6586**	1.0215	5.1167	1.6630**	3.7398**	6.2088**
t-value	2.6100	1.0600	1.1300	2.3500	3.0300	2.9000
Prob >|t|	0.0146	0.3000	0.2706	0.0264	0.0055	0.0074
Stocks:Use	-0.2862**	-0.1715**	-0.0725	-0.1550**	-0.0891**	-0.5170**
t-value	-2.5500	-2.7300	-0.4600	-3.0900	-2.8500	-2.4000
Prob >|t|	0.0166	0.0113	0.6463	0.0046	0.0085	0.0238
Trend	0.0234*	0.0002	-0.0520	0.0004	-0.0052**	-0.0331**
t-value	1.8700	0.0600	-1.1200	0.3600	-2.9600	-2.7300
Prob >|t|	0.0720	0.9554	0.2724	0.7222	0.0065	0.0110
Other Acreage	-1.7762*	0.1310	-0.4919	-0.5254	-0.1037	NA
t-value	-1.9000	0.2800	-0.3100	-1.6800	-1.4000	NA
Prob >|t|	0.0677	0.7824	0.7567	0.1038	0.1738	NA
Acreage Lag	0.2245	0.7271**	-0.8110	0.5285**	-0.0081	-0.6568
t-value	0.6300	2.1100	-0.4900	2.4400	-0.0200	-1.0900
Prob >|t|	0.5340	0.0447	0.6251	0.0214	0.9813	0.2847
R^2	0.9148	0.8226	0.7083	0.7130	0.7670	0.6111
Durbin-Watson	1.6074	1.3209	1.4166	2.1270	1.5320	1.8734

[a] Yule-Walker estimates reported based on ordinary least squares Durbin-Watson statistics.
Note: ** Significant at 5%; * significant at 10%.

Cotton Advisor: An Android Application for Cotton Stakeholders

D. Saraswat[1]

RESEARCH PROBLEM

The University of Arkansas System, Division of Agriculture has provided production information to cotton producers in Arkansas for decades through printed publications, websites, and web-based calculators. Increasing use of mobile devices (smartphones, tablet laptops, iPads) by the agricultural community requires researchers to understand geographic distribution of bandwidth availability and develop mobile applications (popularly known as "apps") for providing research-based information on-the-go.

BACKGROUND INFORMATION

Industry figures point to the fact that the sale of personal computers (PCs) is being outpaced by smart phones and tablet computers. Estimates suggest that by the end of 2014, a combined sale of more than one billion smart phones and tablet computers is expected compared to 300 million PCs. The International Telecommunications Union (ITU, 2013) predicts more mobile phones in use by the end of 2014 than the total global population. A survey conducted in Iowa found that younger farmers are showing a strong preference toward accessing information via tablets and/or smart phones. This trend is expected to broaden as younger producers take on roles within farming operations (Luckerson, 2014).

RESEARCH DESCRIPTION

The research aims to develop an Android app that eliminates the need to carry books, factsheets, or a laptop into the field for accessing information needed on-site. The App consists of an interactive calculator and organizes cotton-related information into different modules.

RESULTS AND DISCUSSION

In March 2014, the "Cotton Advisor" app was launched for use on smartphones and tablet computers powered by the Android operating system (OS).

---

[1] Associate professor, Department of Biological and Agricultural Engineering, Little Rock.

After initial installation, users can access cotton production information in an interactive manner without the need for an Internet connection. Thus, it serves the purpose of providing a 24/7, pocket expert for farmers, agricultural consultants, Extension agents, and college students in the Cotton Belt.

The app is available for free from Google's Play Store (http://alturl.com/crjoo) for use on Android smartphone or tablet computers running version 2.3 or higher operating system.

Using Cotton Advisor App

Download Manager: Once a user installs the app on an Android device and clicks the launch icon, the app makes a request that a file or files be downloaded and the download manager, an Android system service, starts working in the background. Users can check the progress of the download by swiping down and looking at their notification center.

The information included in the app is mostly developed by various projects funded by Cotton Incorporated and other cotton organizations. The current design of the app has been adopted to accommodate future expansion needs. Depending on information needs (harvest, weed management, insects etc.), users interact with a particular section to access publication or video-based information. These sections will henceforth be referred as modules and the current version of the app consists of eight modules as follows:

Harvest Calculator: This module consists of an interactive calculator prepopulated with default data provided by Ed Barnes (Director, Agricultural and Environmental Research), Cotton Incorporated. Through a series of interactive choices and inputs, the user is able to obtain information about harvesting rate and total hours required to complete harvesting of their field. Grayed out fields require user inputs; whereas other fields require users to interactively select options that best meet their situation. Pressing the "Calculate" button will display the results. Users can click on the "Help" button to access other relevant information about the harvest calculator. Any time a user wants to clear all filled out values, pressing the "Clear Values" button will do that.

Weed Management: Farmers are aware that following planting, cotton requires eight weeks of weed-free growth to make maximum yields. The information in this module comprises video (Rolling High Rye) and publications (Managing Herbicide Resistance and Weed Management in Transgenic Cotton) to help with weed control—especially where herbicide resistant weeds are present.

Insect Pest and Disease Management: Insect and disease pressure can decrease yield potential fast. The publications in this module can be useful for identifying and treating common cotton pests. The module lists titles of publications under two headings: Insect Management and Disease Management, respectively. The Insect Management part is comprised of eight publications whereas Disease Management has one publication included at this time.

Nitrogen and Plant Growth Regulators: Two other key inputs for cotton are nitrogen and plant growth regulators (PGRs). Three publications on managing both of these inputs are included in this section, as well as some suggestions on sensor-based application rates.

End of Season: It is critical to protect the investment made during the season. This module contains 10 videos and three publications discussing maintenance of harvest equipment, yield mapping, and protecting seed cotton.

Season-Long Production Principles: This module includes two documents that cover cotton production issues that may be encountered throughout the season and are good reference documents for cotton growth and development.

Irrigation Management: This module contains two documents that cover information about cotton irrigation management for humid regions.

News and Social Media: The news released from Cotton Incorporated through RSS feed, facebook, and twitter accounts is directly channeled through this module. A user is not required to have either facebook or twitter accounts for getting updated news from Cotton Incorporated. A facebook or twitter account will only be required when a user wants to contribute to Cotton Incorporated releases.

PRACTICAL APPLICATION

Once the app is properly installed on an Android powered smartphone or tablet computer, Internet connection is not required by users for accessing various publications and videos included in the app. The app eliminates the need to carry books, factsheets, or a laptop into the field for accessing information needed on-site.

ACKNOWLEDGMENTS

The funding support by Cotton Inc.; inputs provided by Ryan Kurtz and Ed Barnes from Cotton Incorporated; individuals and organizations providing technical content for the app; and student support from Alec Crow and Dhivya Kumar, are hereby greatly acknowledged.

LITERATURE CITED

(ITU). International Telecommunications Union, Geneva, Switzerland. 2013. Internet site: http://www.itu.int/en/ITU-D/Statistics/Pages/default.aspx

Luckerson, V. 2014. Tech's biggest promises for 2014. Time Internat. 183:1. Internet site: http://0-search.proquest.com.library.uark.edu/docview/1490995704?accountid=8361

APPENDIX I

STUDENT THESES AND DISSERTATIONS RELATED TO COTTON RESEARCH IN PROGRESS IN 2013

Burke, James. The response of cotton (*Gossypium hirsutum* L.) to slow release foliar fertilization and the effect of environment on absorption. (M.S., advisor: Oosterhuis)

Clarkson, Derek. Insecticide/herbicide interactions of tankmixes on cotton. (M.S., advisor: Lorenz)

FitzSimons, Toby. Cotton plant response to high temperature stress during reproductive development, remote sensing, and amelioration. (Ph.D., advisor: Oosterhuis)

Greer, Amanda. Relationship between Telone II and nitrogen fertility in cotton in the presence of reniform nematodes. (M.S., advisor: Kirkpatrick)

Griffith, Griff. Glyphosate-resistant Palmer amaranth in Arkansas: Resistance mechanisms and management strategies. (Ph.D., advisor: Norsworthy)

Hannam, Josh. Pathogens of the tarnished plant bug, *Lygus lineolaris*, in Arkansas (M.S., advisor: Steinkraus)

Johnson, Dennis Brent. distribution and control of glyphosate-resistant johnsongrass (*Sorghum halepense*) in Arkansas Soybean. (M.S., advisor: Norsworthy)

Kathiar, Soolaf. Ecology of insect pests of cotton and their natural enemies. (Ph.D., advisor: Lanza)

Kelly, Erin. Variation in crop and insect pest dynamics across soil EC based management zones in Arkansas cotton (M.S., advisor: Teague)

Lewis, Austin. Field validation of irrigation planning tools in major Arkansas row crops. (M.S., advisor: Reba/Teague)

Loka, Dimitra. Effect of high night temperature on cotton gas exchange and carbohydrates. (Ph.D., advisor: Oosterhuis)

Ma, Jainbing. Influence of soil physical parameters, *Thielaviopsis basicola*, and *Meloidogyne incognita* on cotton root architecture and plant growth. (Ph.D., advisors: Kirkpatrick and Rothrock)

Navas, Juan Jaraba. The influence of the soil environment and spatial and temporal relationship on *Meloidogyne incognita* and *Thielaviopsis basicola* and their interaction on cotton. (Ph.D., advisor: Rothrock)

Phillips, Justin. Effects of 1-Methylcyclopene on cotton reproductive development under heat stress. (M.S., advisor: Oosterhuis)

Pilon, Cristiane. Effect of early water-deficit stress on reproductive development in cotton. (Ph.D., advisor: Oosterhuis)

Pretorius, Mathilda. High temperature tolerance in cotton. (Ph.D., advisor: Oosterhuis)

Raper, Tyson. Potassium deficiency during reproductive development: effect on reproductive development, remote sensing and amelioration. (Ph.D., advisor: Oosterhuis)

Schrage, Brandon. Cotton Injury due to soil- or foliar-applied herbicides: An assessment based on the influence of genetic, agronomic, and environmental factors. (M.S., advisor: Norsworthy)

Von Kanel, Michael B. Fruit injury and developing injury thresholds in transgenic cotton. (M.S., advisor: Lorenz)

Zhang, Jin. Identification of heat stress genes related to heat tolerance in *Gossypium hirsutum* L. (M.S., advisor: Stewart and Srivastava)

APPENDIX II

RESEARCH AND EXTENSION 2013 COTTON PUBLICATIONS

BOOKS

Oosterhuis, D.M. (ed.) 2013. Summaries of Arkansas Cotton Research 2012. Arkansas Agricultural Experiment Station Research Series 610, Fayetteville, Ark.

REFEREED

Bagavathiannan, M.V., J.K. Nosworthy, K.L. Smith, and P. Neve. 2013. Modeling the evolution of glyphosate resistance in barnyardgrass (*Echinochloa crus-galli*) in cotton-based production systems of the Midsouthern United States. Weed Technol. 27:475-487.

Bourland, F.M. and D.C. Jones. 2013. Registration of 'UA103' cotton cultivar. J. Plant Reg. 7:135-139.

Bourland, F.M. and D.C. Jones. 2013. Registration of Arkot 0111, Arkot 0113, and Arkot 0114 Germplasm Lines of Cotton. J. Plant Reg. (in press)

Gore, J., D. Cook, A. Catchot, F. Musser, S. Stewart, B.R. Leonard, G. Lorenz, G. Studebaker, D. Akin, K. Tindall, and R. Jackson. 2013. Impact of two-spotted spider mite (Acari: Tetranychidae) infestation timing on cotton yields. J. Cotton Sci. 17:34-39.

Hutmacher, R.B., M. Ulloa, S.D. Wright, B.T. Campbell, R. Percy, T. Wallace, G. Myers, F. Bourland, D. Weaver, P. Chee, P. Thaxton, J. Zhang, W. Smith, J. Dever, V. Kuraparthy, D. Bowman, D. Jones, and J. Burke. 2013. Elite Upland cotton germplasm-pool assessment of Fusarium wilt (FOV) resistance in California. Agron. J. 105:1635-1633.

Jaureguy, L.M., F.L. Rodriguez, L. Zhang, P. Chen, K. Brye, D.M. Oosterhuis, A. Mauromoustakos, and J.R. Clark. 2013. Selection of high inorganic phosphorus-low stachyose soybean breeding lines. J. Crop Improvement 27:342-359.

Jaureguy, L.M., F.L. Rodriguez, L. Zhang, P. Chen, K. Brye, D.M. Oosterhuis, A. Mauromoustakos, and J.R. Clark. 2013. Planting date and delayed harvest effects on soybean seed composition. Crop Sci. 53:1-14.

Kawakami E.M., D.M. Oosterhuis, and J.L. Snider. 2013. High temperature and urea fertilization with NBPT and DCD on cotton growth and physiology. J. Plant Nutr. 36:1615-1639.

Kawakami, E.M., D.M. Oosterhuis, J.L. Snider, and T.R. Fitzsimons. 2013. High temperature and ethylene antagonist 1-methylcycloprpene alter ethylene evolution patterns, antioxidant responses, and boll growth in *Gossypium hirsutum* . Amer. J. Plant Sci. 4:1400-1408.

Liu, J., Y. Ma, F. Lv, J. Chen, Z. Zhou, Y. Wang, A. Abudurezikekey, and D.M.Oosterhuis. 2013. Changes of sucrose metabolism in leaf subtending to cotton boll under cool temperature due to late planting. Field Crops Res. 144:200-211.

Loka, D.A. and D.M Oosterhuis. 2013. Effect of 1-Methylcyclopropene on gas exchange and carbohydrate concentrations of the cotton flower and subtending leaf under water-deficit stress. Amer. J. Plant Sci. 4:142-152.

Loka, D.A., D.M. Oosterhuis, J.D. Mattice, and B.L. McMichael. 2013. Polyamine metabolism of the cotton flower and its subtending leaf under water-deficit stress in the field. Am. J. Plant Sci. 4:84-91.

Ma, J., T.L. Kirkpatrick, C.S. Rothrock, and K. Brye. 2013. Effects of soil compaction and *Meloidogyne incognita* on cotton root architecture and plant growth. J. Nemato. 45:112-121.

Ma, J., T.L. Kirkpatrick, C.S. Rothrock, and K. Brye. 2013. Effects of soil compaction and *Meloidogyne incognita* on cotton root architecture and plant growth. J. Nematol. 45:112-121.

Nalley, L., D.M. Danforth, Z. Niederman, and T.G. Teague. 2013. A Scan level cotton carbon life cycle assessment: has bio-tech reduced the carbon emissions from cotton production in the USA? J. Cotton Sci. 17:80-88.

Oosterhuis, D.M., D. Loka, and T. Raper, 2013. Potassium and stress alleviation: Physiological functions and management. J. Plant Nutr. Soil Sci. 176:331-343.

Reba, M.L., T.G. Teague, and E. Vories. 2013. A retrospective review of cotton irrigation on a production farm in the Mid-South. J. Cotton Sci. (in press)

Riar, D. S., J. K. Norsworthy, L. E. Steckel, D. O. Stephenson, IV, and J. Bond. 2013. Consultant perspectives on weed management needs in Midsouthern United States cotton: A follow-up survey. Weed Technol. 27:778-787.

Riar, D.S., J.K. Norsworthy, L.E. Steckel, D.O. Stephenson, IV, T.W. Eubank, J. Bond, and R.C. Scott. 2013. Adoption of best management practices for herbicide-resistant weeds in midsouthern United States cotton, rice, and soybean. Weed Technol. 27:788-797.

Roselem, C.A., D.M. Oosterhuis, and F.S. De Souza. 2013. Cotton response to mepiquate chloride and temperature. Scientia Agricola 70:82-87.

Snider, J.L., D.M. Oosterhuis, G.D. Collins, C. Pilon, and T.R. Fitzsimons. 2013. Field-acclimated *Gossypium hirsutum* cultivars exhibit genotypic and seasonal differences in photosystem ll thermostability. Plant Physiol. 170:489-496.

Stewart, S.D., D.S. Akin, J. Reed, J. Bacheler, A. Catchot, D. Cook, J. Gore, J. Greene, A. Herbert, R.E. Jackson, D.L. Kerns, B.R. Leonard, G.M. Lorenz, S. Micinski, D. Reisig, P. Roberts, G. Studebaker, K. Tindall, and M. Toews.

2013. Survey of thrips species infesting cotton across the southern U.S. Cotton Belt. J. Cotton Sci. 17:263-269.

NON-REFEREED

Bagavathiannan, M. V., J. K. Norsworthy, K. L. Smith, D. S. Riar, and P. Neve. 2013. Management considerations for reducing the risk of barnyardgrass evolving resistance to glyphosate in Midsouth cotton. pp. 95-101. *In:* D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research 2012. Agricultural Experiment Station Research Series 610.

Bourland, F.M. 2013. My Turn – Another challenge for cotton. p. 22. Cotton Farming. April 2013. One Grower Publishing, LLC. Redwood Valley, Calif.

Bourland, F.M. 2013. Novel approaches used in the University of Arkansas cotton breeding program. pp. 409-418. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Bourland, F.M. 2013. University of Arkansas cotton breeding program 2012 progress report. p. 1719. *In:* D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research 2012. Agricultural Experiment Station Research Series 610.

Boykin, J.C., F. Bourland, and D.M. Dobbs. 2013. Relationship of leaf and bract trichomes to trash content of ginned lint. pp. 774-782. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Burke, J.M., Longer, D.E., Oosterhuis, D.M., Kawakami, E.M., and Loka, D.A. 2013. The effect of source of biochar on cotton seedling growth and development. pp. 85-88. *In:* D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research 2012. Agricultural Experiment Station Research Series 610.

Cook, D.R., J. Gore, S.D. Stewart, G.M. Lorenz, A.L. Catchot, D.L. Kerns, G. Studebaker and F.R. Musser. 2013. Impact of spray adjuvants on insecticide performance. pp. 595-603. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Coomer, T.D., D.E. Longer, D.M. Oosterhuis, and D.A. Loka. 2013. The influence of poultry litter biochar on early season cotton growth. Discov. J. 14:12-17.

Coomer, T.D., D.M. Oosterhuis, D.E. Longer, and D.A. Loka. 2013. Effect of poultry litter biochar on early-season cotton growth. pp. 89-94. *In:* D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research 2012. Agricultural Experiment Station Research Series 610.

Dunn, K.C. and A. Flanders. 2013. 2012 Geographical Distribution of Arkansas Cotton Acreage. University of Arkansas System Cooperative Extension Publication. 7 pp. www.uaex.edu/farm-ranch/economics-marketing/docs/acreage_cotton_2012.pdf

Echer, F.R., D.M. Oosterhuis, D.A. Loka, and C.A. Rosolem. 2013. Molybdenum and abscisic acid effects on cotton under high night temperature stress. pp. 56-62. *In:* D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research 2012. Agricultural Experiment Station Research Series 610.

Eder, Z.P., G.D. Morgan, D. Fromme, D.A. Mott, G. Collins, and F. Bourland. 2013. Cotton leaf grade as influenced by cotton defoliation and varieties. pp. 45-46. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Fitzsimons, T.R. and D.M. Oosterhuis. 2013. The biochemical effects of heat stress on cotton flowering. pp. 821-826. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Fitzsimons, T.R. and D.M. Oosterhuis. 2013. Acclimatization of cotton exposed to high-temperature stress. pp. 51-55. *In:* D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research 2012. Agricultural Experiment Station Research Series 610.

Flanders, A. 2013. Cotton Acreage Response to Price Signals Due to Agricultural Policy and Market Conditions. p. 712. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Flanders, A. and F. Bourland. 2013. Cotton Yield, Quality, and Revenue: 2012 Arkansas Cotton Variety Test. Cotton Comments 10-13. University of Arkansas System Cooperative Extension Service Little Rock. 8 pp. http://www.uaex.edu/farm-ranch/economics-marketing/docs/Cotton%20Comments%202013.pdf.

Jaraba, J., C.S. Rothrock, T.L. Kirkpatrick, and K. Brye. 2013. Soil texture influence on *Meloidogyne incognita* and *Thielaviopsis basicola* and their interaction on cotton. Phytopathology. (in press)

Kelly, E.J., T.G. Teague, and D.K. Morris. 2013. Variability of thrips abundance across soil EC based management zones in cotton with and without wheat cover crop. pp.153-158. *In*: D.M. Oosterhuis (ed.), Summaries of Arkansas Cotton Research 2012. Agricultural Experiment Station Research Series 610.

Loka, D.A., D.M. Oosterhuis, J. Mattice, and C. Pilon. 2013. Effect of water-deficit stress during reproductive development on polyamine content of cotton flowers. pp. 83-85. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Loka, D.A., Oosterhuis, D.M., Pilon, C., and McMichael, B.L. 2013. Water-deficit stress effects on polyamine metabolism of the cotton flower and subtending leaf under field conditions. pp. 36-40. *In:* D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research 2012. Agricultural Experiment Station Research Series 610.

Lorenz, G., G. Studebaker, S.D. Stewart, A.L. Catchot, D.R. Cook, J. Gore, and D.L. Kerns. 2013. Impact of foliar applications of Prevathon on conventional and dual gene transgenic cotton in the midsouth. pp. 883-889. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

McClelland, B., T. Barber, and A. Flanders. 2013. Cotton Research Verification 2012 Annual Report. University of Arkansas System Cooperative Extension Publication AG1285.

Mozaffari, M. and N.A. Slaton. 2013. Corn and cotton response to urea and an enhanced efficiency N fertilizer. pp. 29-34. *In:* N.A. Slaton (ed.) W.E.

Sabbe Arkansas Soil Fertility Studies 2012. Agricultural Experiment Station Research Series 608.

Mozaffari, M., T. Teague, M. Daniel, N.A. Slaton, C.G. Herron, and S.D. Carroll. 2013. Effect of urea and environmentally smart nitrogen on cotton yield in a Marvel silt loam in Arkansas. pp. 81-84. *In*: D.M. Oosterhuis (ed.), Summaries of Arkansas Cotton Research 2012. Agricultural Experiment Station Research Series 610.

Oosterhuis, D.M. and E.M. Kawakami. 2013. Increasing yields using urea with urease inhibitors. Fluid J. 21:4-9.

Oosterhuis, D.M., T.B. Raper, C. Pilon, and J.M. Burke. 2013. Development of 1-Methylcyclopropene application triggers in cotton production. pp. 63-65. *In:* D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research 2012. Agricultural Experiment Station Research Series 610.

Pilon, C., D.M. Oosterhuis, and D.A. Loka. 2013. Effect of water-deficit stress on photosystem II thermosensitivity in cotton. pp. 31-35. *In:* D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research 2012. Agricultural Experiment Station Research Series 610.

Pretorius, M.M., D.M. Oosterhuis, D.A. Loka, and T.R. Fitzsimons. 2013. Screening for temperature tolerance in cotton. pp. 45-50. *In:* D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research 2012. Agricultural Experiment Station Research Series 610.

Raper, T.B., D.M. Oosterhuis, E.M. Barnes, P. Andrade-Sanchez, P.J. Bauer, G.L. Ritchie, D.L. Rowland, and J.L. Snider. 2013. Development of an available soil moisture index to characterize drought stress experienced in cotton variety trials. pp. 20-25. *In:* D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research 2012. Agricultural Experiment Station Research Series 610.

Raper, T.B., D.M. Oosterhuis, E.M. Barnes, P. Andrade-Snachez, P.J. Bauer, G.L. Ritchie, D.L. Rowland, and J.L. Snider. 2013. Regional evaluation of wireless soil moisture sensor system s and advanced irrigation scheduling technologies to optimize water use efficiency. pp. 810-818. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Raper, T.B., D.M. Oosterhuis, L. Espinoza, C. Pilon, and J. Burke. 2013. Spectral aspects of K deficiencies in multiple cotton cultivars at the canopy level. pp. 292-298. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Raper, T.B., D.M. Oosterhuis, L. Espinoza, C. Pilon, and J.M. Burke. 2013. Sensitivity analysis of two canopy nitrogen stress indices to variety and available potassium. pp. 76-80. *In:* D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research 2012. Agricultural Experiment Station Research Series 610.

Raper, T.B., D.M. Oosterhuis, C. Pilon, and J.M. Burke. 2013. Evaluation of a calcium-containing, soil-applied nitrogen source to increase cotton yields. pp. 66-70. *In:* D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research 2012. Agricultural Experiment Station Research Series 610.

Raper, T.B., D.M. Oosterhuis, R.L. Raper, and D.H. Pote. 2013. Varietal and short-term drought impacts on soil compaction in a Memphis silt loam. pp. 26-30. *In:* D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research 2012. Agricultural Experiment Station Research Series 610.

Reba, M.L., T.G. Teague, and E.D. Vories. 2013. A review of irrigation termination practices in Northeast Arkansas. pp.45-50. *In*: D.M. Oosterhuis (ed.), Summaries of Arkansas Cotton Research 2012. Agricultural Experiment Station Research Series 610.

Riar, D. S., J. K. Norsworthy, M. T. Bararpour, H. D. Bell, and B. W. Schrage. 2013. Activation and length of residual herbicides under furrow and sprinkler irrigation. pp. 107-112. *In:* D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research 2012. Agricultural Experiment Station Research Series 610.

Rothrock, C.S., S.A. Winters, J.D. Barham, A.B. Beach, M.B. Bayles, P.D. Colyer, T. Kelley, R.C. Kemerait, G.W. Lawrence, K.S. Lawrence, G.B. Padgett, P.M.Phipps, G.L. Sciumbato, R. Thacker, and J.E. Woodward. 2013. Report of the cottonseed treatment committee for 2012. pp. 157-164. *In:* D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research 2012. Agricultural Experiment Station Research Series 610.

Schrage, B.W., J. K. Norsworthy, K. L. Smith, D. B. Johnson, M. V. Bagavathiannan, and D. S. Riar. 2013. Factors contributing to cotton injury from soil-applied residual herbicides. pp. 102-106. *In:* D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research 2012. Agricultural Experiment Station Research Series 610.

Studebaker, G.E., and F.M. Bourland 2013. Effect of varietal selection and planting date on tarnished plant bug levels in cotton. p. 159-161. *In:* D.M. Oosterhuis (ed.) Summaries of Arkansas Cotton Research 2012. Agricultural Experiment Station Research Series 610.

Studebaker, G.E., Editor. 2013. Cotton insect control in insecticide recommendations for Arkansas. pp. 66-76. University of Arkansas System Cooperative Extension Publication MP144.

Taillon, N.M., G.M. Lorenz, G. Studebaker, W.A. Plummer, B.C. Thrash, D.L. Clarkson, L.R. Orellana Jimenez and M.E. Everett. 2013. Rainfastness of selected insecticides used for control of tarnished plant bug in Arkansas cotton. pp. 255-257. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Teague, T.G. and C.R. Shumway. 2013. Cotton Response to Irrigation Timing and Use of Enhanced Efficiency Nitrogen Fertilizer and Biosolids. pp. 73-82. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Teague, T.G., E.J. Kelly, D.K. Morris, and D.M. Danforth. 2013. Zone management in center pivot irrigated fields — improving efficiency in insect control termination using Cotman in spatially variable cotton fields. pp. 1133-1144. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

ABSTRACTS

Bagavathiannan, M. V., J. K. Norsworthy, K. L. Smith, and P. Neve. 2013. Simulating the evolution of glyphosate-resistant barnyardgrass in Midsouth cotton: key management considerations. p. 1033. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Bagavathiannan, M. V., J. K. Norsworthy, K. L. Smith, and P. Neve. 2013. Learnings from simulation models for glyphosate-resistance management in Midsouth cotton-based production systems. p. 319. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Bourland, F. 2013. Working definitions of cotton seed and seedling vigor. p. 395. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Brennan, J.R., J.K. Norsworthy, M.V. Bagavathiannan, Z.T. Hill, H.D. Bell, D.S. Riar, and C.J. Meyer. 2013. Assessment of the tolerance of various crops to different rates of pre-applied fluridone. p. 13. Arkansas Crop Protection Association Meeting, N. Little Rock, Ark.

Burke, J.M., D.M. Oosterhuis, and B. Raper. 2013. The response of cotton to slow release foliar fertilizer. p. 305. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Eder, Z.P., G.D. Morgan, D. Fromme, D.A. Mott, G. Collins, and F. Bourland. 2013. Cotton Variety characteristics and their impact on cotton leaf grade. p. 456. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Hill, Z. T., J. K. Norsworthy, D. B. Johnson, B. W. Schrage, H. D. Bell, and S. S. Rana. 2013. Use of fluridone for Palmer amaranth (*Amaranthus palmeri*) control in Arkansas cotton. p. 324. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Hill, Z. T., J. K. Norsworthy, M. T. Bararpour, and D. B. Johnson. 2013. Use of fluridone for residual Palmer amaranth (*Amaranthus palmeri*) control on ditchbanks and turnrows. p. 864. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Johnson, D. B., J. K. Norsworthy, B. W. Schrage, H. D. Bell, and Z. T. Hill. 2013. Factors contributing to cotton injury from soil-applied herbicides. p. 1248. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Johnson, D. B., J. K. Norsworthy, H. D. Bell, D. O. Stephenson, D. K. Miller, and J. A. Bond. 2013. Herbicide programs in Glytol-Liberty Link cotton. p. 662. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Kelly, E.J., T.G. Teague, and D.K. Morris. 2013. Monitoring insect pest populations across soil EC based management zones in mid-South cotton with and without wheat cover crop. p. 428. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Larson, J.A., R.K. Roberts, D.M. Lambert, B.C. English, K.J. Bryant, R. Hogan, A. Mishra, L. Falconer, and J.M. Reeves. 2013. Weed resistance to herbicides in cotton production: summary results from a farmer survey. p. 918. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Liu, Z., T. Kirkpatrick, T. Griffin, and S. Monfort. 2013. Spatial econometric modeling for site-specific nematode management. p. 757. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Norsworthy, J. K., R. Lassiter, J. Bond, A. S. Culpepper, D. Dodds, D. Miller, L. Steckel, D. Stephenson, and A. York. 2013. Efficacy of Enlist Duo™ (glyphosate + 2,4-D choline) on glyphosate-resistant Palmer amaranth: a summary of trials in Enlist™ cotton. pp. 1041-1042. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Oosterhuis, D.M. 2013. Dealing with heat and drought. 16th Annual National Conservation Systems Cotton and Rice Conference. Baton Rouge, La., 31 Jan - 1 Feb. 2013.

Reba, Michele L., T. G. Teague, and E. D. Vories. 2013. Retrospective review of cotton irrigation termination in the Midsouth. p. 865. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Riar, D. S., J. K. Norsworthy, M. T. Bararpour, and B. W. Schrage. 2013. Activation and length of residual herbicides under sprinkler irrigation. p. 322. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Riar, D. S., J. K. Norsworthy, M. T. Bararpour, H. D. Bell, B. W. Schrage, S. S. Rana, and J. A. Bond. 2013. Activation and length of residual herbicides under furrow irrigation. p. 1249. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Schrage, B. W., J. K. Norsworthy, and D. B. Johnson. 2013. Environmental and agronomic factors affecting injury to cotton from soybean-applied herbicides. p. 31. *In*: Proc. Southern Weed Science Society, Houston, Texas, 28-30 Jan. 2013.

Schrage, B. W., J. K. Norsworthy, Z. Hill, and D. Riar. 2013. Palmer amaranth development and seed production as influenced by emergence date in cotton. p. 1040. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Schrage, B. W., J. K. Norsworthy, H. Bell, B. Johnson, Z. Hill, and D. Riar. 2013. Effect of shading, variety, and application timing on cotton tolerance to glufosinate. p. 332. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Schrage, B. W., J. K. Norsworthy, H. D. Bell, and Z. T. Hill. 2013. Does light intensity influence cotton's tolerance to glufosinate? p. 169. *In*: Proc. Southern Weed Science Society, Houston, Texas, 28-30 Jan. 2013.

Schrage, B. W., J. K. Norsworthy, Z. T. Hill, and D. S. Riar. 2013. Cotton tolerance to glufosinate as influenced by cloud cover, variety selection, and application timing. p. 11. Arkansas Crop Protection Association Meeting, N. Little Rock, Ark.

Snider, J.L., D.M. Oosterhuis, G. Collins, C. Pilon, and T.R. Fitzsimons. 2013. Field grown cultivars exhibit genotypic and seasonal differences in photosystem 11 heat tolerance. p. 905. *In*: Proc. Beltwide Cotton Conf., San Antonio, Texas, 7-10 Jan. 2013. National Cotton Council, Memphis, Tenn.

Stephenson, D., J. K. Norsworthy, R. L. Landry, B. C. Woolam, and D. B. Johnson. 2013. Effectiveness of glufosinate with and without clethodim as influenced by johnsongrass (*Sorghum halepense*) height in glufosinate-resistant cotton (*Gossypium hirsutum*). p. 166. *In*: Proc. Southern Weed Science Society, Houston, Texas, 28-30 Jan. 2013.

NOTES

NOTES