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Summaries of Arkansas Cotton Research 2008

Derrick M. Oosterhuis

University of Arkansas, Fayetteville

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Summaries of Arkansas Cotton Research 2008



Edited by Derrick M. Oosterhuis

ARKANSAS AGRICULTURAL EXPERIMENT STATION
Division of Agriculture University of Arkansas System
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DIVISION OF AGRICULTURE

Summaries of Arkansas Cotton Research 2008

Oosterhuis

AAES

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**SUMMARIES OF
ARKANSAS COTTON
RESEARCH 2008**

Derrick M. Oosterhuis, Editor

**Arkansas Agricultural Experiment Station
Division of Agriculture
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PREFACE

Cotton acres continued to decline in 2008 due to relatively high commodity prices and lower production costs associated with soybean and corn compared to cotton. According to the Arkansas Agricultural Statistics Service, producers reduced cotton acres by 25% from 850,000 acres in 2007 to 640,000 in 2008. Mid-South Mississippi river valley states decreased 32% from 2.7 million in 2007 to 1.85 million in 2008. Cotton lint yields were also down 49 lb/acre on average. In 2007 the average cotton yield was 1071 lb lint/acre; this decreased to 1022 lb lint/acre in 2008. Arkansas producers have excelled in averaging more than two bales/acre (1 bale = 500 lb) over the last several years. Increased production costs, especially costs of fuel and fertilizer, have increased to the point where increased average yields of 1200 lb lint/acre are needed to break even on production costs. In 2008, Arkansas' farmers produced 1.31 million bales, third in production behind Texas and Georgia.

The 2008 production season was much like 2007 in that extended cool, wet weather slowed cotton planting to below the five-year average. The result was delayed cotton planting and later maturity across much of the state. Extended periods of cool, wet weather increased incidence of seedling disease and many acres were replanted as a result. Fortunately, environmental conditions improved and most of the cotton acres were able to catch up toward the end of the season. Weed resistance, particularly glyphosate-resistant Palmer amaranth (pigweed) continues to be an emerging problem for many producers across Arkansas. In 2008, twenty counties were identified as having a population of Palmer amaranth. The severity of this problem weed in cotton will encourage increased utilization of residual herbicides for weed management in 2009. The increase in glyphosate resistance across the state may lead to the highest use of residuals since the development of glyphosate tolerant varieties in 1997. Insect pests for 2008 were heavy in areas, especially where other crops were added in rotation to the farm mix. In future seasons it will be important to look at pest management in a whole-farm approach as far as crop diversity and field selection to possibly reduce flushes of sucking pests around alternative crop borders. The defining moments for the 2008 growing season came on the heels of hurricanes Gustav and Ike. Many producers in southeast Arkansas received up to 30 inches of rain and lost up to 40% of their crop to these hurricanes. The devastating results were tremendous hard-lock and boll rot. Much of the lint never made it into the picker. Producers in northern Arkansas did not receive as much rain but wind did become a factor for many.

Overall, 2008 had its ups and downs, had the hurricanes not robbed yield across the state the possibility of a record yield would have been high. Production costs in the future and prices of other commodities will play a large role in deciding Arkansas cotton acres for 2009.

Tom Barber and Derrick Oosterhuis

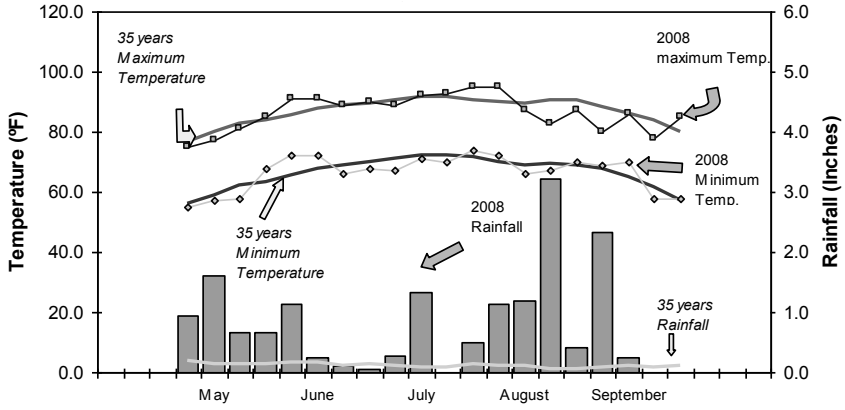


Fig. 1. Weekly maximum and minimum temperatures and rainfall for 2008 compared with the long-term 35-year averages in eastern Arkansas.

ARKANSAS COTTON RESEARCH GROUP

2008

The University of Arkansas Cotton Group is composed of a steering committee and three sub-committees representing production, genetics, and pest management. The group contains appropriate representatives in all the major disciplines as well as representatives from the Cooperative Extension Service, the Farm Bureau, the Agricultural Council of Arkansas, and the State Cotton Support Committee.

The objective of the Arkansas Cotton Group is to coordinate efforts to improve cotton production and keep Arkansas producers abreast of all new developments in research.

Steering Committee: Don Alexander, Fred Bourland, Frank Groves, Gus Lorenz, Gene Martin, Robert McGinnis, Derrick Oosterhuis (Chm.), Craig Rothrock, James Stewart, and David Wildy.

Pest Management: Scott Aiken, Terry Kirkpatrick, Gus Lorenz, Randy Luttrell, Jason Norsworthy, Craig Rothrock (Chm.), Kenneth Smith, Don Steinkraus, Glenn Studebaker, and Tina Teague.

Production: Sreekala Bajwa, Kelly Bryant, Leo Espinoza, Dennis Gardisser, Frank Groves, Gus Lorenz, Morteza Mozaffari, Jason Norsworthy, Derrick Oosterhuis (Chm.), Lucas Parsch, Daniel Stephenson, and Phil Tacker.

Genetics: Fred Bourland, Hal Lewis, and James Stewart (Chm.).

ACKNOWLEDGMENTS

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



2008 Cotton Achievement Award

**Kenneth L. Smith
Professor, CSES, CES,
Monticello, Ark.**

The 2007 Arkansas Cotton Achievement Award was given to the Boll Weevil Eradication Board for the team effort that led to the eradication of the Boll Weevil in Arkansas. The 2008 award goes to Professor Ken Smith, extension weed scientist, Division of Agriculture, University of Arkansas System, who has had a profound effect on cotton weed management in Arkansas. According to his nomination letter, Smith is “an innovative leader in

Arkansas cotton... When extension fact sheets, bulletins, or popular-press articles are needed, Ken writes them and makes them available to producers, consultants, extension agents, and professionals in Arkansas and adjoining states.” These include numerous articles for the *Delta Farm Press* on weed management issues in cotton, so that his influence extends beyond the borders of Arkansas.

Herbicide-resistant weeds, particularly glyphosate resistance in marehail and pigweed, are a favorite topic of discussion recently. Smith predicted that Palmer amaranth and barnyardgrass would become resistant to glyphosate. His prediction proved true in 2005 with the discovery of glyphosate-resistant pigweed in Mississippi County. After glyphosate-resistant pigweed was discovered, Smith formed the Arkansas Herbicide Resistance Committee, the first state-wide committee in the U.S., which put in place a mechanism to bring industry, university, and extension together to address current and future problems with herbicide-resistant weeds. He applied a model developed by Paul Neve (University of Warwick, England) to the Arkansas resistant weed situation and identified management strategies that producers could use to economically and effectively manage Palmer amaranth while reducing the risk of glyphosate resistance.

During his career Ken Smith has been directly responsible for saving Arkansas cotton producers many millions of dollars. For the reasons given above he is the 2008 recipient of the Arkansas Cotton Achievement Award.



COTTON INCORPORATED AND THE ARKANSAS STATE SUPPORT COMMITTEE

The *Summaries of Arkansas Cotton Research 2008* 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's Division of Agriculture, the Cotton Board, and Cotton Incorporated. Seven and one-half percent of the grower contributions to the total Cotton Incorporated budget are allocated to the State Support Committees of the 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, Los Angeles, 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.

Arkansas Cotton State Support Committee / Cotton Incorporated Funding 2008.

Projects	Researcher	Short title	\$ Funding
02-291AR	Oosterhuis	Annual Research Summaries	\$6,500
06-797AR	Lorenz	Plant bug thesholds	\$21,520
07-973AR	Bourland	Cotton breeding	\$26,804
07-974AR	Windham	Irrigation start and stop	\$23,780
07-975AR	Espinoza	Gypsum	\$23,715
07-976AR	Lorenz	Comparison of Bt technologies	\$25,565
07-977AR	Oosterhuis	High temperature effects	\$15,975
07-978AR	Barber	Verification program	\$31,073
07-979AR	Rothrock	Black root rot	\$19,916
07-980AR	K. Smith	Resistant pigweeds - survey	\$19,661
07-981AR	Barber	15-inch rows	\$24,035
07-986AR	Oosterhuis	Cuticle penetration	\$4,165
08-324AR	Barber	Defoliation timing	\$14,600
08-325AR	Burgos	Resistant pigweeds - genetics	\$11,455
08-326AR	Kirkpatrick	Soils & nematode thresholds	\$24,094
08-330AR	Norsworthy	Resistant pigweeds - prediction	\$11,907
08-331AR	Sadaka	Fast pyrolysis of gin waste	\$30,872
08-332AR	Teague	Plant bugs in irrigated cotton	\$26,544
08-337AR	Windham	Soils & cotton populations	\$28,500
TOTAL			\$390,681

**SUMMARIES OF
ARKANSAS COTTON RESEARCH
— 2008 —**

University of Arkansas Cotton Breeding Program - 2008 Progress Report

Fred M. Bourland¹

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 which will 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 which are highly adapted to Arkansas environments and possess good host-plant resistance traits. Bourland (2008) provided the most recent update of the current program.

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 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

¹ Director, Northeast Research and Extension Center, Keiser.

evaluated over multiple years and in regional tests. Improved strains are used as parents in the breeding program and/or released as germplasm or cultivars. Bourland (2004) described the selection criteria presently being used.

RESULTS AND DISCUSSION

Breeding Lines

A primary focus of conventional crosses in 2008 was to combine lines having specific morphological traits, enhanced yield components and improved fiber characteristics. In the conventional breeding effort, 24 new crosses, 12 F₂ populations 18 F₃ populations, 16 F₄ populations, 645 first year progeny, and 250 advanced progeny were evaluated. Bolls were harvested from superior plants in F₂ and F₃ populations and bulked by population. Individual plants (896) were selected from the F₄ populations. After discarding individual plants for fiber traits, 600 progeny from the individual plant selections will be evaluated in 2009. Also, 168 superior F₅ progeny were advanced, and 72 F₆ advanced progeny were promoted to strain status.

Additionally, transgenic forms of Arkot lines crossed with lines possessing nectariless, frego bract, high glanding, or red leaf traits were advanced in 2008. The transgenic effort included evaluation of 12 F₂ populations, 203 first year progeny, and 34 advanced progeny. After discarding for field performance and fiber traits, 30 of the first year progeny will be evaluated as advanced progeny in 2009. Also, eight of the advanced progeny were advanced to strain status and will be evaluated in a multiple location replicated test in 2009. The eight transgenic strains (all Round-up Ready Flex) include four frego-bract lines, three high-gossypol lines, and one nectariless line. The frego-bract lines are being developed as part of an effort to evaluate them for use as a trap and/or monitoring of tarnished plant bugs.

Strain Evaluation

In 2009, 108 strains were evaluated in replicated strain tests at multiple locations. Within each test, strains were compared to standard cultivars (DP 393 and SG 105). Based on their performance, 36 of the strains were selected and entered into 2009 New and Advanced Strain Tests. Superior strains exhibited a wide range of lint percentages, leaf pubescence, maturity, and fiber quality. The 2008 New and Advanced Strains were tested for host plant resistance (tarnished plant bug, bacterial blight, fusarium wilt, and resistance to seed deterioration). Selected lines were evaluated in regional strain tests.

Germplasm Releases

Germplasm releases are a major function of most public breeding programs. In 2008, the Arkansas Agricultural Experiment Station released two cotton germplasm lines, Arkot 9704 and Arkot 9706, which were developed by this breeding program. Both lines have been best adapted to central and south Arkansas test environments

with Arkot 9706 tending to yield more and be later maturing than Arkot 9704. Yield components (lint weight per seed, number of fibers per seed, and lint percentages) of both lines exceeded check cultivars. Both lines are worthy or near-worthy of cultivar status relative to yield, fiber quality and host plant resistance.

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 breeders or released as cultivars. In either case, Arkansas cotton producers should benefit from having cultivars that are specifically adapted to their growing conditions.

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Association Mapping of Important Phenotypic Traits in *Gossypium arboreum* Accessions

Stella K. Kantartzi and James McD. Stewart¹

RESEARCH PROBLEM

Mapping of genes in plants normally involves the use of segregating populations derived from parents with contrasting phenotypes and/or genotypes. Recombination frequencies between markers and the genes of interest are estimated from their patterns of co-segregation. Using linkage-based association analysis (including QTL interval mapping) in cotton, a large number of genes for various traits (quality traits, resistance to biotic stresses, etc.) have already been tagged with markers (e.g., Lacape et al., 2005; Wright et al., 1998). While this approach has served plant geneticists and breeders well, it has a few limitations. Firstly, before linkage analysis is possible one must grow the plants for two to three generations. Secondly, very large segregating populations are required to achieve high resolution mapping which may be needed for marker assisted selection (MAS) or cloning of candidate genes by chromosome landing strategies (Tanksley, 1993). Thirdly, only two alleles at any particular locus can be assessed. In order to overcome these limitations association studies have been conducted that not only allow mapping of genes/QTLs with a higher level of confidence but also allow detection of genes/QTLs which would otherwise escape detection in linkage-based studies (Darvasi et al., 1993; Neale and Savolainen, 2004).

BACKGROUND INFORMATION

The basic objective of association mapping (AM) studies is to detect correlations between genotypes and phenotypes in a sample of individuals on the basis of linkage disequilibrium (LD) (Zondervan and Cardon, 2004). The potential of LD and regression methods to identify and characterize loci/genes associated with different complex traits in true breeding lines has been demonstrated (Kraakman et al., 2004). Of particular interest to breeders is the possibility of using existing germplasm resources for gene and allele discovery on the basis of association mapping strategies (Kruglyak, 1999; Jorde, 2000).

¹ Post-doctoral research associate and university professor, respectively, Crop, Soil, and Environmental Sciences Department, Fayetteville.

Understanding population structure is important to avoid identifying spurious associations between phenotype and genotype in association mapping (Pritchard et al., 2000). Detection of marker-trait associations in breeding germplasm has potential advantages over classical linkage analysis and QTL mapping (Jannink and Walsh, 2002).

RESEARCH DESCRIPTION

Fifty-six accessions of *G. arboreum* from nine regions of Africa, Asia, and Europe were evaluated by association mapping. The accessions were primarily cultivated varieties and are included in the USDA-ARS National Plant Germplasm System (<http://www.ars-grin.gov/npgs/>). Fiber quality measurements were obtained by STAR LAB, Knoxville, Tenn., on fibers from field plants grown at Fayetteville, Ark., in the years 1989 through 1991. The accessions were also grown at College Station, Texas, in 1991 for verification of observations.

Genomic DNA of the accessions was obtained from greenhouse-grown plants. After young leaf samples (~200 mg each) were ground in liquid nitrogen, DNA was isolated from each with DNeasy® Plant Mini Kits (Qiagen Inc., Valencia, Calif.) according to the manufacturer's protocol. Ninety-eight microsatellites developed at the Brookhaven National Laboratory were selected that covered 21 chromosomes of cotton. A PCR was performed in a 50 µl volume containing 1 µl of DNA extract (40 ng/µl), 250 nM of each primer, 200 µM of each dNTP, 0.5 U of Taq polymerase and reaction buffer. Thirty PCR cycles, each consisting of 30 s denaturation at 96°C, 30 s annealing at [T_m-5°C] and 1 min polymerization at 72°C, were performed in a Hybaid thermocycler. Polymorphism at each locus was assessed by electrophoresis of the PCR products in a horizontal gel system at 110V for 4 h through 4% Metaphore gels stained with ethidium bromide (0.5 µg/ml) using a running buffer consisting of "I agree," 89 mM Tris, 89 mM borate, and 2 mM EDTA pH 8.3.

A model-based approach implemented in the software package STRUCTURE (Pritchard et al., 2000) was used to subdivide the set of accessions. Distance-based analysis of the accessions using Euclidean inferred ancestry for each accession and the key for identifying the accessions is shown in the neighbor-joining tree generated by the unweighted pair group method using arithmetic averages (UPGMA) (Fig. 1). All association tests were run with the general linear model (GLM) ($Y=Xb + e$, where Y is the vector of observations; b is an unknown vector containing fixed effects including genetic marker and population structure (Q); X is the known design matrix; and e is the unobserved vector of random residuals) described by Yu et al. (2006) in TASSEL 1.9.4.

RESULTS AND DISCUSSION

Ninety-eight SSR primer pairs produced a total of 211 alleles among the 56 accessions assayed. The mean number of polymorphic alleles per locus was 2.33 (StDev = 0.91), but the number ranged from 2 (BNL0256 on chromosome 10) to 5 (BNL0448 on chromosome 20). The average genetic diversity across all SSR loci was 0.40, ranging from 0.00 to 0.66.

Analysis of genetic distance and population structure provided evidence of significant population structure in the *G. arboreum* accessions and identified the highest likelihood at $K=6$ (Fig. 1). Analysis of these data identified the major substructure groups when the number of populations was set at two, however, which was consistent with clustering based on genetic distance. Figure 1 shows that the two groups were separated by a relatively large genetic distance.

Association analysis (Table 1) identified marker-trait associations ($P=0.05$) for all the traits evaluated. Lint percent, lint color, elongation, micronaire, and perimeter were associated with four markers each; length with three markers; and strength and maturity with two and five markers, respectively. A total of 30 marker-trait associations were identified with 19 SSR markers located on 11 chromosomes. It is worth mentioning that the correlated parameters of elongation, maturity, and micronaire were associated with a common marker, BNL1030. Also, micronaire and length were associated with SSR marker BNL1122. LD (R^2 values) between markers ranged from 10% to 20% (Table 1). Of the 30 marker-trait associations, four identified 15% or more of the total variation for lint percent (BNL0256 and BNL1122), lint color (BNL0542), and length (BNL1122).

PRACTICAL APPLICATION

In theory, genetic association mapping has greater power than linkage studies to identify variants with weak effects that might contribute risk for common complex traits (Rich and Merikangas, 1996). Whole-genome association studies have the advantage of enabling the entire genome to be assessed for trait-associated variants, rather than analyzing specific candidate genes. Application of association mapping to plant breeding seems to be a promising means of overcoming the limitations of conventional linkage mapping (Stich et al., 2005).

ACKNOWLEDGMENTS

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Table 1. Association of SSR markers with fiber traits (lint percent, lint color, elongation, micronaire, strength, length, maturity, and perimeter).

Trait	SSR marker ^z	Chromosome no.	<i>P</i>	R ² ^y
Lint percent	BNL0542	5	0.0351	12.24
	BNL3948	9	0.0053	13.55
	BNL0256	10	0.0029	18.77
	BNL1122	16	0.0418	16.54
Lint color	BNL0226b	3	0.0124	11.02
	BNL0542	5	0.0024	15.81
	BNL0448	22	0.0049	13.74
	BNL1047b	22	0.0088	12.09
Elongation	BNL1434	2	0.0032	11.06
	BNL1030	9	0.0116	11.21
	BNL1047b	22	0.0123	15.00
	BNL1673	22	0.0246	11.12
Micronaire	BNL0226b	3	0.0116	13.34
	BNL3408	3	0.0364	14.45
	BNL1030	9	0.0063	13.02
	BNL1122	16	0.0372	10.12
Strength	BNL0598	12	0.0506	10.04
	BNL0834	17	0.0419	12.10
Length	BNL1122	16	0.0486	19.94
	BNL1694	16	0.0304	10.57
	BNL1421	18	0.0159	10.30
Maturity	BNL0852	5	0.0049	13.76
	BNL0686	9	0.0408	13.20
	BNL1030	9	0.0198	14.41
	BNL1679	12	0.0476	10.02
	BNL1047	22	0.0199	11.92
	BNL0530	4	0.0373	10.85
Perimeter	BNL1030	9	0.0352	12.12
	BNL1679	12	0.0270	14.45
	BNL1421	18	0.0132	12.00

^z Only SSR markers with significant marker-trait association are mentioned ($P=0.05$).

^y R² indicates the percentage of the total variation.

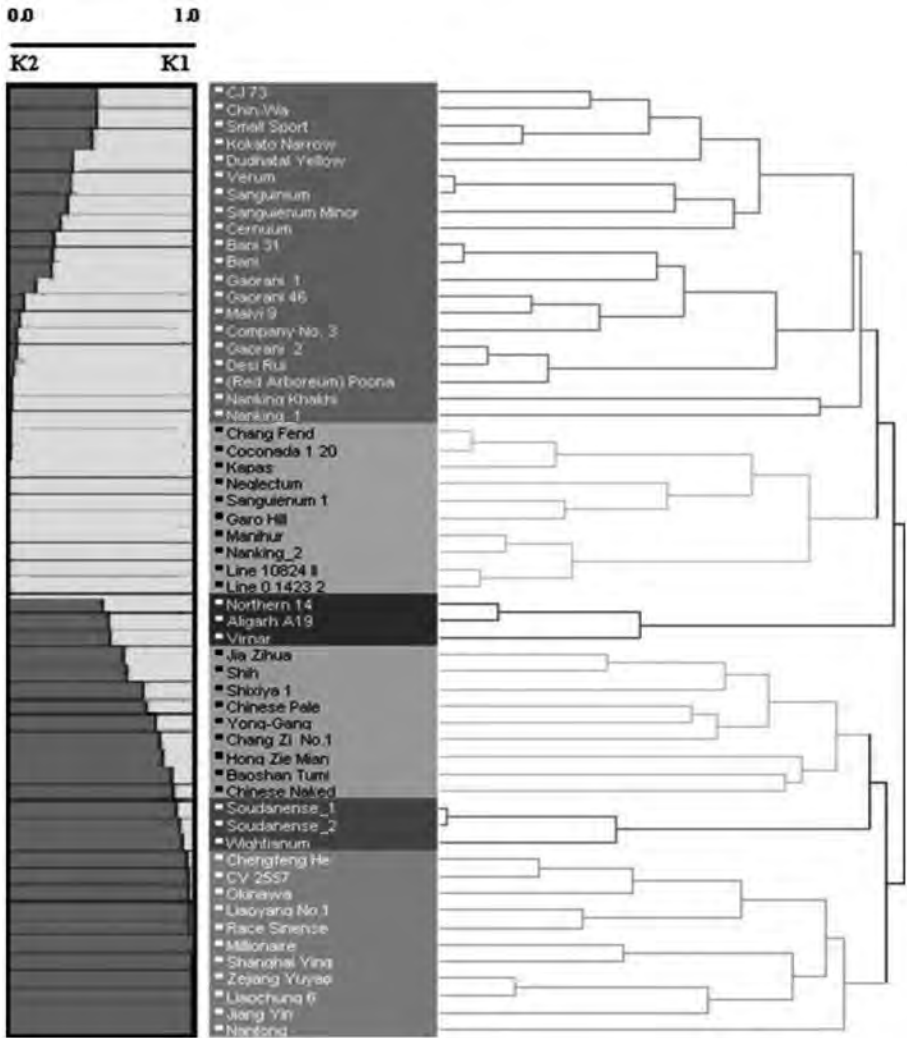


Fig. 1. Population structure and distance-based analysis of the 56 *G. arboreum* accessions using Euclidean inferred for each accession. Initially, the accessions were divided into clusters based on UPGMA and neighbor joining (right side). Next, the accessions were divided into six ancestral backgrounds defined as K (center) based on analysis in STRUCTURE were assigned to a single background or to two backgrounds (left) if the genotype indicated the accession was admixed with membership in two different backgrounds and estimated on a scale from 1.0 (accession is from one K only) to 0.0 (accession is not from this K).

Molecular Diversity and Determination of Hybridization Among the G-genome *Gossypium* Species

Rashmi S. Tiwari and James McD. Stewart¹

RESEARCH PROBLEM

Interspecific hybridization and trait introgression are important processes for speciation and played a major role in the evolution of G-genome *Gossypium* species (Cronn and Wendel, 2003; Wendel et al., 1991). Morphological and molecular studies of *Gossypium bickii* (G-genome), in the section *Hibiscoidea*, shows the evidence of ancient interspecific hybridization (Wendel et al., 1991). This suggests that natural hybridization is occurring among Australian diploid *Gossypium* species and, speciation may be continuing among the species. Knowledge of the molecular diversity of the species in the genome would be helpful in accession selection for cotton improvement.

BACKGROUND INFORMATION

Gossypium australe is the most diverse species in the genome and has a broad distribution from near the east coast to the west coast and from south to north across the continent approximately in line with the southern area of the Northern Territory to Katherine in the north. However, *G. bickii*, which occurs within the central Northern Territory, shows bi-phyletic evolutionary history. This species shares a common nuclear ancestor with other two G-genome species (*G. australe* and *G. nelsonii*), however the chloroplast genome of the species was donated by a C-genome species (similar to *G. sturtianum*). *G. nelsonii* is distributed in the central Northern Territory to central Queensland. All four species grow sympatrically in various combinations (Stewart et al., 1987; Office of the Gene Technology Regulator, 2002; Cronn and Wendel, 2003; Wendel et al., 1991).

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RESEARCH DESCRIPTION

Fifty-seven accessions of four species (*G. australe*, *G. bickii*, *G. nelsonii*, and *G. sturtianum*) and possible natural hybrids were examined in the study. A few accessions of *G. sturtianum* (C-genome) sympatric to these species were analyzed for possible hybridization. Seeds of accessions were collected from different regions of Queensland, Northern Territory, and Western Australia by Dr. J. McD. Stewart or were obtained from the Australian Centre for Plant Biodiversity. Three plants of each accession were grown in a greenhouse in 6-in. pots. The method of Zhang and Stewart (2000) was used for DNA extraction. The DNA of some accessions was extracted with QIAGEN DNeasy® Plant Mini Kits. The genetic diversity among the species was analyzed with the aid of amplified fragment length polymorphism (AFLP)(Vos et al.,1995). The AFLP procedures, with some modifications by Bill Hendrix (unpublished), CBGE Lab, University of Arkansas, Fayetteville, Ark., were from the Invitrogen AFLP Protocol® (<http://www.invitrogen.com/content/sfs/manuals/aflpii.pdf>) and Wendel AFLP Lab Protocol (<http://www.eeob.iastate.edu/faculty/WendelJ/home.htm>). Polymorphic bands between accessions were manually scored as present (1) and absent (0) for each DNA sample. Only major bands were considered in the analysis. The data were analyzed by the neighbor-joining (NJ) method and an unrooted dendrogram was generated using PAUP version 4b2 (Swofford, 2002).

RESULTS AND DISCUSSION

Six primer combinations were used for the AFLP selective amplification, which produced 141 major DNA fragments of which 133 were polymorphic. The resulting neighbor-joining dendrogram (Fig. 1) showed four groups (clades) corresponding to the four species. All accessions of *G. australe*, except for three accessions which were collected from the Western Australia, (2, 6, 7) and one accession (31) from near Kathrine in the Northern Territory fell in one cluster and showed genetic similarity with mean pair-wise genetic distance of 0.031 to 0.149. This similarity of widely distributed *G. australe* suggests that seeds were dispersed through relatively recent transportation activity (J. Stewart, personal communication) and subsequently gave rise to the sampled populations. Large populations of the *G. australe* occur adjacent to roadsides (Office of the Gene Technology Regulator, 2002). *Gossypium nelsonii* clustered on the same branch with the western accessions of *G. australe*, with the level of similarity ranging from 0.168 (between 6 and 48) to 0.308 (between 7 and 51) in mean pair-wise genetic distance. The presence of bands that are primarily unique to *G. australe* in accessions of *G. nelsonii* also suggest the invasion of the habitat of *G. nelsonii* by *G. australe* (J. Stewart, personal communication). The position of *G. bickii* on another branch of the G-genome species tree with the similarity of DNA fragments to *G. australe* with the mean pair-wise genetic distance between 184 to 0.429, and 0.253 to 0.348 with *G. nelsonii*, strongly suggest that *G. bickii* shares a common nuclear ancestor with *G. australe* and *G. nelsonii*. *G. bickii* also had higher genetic similarity to *G. australe* than to *G. sturtianum*. These observations strongly support a monophyletic origin of the G-genome. However, cytoplasmic introgression from the C genome to *G. bickii* is

involved in the evolution of this species (Wendel et al., 1991). The origin of *G. bickii* most likely is polyphyletic. This molecular evidence shows that natural hybridization is occurring among the G-genome *Gossypium* species and implies that speciation is also occurring.

PRACTICAL APPLICATION

By using a molecular method we have obtained a snapshot of the evolution of G-genome *Gossypium* species which suggests that hybridization and introgression is occurring among these taxa. This information would be helpful in accession selection for cotton improvement.

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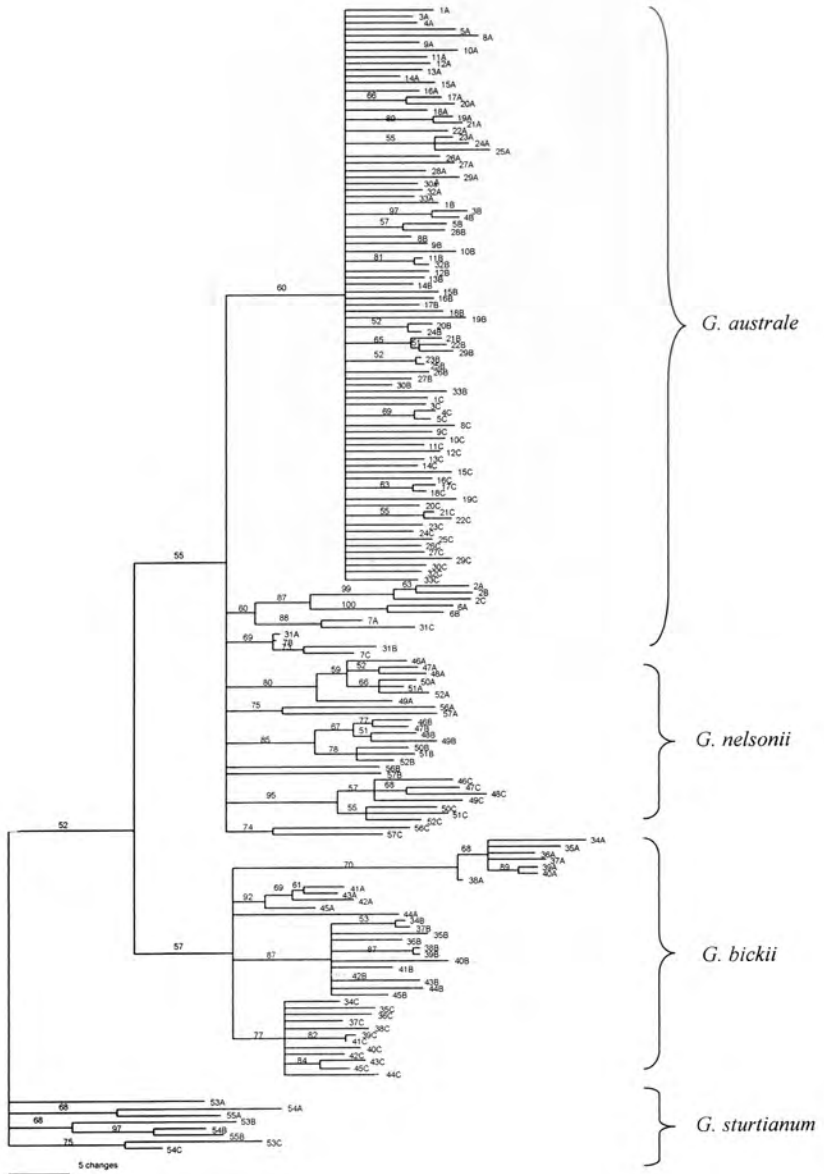


Fig. 1. Unrooted neighbour-joining dendrogram for *G. australe*, *G. bickii*, *G. nelsonii*, *G. sturtianum*, and possible hybrids, based on AFLP markers. A, B, and C indicate three different plants of each accession. Numbers at the branch points indicate bootstrap support for accessions clustered to the right of the number.

Effect of Salt on Several Genotypes of *Gossypium*

Rashmi S. Tiwari and James McD. Stewart¹

RESEARCH PROBLEM

Salinity is a common abiotic stress during the cotton growing season. Salinity stress causes a series of negative effects on cotton growth, yield, and fiber quality. Although cotton is considered as moderately sensitive to saline with a 7.7 dS m⁻¹ threshold salinity level, its yield, quality, and seed germination are affected by different salinity levels. Therefore, identification of salt-tolerance in cotton germplasm resources is an important aspect for further improvement in cotton production.

BACKGROUND INFORMATION

Studies have shown that salinity affects the growth of the plant to various degrees at all stages of the plant's life cycle at different salinity levels (Ashraf, 2002). The seed germination and seedling stages are very sensitive to salinity (Qadir and Shams, 1997; Ahmad et al., 2002). Salinity adversely affects the growth of primary roots, leaf area, shoot length, shoot and root fresh weight, and root growth, however there are reports that show an increase in root growth at moderate salinity levels (Ahmad et al., 2002). According to Fryxell (1979), *G. hirsutum*, *G. darwinii*, and *G. tomentosum* have the capacity to grow in high salinity because these species show long-distance dispersal through drift in ocean currents. *Gossypium hirsutum* dispersed from its geographic origin in Central America and Mexico through ocean currents, to distant Pacific islands (Socorro Island, Marquesas, Wake Island, northern Australia, etc.), *G. darwinii* from western South America to the Galapagos Islands (Fryxell, 1979; Wendel and Albert, 1992), and *G. tomentosum* from tropical America to the Hawaiian Islands (Wendel and Albert, 1992). This study was conducted to determine the phenotypic effect of salt on cotton and identify salt-tolerant genotypes of *Gossypium* under salt stress.

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RESEARCH DESCRIPTION

Three wild tetraploid species, *G. hirsutum* (LMK-4, PI501500), *G. tomentosum* (JFZ-8, JFZ-15, JFZ-30), and *G. darwinii* (AD5-7, AD5-14, AD5-31) were utilized for identification of salt-tolerance compared to cultivated *G. hirsutum* (ST444RB, DP33B). To evaluate the response of the selected genotypes to salt at seed germination, ten seeds of each genotype were sown in petri dishes on a germination paper soaked in one of eight NaCl concentrations (50, 75, 100, 125, 150, 175, 200, and 250) and were incubated at 28°-30°C for 7 days. After 7 days germination rate was recorded separately for each genotype with the following formula:

$$\text{Germination Rate (\%)} = \left(\frac{\text{Number of seeds germinated}}{\text{Number of seeds sown in each petri dish}} \right) \times 100$$

For evaluation of genotypic response to salt at seedling stage, seed of each genotype were sown in vermiculite at 30°C. After uniform germination, 4-days old seedlings were transplanted to pots filled with soil and irrigated with half-strength Hoagland solution. The seedlings were divided in a complete randomized design with three replications (six seedling/rep). Polythene sheets were used to stop the outflow of salt (NaCl) during application (four weeks after transplanting). The NaCl concentration was increased daily by adding 25 mM NaCl at 24 h intervals until a final concentration of 250 mM was reached. After three weeks of 250 mM NaCl, seedling development data were measured by taking leaf area, shoot and root length, and fresh weight of shoot and root. For each analysis all three replicates were combined and the mean value of each parameter was recorded. For this measurement plants were uprooted carefully and washed with distilled water to obtain fresh weight. The data were analyzed using ANOVA (SAS 9.1, SAS Institute, Inc.) and the means were compared by the least significant difference (LSD) at 0.05 confidence level.

RESULTS AND DISCUSSION

Seed germination was decreased by the concentration of salt (data not shown). Increasing salt concentration reduced germination of all three species. Germination of *G. tomentosum* was completely inhibited at more than 125 mM NaCl while *G. darwinii* was severely inhibited (>72%) at this concentration. The accessions of *G. hirsutum* were inhibited only about 33% or less at this concentration. At the seedling stage leaf area, shoot length, and shoot and root fresh weight were all decreased by salinity. Leaf damage and plant death were the major observable responses of the plants at 250 mM NaCl. Plant death was most common in *G. darwinii* (Table 1). Root length of cultivated *G. hirsutum* (444RB and DP33B) was increased by salinity, however, shoot and root fresh weight were decreased in all three species. Cultivated (ST444RB, DP33B) and wild *G. hirsutum* (LMK-4) were the most resistant to salt at germination and at 4 weeks after germination.

PRACTICAL APPLICATION

Salt tolerant genotypes were identified. The most salt tolerant genotype was among the cultivated cottons (DP33B and ST444RB), thus it should be relatively simple to incorporate salt tolerance into new genotypes of *G. hirsutum*. On the other hand, increased tolerance to salinity was not found.

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Table 1. Seedling survival of various *Gossypium* species and genotypes at high salinity.

Species	Genotypes	No. surviving	Average
<i>G. hirsutum</i>	ST444RB	13	~15
	DP33B	14	
	501500	15	
	LMK-4	16	
<i>G. tomentosum</i>	JFZ-8	5	~11
	JFZ-15	11	
	JFZ-30	15	
<i>G. darwinii</i>	AD5-7	8	6
	AD5-14	6	
	AD5-31	4	

Screening for Temperature Tolerance in Cotton

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RESEARCH PROBLEM

Although cotton originates from hot climates, it does not necessarily yield best at excessively high temperatures. Recent research has indicated that high temperature is a major abiotic factor adversely affecting cotton yields (Oosterhuis 2002). Work in growth chambers in Mississippi showed that the ideal temperature range for cotton was from 68° to 86°F (Reddy et al., 1991). However, from a physiological point of view, the ideal temperature range for cotton for optimal metabolic activity is 74° to 90°F with an optimum for photosynthesis of 82°F (Burke et al., 1988). Once temperatures reach about 95°F, growth rate begins to decrease (Bibi et al., 2008). However, average daily maximum temperatures during boll development in July and August in the U.S. Cotton Belt are almost always above 95°F, well above the optimum for photosynthesis. The overall objective of this study was to determine the best technique to screen cotton germplasm for temperature tolerance, and use this to evaluate contrasting groups of cotton genotypes for temperature tolerance in controlled environment, the results to be used in cotton breeding selection for temperature tolerance.

BACKGROUND INFORMATION

A strong correlation between yield and temperature during boll development has been reported (Oosterhuis, 2002), with high temperatures being associated with low yield and cooler temperatures being associated with high yields (Oosterhuis, 1999). Although cotton can grow at elevated temperatures, it does not necessarily grow best at high temperatures. Furthermore, high, above average temperatures during the day can decrease photosynthesis and carbohydrate production. Our research has shown that there is no sharp threshold but rather a gradual decline in net photosynthesis with a greater than 50% decrease at about 95°F (Bibi et al., 2006, 2008). High temperatures

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and decreased carbohydrate can reduce boll size by decreasing the number of seeds per boll, and the number of fibers per seed. High temperatures can affect pollen formation and subsequent fertilization resulting in motes and fewer seeds per boll (Snider et al., 2008). Current commercial cotton cultivars do not appear to have much tolerance to high temperatures (Brown and Oosterhuis, 2000). The objective of this study was to determine the best techniques to screen cotton germplasm for temperature tolerance (Bibi et al., 2006) and then to screen current lines for the Arkansas breeding trials for temperature tolerance. The results will be used for germplasm selection for improved temperature tolerance in commercial cultivars.

RESEARCH DESCRIPTION

Screening Techniques

In the first part of this study, a selection of cotton (*Gossypium hirsutum* L.) genotypes was grown in 0.5-L pots of Suregro horticultural mix in large controlled environment chambers (PW35, Conviron, Winnipeg, Canada). The pots were watered daily with half strength Hoagland's nutrient solution. The growth chamber was maintained at 30/20°C (day/night temperature), 80% relative humidity, and 12 h photoperiods. When the plants reached the pinhead square stage, they were divided into two sets, and half moved to another growth chamber, in which temperature was elevated every three days in 3°C increments from 30° to 42°C. The night temperature was maintained at 20°C. After three days at the elevated temperature, measurements were made of chlorophyll fluorescence, membrane leakage, leaf photosynthesis, and leaf extension growth in each of the two temperature regimes.

The second part of the study involved formulating a screening technique using the measurements determined above. Plants were grown at 30/20°C (day/night temperature) for two weeks (until the third fully expanded main-stem leaf), after which they were subjected to 45°C constant temperature for 6 hours. Chlorophyll fluorescence was measured at 0, 2, 4, and 6 h that the plants were at 45°C. After the 6-h period the temperature was dropped back to 30/20°C (day/night) normal temperature until the next day (24 h after) to let the plants recover, and chlorophyll fluorescence measured again. This provided a measure of how genotypes respond to high temperature and, perhaps more important, how they recover from a period of high temperature.

Screening Genotypes

A series of growth chamber studies were conducted using cotton plants grown in 0.5-L pots of Suregro potting media, watered daily as described above. The pots were arranged in a randomized complete block design with 6 replications. Representative cultivars from the Arkansas Cotton Variety tests were screened for temperature tolerance using the technique described above, i.e., after two weeks, the temperature was increased from 30°C to 45°C for 6 h, and chlorophyll fluorescence measured at 0, 2, 4, and 6 h, after which the temperature was lowered back to 30°C for 24 hours to let the plants recover, and chlorophyll fluorescence measured again.

RESULTS AND DISCUSSION

Screening Techniques

The first part of this study evaluated and quantified the effect of high day temperatures on cotton plant metabolism and physiological processes. The techniques that we used for measuring plant response to high temperature were chlorophyll fluorescence and membrane leakage (physiological measurements) and the activity of select antioxidant enzymes, total soluble proteins, polyamines, and the sugar alcohol, myoinositol. High temperatures had a strong negative effect on photosynthesis, chlorophyll fluorescence, membrane leakage, and leaf extension growth with significant decreases above 35°C (95°F) which would have effects on seed proteins and therefore yields (Bibi et al., 2008). Of all the techniques used to quantify cotton plant response to high temperature, fluorescence and membrane leakage were the most sensitive and practical techniques in both controlled and field conditions. However, fluorescence appeared to be more reliable, whereas membrane leakage showed somewhat more variability.

Screening Genotypes

To date, 134 entries from the Arkansas Variety Tests have been screened in this method. The data have been analyzed and plotted and are currently being evaluated to select the most promising lines showing temperature tolerance. An example of the response of genotypes to this high temperature screening technique is provided in Figure 1. In this example, only PHY370WR and DP515BGRR exhibited both tolerance to elevated temperature as well as an ability to recover from the high temperature without any subsequent detrimental effect. In general, the majority of the 134 lines tested to date did not show any appreciable tolerance to high temperatures. The tolerant lines selected from this study will be compared with the yields in field tests that experienced heat stress. In addition they will be grown in a glasshouse in large (10 x 10 x 2 ft) beds at high temperatures to determine their potential to grow in more field-like conditions under elevated temperatures.

A final comment: Cotton yields in the U.S. are well below the potential (Oosterhuis and Stewart, 2004) and suffer from unpredictability and year-to-year variability. This has been associated with high temperatures during the flowering and early boll development stages (Oosterhuis, 2002). In spite of best management efforts, the occurrence of untimely and severe weather can still adversely affect cotton growth and yield. Current research efforts are aimed at understanding what is happening during boll-filling, and devising methods to alleviate the problem, e.g. breeding for temperature tolerance. Improved understanding of the factors affecting boll development will allow us to formulate new strategies for more stable and consistently high yields.

PRACTICAL APPLICATION

This project has quantified the effects of high temperature on cotton growth and identified methods of evaluating the effects on high temperature stress on cotton. A

technique has been formulated to screen cotton genotypes for temperature tolerance. The technique is being used to screen entries from the Arkansas Cotton Variety Tests and advanced breeding lines for temperature tolerance. A few lines have been identified with appreciable temperature tolerance, but the majority of the entries have not shown any temperature tolerance and have been susceptible to high temperature stress. This is an on-going project to screen available cotton germplasm for high temperature tolerance, with the aim of improving the performance of cotton cultivars under conditions of high temperatures which are often experienced in the U.S. Cotton Belt.

ACKNOWLEDGMENTS

Support for this research was provided by Cotton Incorporated.

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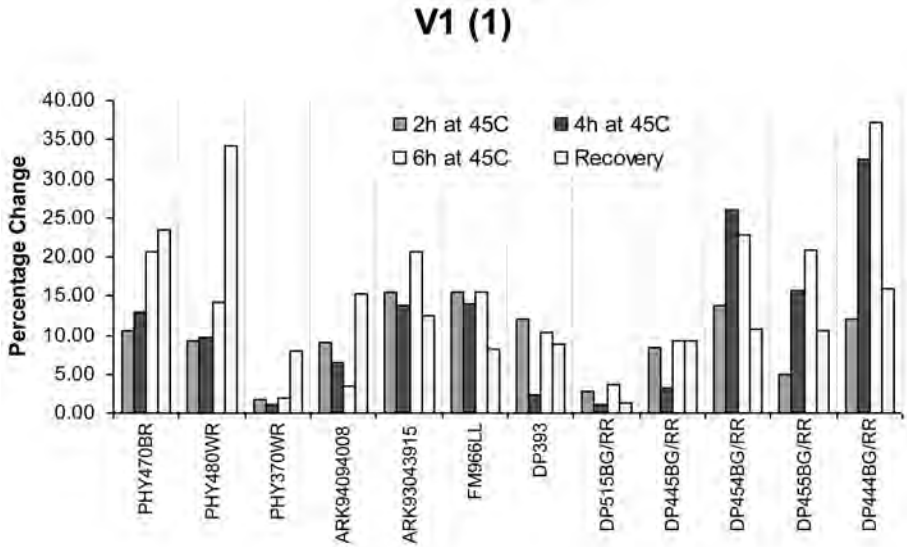


Fig. 1. Percentage change in chlorophyll fluorescence at 2, 4, and 6 hours at 45°C and 24 hours later (recovery 30/20°C) compared with the chlorophyll fluorescence measured before the temperature treatment for a selection of cotton cultivars.

Comparison of the Defoliants ADIOS and DROPP for Immediate Physiological Effect on Leaf Growth of Field-Grown Cotton

*Derrick M. Oosterhuis, Dimitra Loka, Diana Storch,
John L. Snider, and Eduardo Kawakami¹*

RESEARCH PROBLEM

Defoliants constitute an important management component of cotton production. However, defoliation is perhaps the most frustrating practice the grower must manage. The results are often very variable and there is always some uncertainty about the outcome of a defoliant application. There are several factors that influence the chemical defoliation process, including the condition (activity of the leaves) and density of the crop canopy, the weather at the time of application and shortly thereafter, and the defoliant and rate used. The objective of this study was to use current analytical technology to document the immediate biochemical effect of the defoliant Dropp, compared to a new defoliant Adios, on leaf growth of field-grown cotton.

BACKGROUND INFORMATION

Cotton is a perennial with an indeterminate growth habit. In addition, cotton has a complex flowering pattern with a three-eighths phyllotaxy which means that cotton matures over an extended period. Defoliants are therefore necessary, not only to remove vegetative material to facilitate mechanical harvesting but also to synchronize the opening of the bolls. There are a range of defoliants available on the market, but comparisons of their speed of action is not readily available. This study focused on assessing a technique to determine how rapidly a defoliant works, in order to evaluate a new defoliant (Adios, from Arysta Liefesciences).

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RESEARCH DESCRIPTION

A field study was planted on 20 May 2008 at the Arkansas Agricultural Research and Extension Center in Fayetteville, Ark. The cotton (*Gossypium hirsutum* L.) cultivar ST4554BRF was planted in Captina silt loam (Typic Fragiudult) using a randomized complete block design with 5 replications. The plot size was three rows 5 m in length. The plots were furrow irrigated as needed to maintain optimum moisture. The trial was fertilized according to recommended practices for cotton, and irrigation by furrow as needed. Treatments consisted of (1) an untreated control, (2) Adios @ 6.4 oz/acre (i.e., 2x the Dropp rate), and (3) Dropp @ 3.2 oz/acre. The defoliant was applied with a pressurized CO₂ backpack sprayer calibrated to deliver 20 gal/acre. Treatments were applied in August at the start of boll opening. Measurements were taken at 1, 4, and 8 days after application and consisted of leaf energy levels (ATP), chlorophyll fluorescence, and membrane leakage using standard published techniques.

RESULTS AND DISCUSSION

The trial was initiated with the application of the treatments just prior to any boll opening. An extremely wet, rainy period followed the treatment application, with rain nearly every day which made sampling difficult and prevented daily sampling as was intended. Measurement of leaf energy (ATP) levels showed an immediate leaf decrease, but no significant differences between the two defoliant treatments (Fig. 1). There was an indication of increased membrane leakage (cell damage and loss of membrane integrity) in Adios on day 4 compared to Dropp, but this difference was only significant on day 8 (Fig. 2). One day after treatment there was a significant decrease in quantum yield (chlorophyll fluorescence) by Adios compared to the untreated control and Dropp (Fig. 3). This indicated that Adios had a greater detrimental effect on photosynthesis (i.e., a lower quantum yield) than Dropp.

PRACTICAL APPLICATION

Measurement of these physiological parameters (ATP, membrane leakage, and chlorophyll fluorescence) proved to be a method of identifying the rapidity of action of a defoliant chemical. Adios appeared to act more rapidly than Dropp.

ACKNOWLEDGMENTS

Support for this research was provided by Arysta LifeSciences

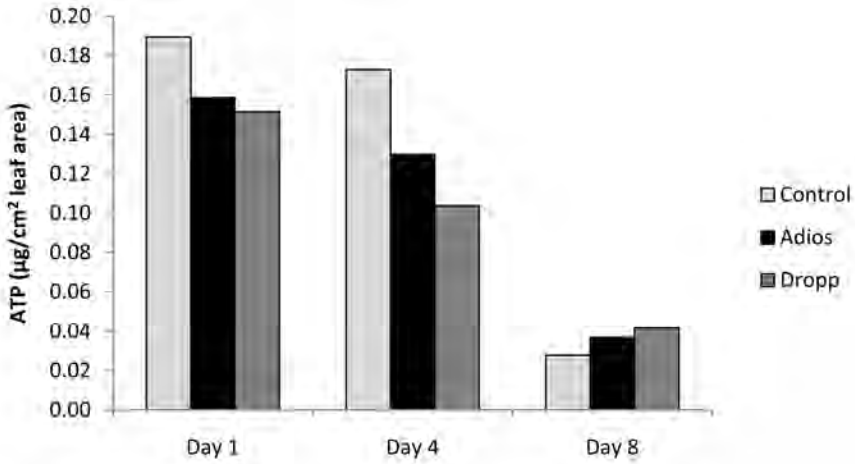


Fig. 1. Effect of defoliation treatments on leaf energy (ATP) levels with time in days (1, 4, and 8) after defoliant application. No significant differences ($P=0.05$).

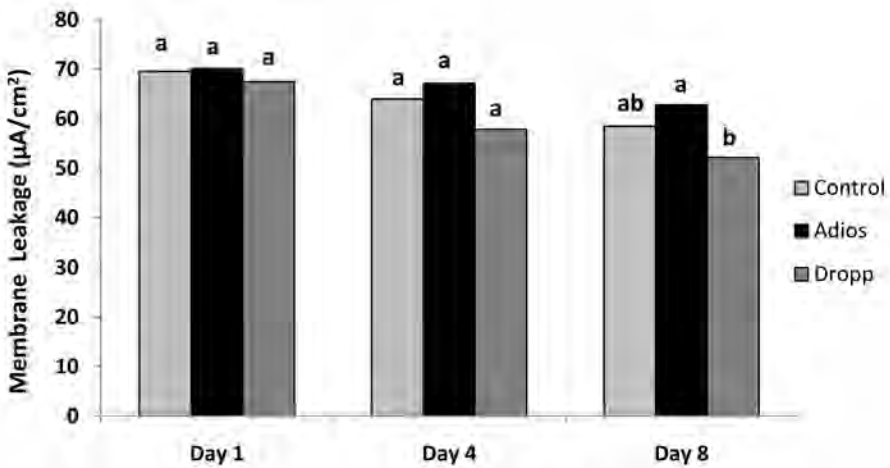


Fig. 2. Effect of defoliation treatments on cell integrity (membrane leakage) with time in days after application. Columns within a group with the same letter are not significantly different ($P=0.05$).

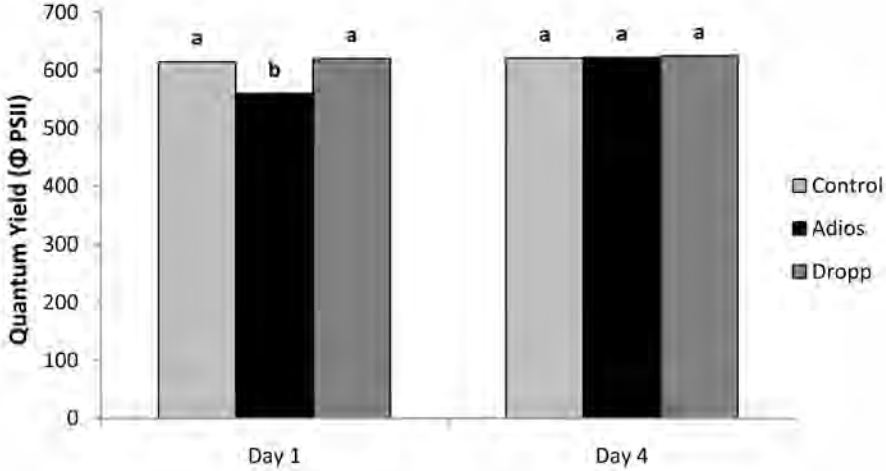


Fig. 3. Effect of defoliation treatments on chlorophyll fluorescence (indication of declining photosynthetic capability) with time in days after application. Columns within a group with the same letter are not significantly different (P=0.05).

The Effect of High Temperature on *In Vivo* Pollen Tube Growth, Calcium Levels, Antioxidant Response, and Superoxide Production in the Cotton Pistil

*John L. Snider, Derrick M. Oosterhuis,
Briggs W. Skulman, Eduardo M. Kawakami, and Diana K. Storch¹*

RESEARCH PROBLEM AND BACKGROUND INFORMATION

Heat stress experienced by cotton plants during a typical growing season in the U.S. is a major cause of disappointingly low yields, with a correlation existing between low yields and high temperature (Oosterhuis, 2002). Because successful pollen tube growth and fertilization of the ovule is a prerequisite for seed and fiber production in cotton, any factor that adversely affects pollen tube growth will adversely affect yield (Stewart, 1986). The optimal temperature for *in vitro* pollen tube growth is from 28 to 32°C (Burke et al., 2004; Kakani et al., 2005), for photosynthesis is 33°C (Bibi et al., 2008), and for successful boll development and fruit retention is 30°C (Reddy et al., 1991), whereas maximum day temperatures in the Mississippi River Delta during flowering often exceed 38°C.

Under stress, plants accumulate reactive oxygen species (ROS), which are capable of damaging nearly every organic component of a living cell (Iba, 2002; Agarwal et al., 2005). As a result, plants exposed to temperature stress respond with increased antioxidant enzyme activity (Gong et al., 1998). In contrast, NADPH oxidase (NOX) produces O₂⁻, which is needed to soften cell walls and promote cell expansion during normal plant developmental processes, including pollen tube growth (Potocky et al., 2007). Calcium enhances both antioxidant enzyme activity (Gong et al., 1998) and NOX activity and is essential for pollen tube growth (Potocky et al., 2007). Therefore, it is imperative to understand how heat stress affects calcium levels, ROS scavenging, and NOX activity in the pistil in relation to *in vivo* pollen tube growth.

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RESEARCH DESCRIPTION

Two experiments were conducted to evaluate the effects of heat stress on reproductive development in *G. hirsutum* L. Experiments were initiated in January and repeated in April 2008. The cotton (*Gossypium hirsutum* L.) cultivar ST4554 B2RF was planted in two-liter pots and placed in two walk-in growth chambers at the Altheimer Laboratory, Arkansas Agricultural Research and Extension Center, Fayetteville, Ark., under 30/20°C day/night temperature regimes. Plants were grown under a 12 h photoperiod and 500 $\mu\text{mol m}^{-2} \text{s}^{-1}$ photosynthetically active radiation (PAR) and were watered daily with half-strength Hoagland's solution. At approximately one week prior to flowering, plants were randomly transferred from one growth chamber to the other, and the day temperature in one of the growth chambers was gradually increased at a rate of 2°C/day until a 38/20°C day/night temperature regime had been reached.

White flowers were excised from the first sympodial position between nodes 5 and 10. Pistils used for pollen tube growth analysis were collected 24 h after anthesis and stored in FAA for future microscopic evaluation of pollen tube growth. All other pistils were collected at midday (1200 to 1300 h) and stored at -80°C for subsequent biochemical analysis or were dried at 47°C for 3 days for total calcium analysis. Pollen tubes were observed in ovules using UV microscopy, and pollen performance was expressed as the number of ovules in an ovary containing a clearly distinguishable pollen tube (fertilized ovules) divided by the total number of ovules in each ovary. The activities of glutathione reductase, superoxide dismutase, and NADPH oxidase were quantified spectrophotometrically, and the total and water soluble calcium contents of pistils were analyzed via inductively coupled plasma spectrophotometer.

RESULTS AND DISCUSSION

Under heat stress, the number of ovules per ovary (26.4 ± 0.93 ovules/ovary) was 20.3% lower than the control (33.2 ± 1.0 ovules/ovary; $P < 0.0001$; Fig. 1A). The number of fertilized ovules in *G. hirsutum* ovaries exposed to high day temperature (14.8 ± 1.5 fertilized ovules/ovary) was 46.4% lower than the control (27.6 ± 0.92 fertilized ovules/ovary; $P < 0.0001$; Fig. 1B). Pollen tube/ovule ratio was 32.9% lower in heat-stressed pistils compared with the control ($P < 0.0001$; Fig. 1C). Total calcium content of heat-stressed pistils was not significantly different than the calcium content of pistils grown under optimal growth temperature conditions ($P = 0.0571$; Fig. 2B). Water soluble calcium content increased substantially under high day temperature, with heat-stressed pistils having 48.2% higher concentrations of water soluble calcium than that of control plants ($P = 0.0082$; Fig. 2A). Superoxide dismutase (SOD) activity did not change in response to high day temperature ($P = 0.834$; Fig. 3A). However, GR-mediated reactive oxygen species (ROS) scavenging and NOX-mediated superoxide production showed contrasting responses to heat stress. Heat stress decreased NADPH oxidase (NOX) activity 18.9% relative to the optimal growth temperature ($P = 0.0034$; Fig. 3B), but increased GR activity 43.1% relative to the optimal growth temperature ($P < 0.0001$; Fig. 3C).

PRACTICAL APPLICATION

Moderate heat stress typical of that observed by cotton plants during peak bloom in the Mississippi River Delta was sufficient to cause major reductions in the number of fertilized ovules (potential seeds) in cotton ovaries. Decreased *in vivo* pollen tube growth was the major cause of low reproductive success, as evidenced by a greater decline in the pollen tube/ovule ratio than in the ovule/ovary ratio. Heat stress resulted in a two-fold increase in water soluble calcium content and no change in total calcium content. We propose that heat stress favors the transformation of bound forms of calcium in pistil cell walls to water soluble forms, possibly due to stress-induced cell wall degradation. High day temperature caused a substantial increase in GR activity, but did not change SOD activity, indicating GR activity may be a more sensitive indicator of moderate stress-induced changes in oxidative status than SOD. NOX activity decreased substantially in response to heat stress, likely contributing to decreased *in vivo* pollen tube growth because of the need for NOX-generated O₂⁻ to promote pollen tube elongation. We hypothesize that moderate heat stress causes a calcium-mediated increase in GR activity in the pistil, which interferes with pollen tube-localized NOX activity as the pollen tube extends through the stylar tissue. Utilization of plant growth regulators that decrease the magnitude of the antioxidant response to stress in reproductive tissues may be important in promoting greater seed set and improving yields under high temperature conditions.

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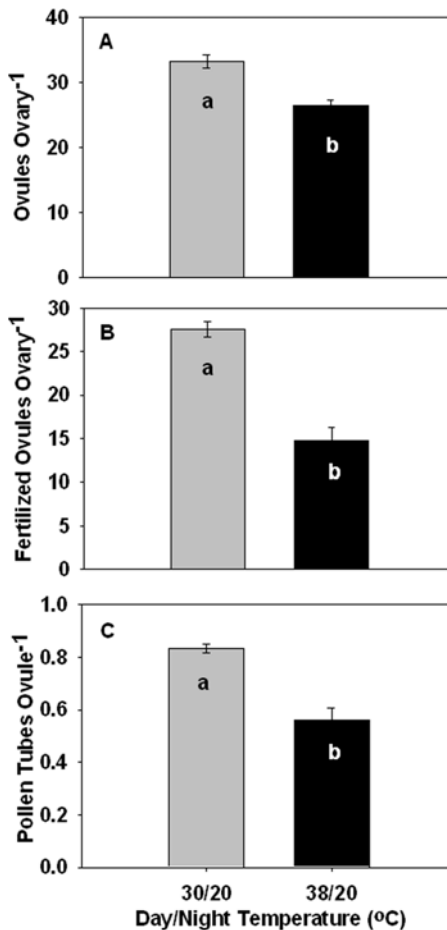


Fig. 1. The number of total ovules, fertilized ovules, and pollen tube/ovule ratio in *G. hirsutum* pistils under normal (30/20°C) and high (38/20°C) day temperature regimes. All values are means \pm standard error (n = 15), and values not sharing a common letter are significantly different (Student's t-test; P < 0.05).

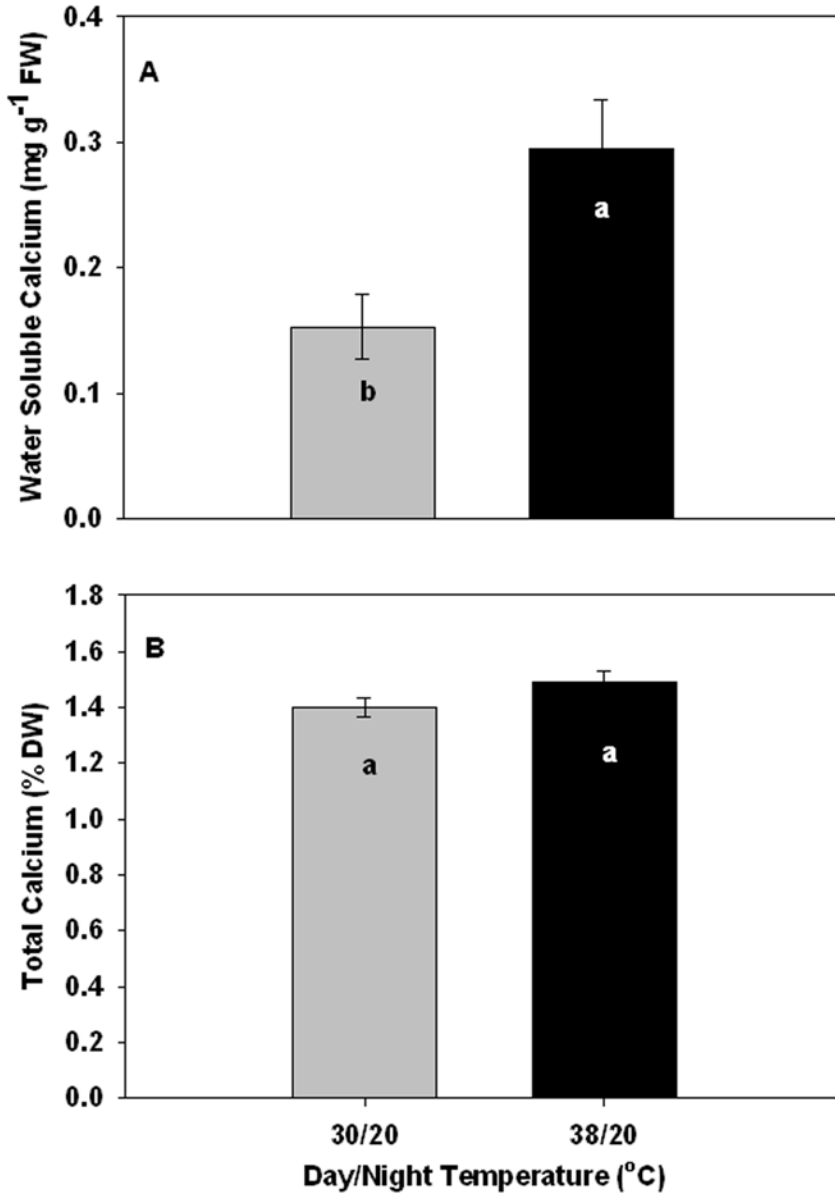


Fig. 2. Water soluble and total calcium responses to high day temperature in *G. hirsutum* pistils exposed to heat stress (38/20°C) and optimal (30/20°C) temperature conditions. All values are means \pm standard error ($n = 15$), and values not sharing a common letter are significantly different (Student's t-test; $P < 0.05$).

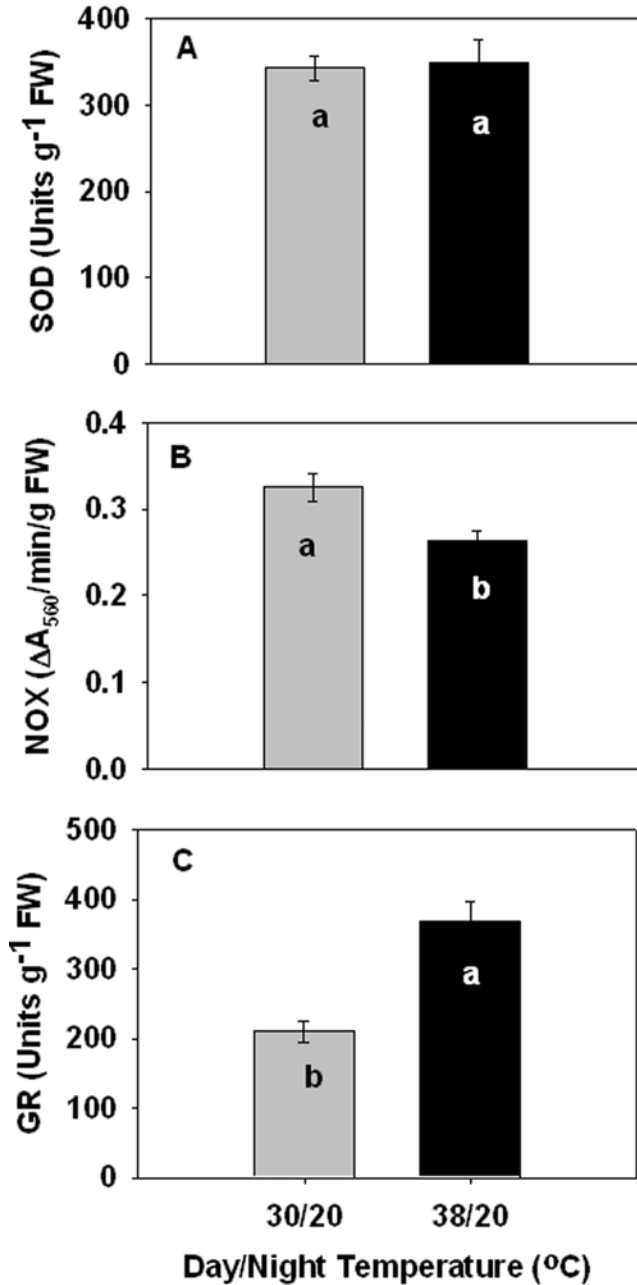


Fig. 3. High day temperature effects on superoxide dismutase (SOD) activity, glutathione reductase (GR) activity, and NADPH oxidase (NOX) activity. All values are means \pm standard error ($n = 15$), and values not sharing a common letter are significantly different (Student's t -test; $P < 0.05$).

Effect of High Temperature on Pollen Tube Growth and Energetics in the Cotton Pistil

John L. Snider, Derrick M. Oosterhuis,
Briggs W. Skulman, Eduardo M. Kawakami, and Diana K. Storch¹

RESEARCH PROBLEM AND BACKGROUND INFORMATION

Environmental stress during floral development is a major reason for the disparity between actual and potential yields in crops with valuable reproductive structures (Boyer, 1982). For Arkansas-grown cotton a correlation exists between high temperature and low yield (Oosterhuis, 2002). The day of anthesis is a critical event in reproductive development for *G. hirsutum*. The flower opens as a white flower at dawn; pollination occurs a few hours later, and fertilization of the ovule occurs 12 or more hours later, after successful pollen tube growth through the style has occurred (Stewart, 1986). Therefore, any abiotic stress that inhibits pollen tube growth from the stigma to the ovules on the day of anthesis will decrease reproductive success. Because actively growing pollen tubes have a high energy requirement relative to vegetative tissues (Tadege and Kuhlemeier, 1997), one major type of support provided by the pistil during active pollen tube growth through the style (in the absence of heat stress) is a readily-available supply of carbohydrates (Herrero and Arbeloa, 1989). In *G. hirsutum*, greater than 60% of the total carbohydrate requirement of developing reproductive tissue is provided by adjacent, subtending leaves (Ashley, 1972). Heat stress limits source leaf strength and carbohydrate allocation to developing sinks by decreasing photosynthesis (Bibi et al., 2008), increasing dark respiration (Cowling and Sage, 1998) and photorespiration (Jiao and Grodzinski, 1996), and inhibiting carbohydrate translocation (McNairn, 1972). The first objective of this study was to measure the effect of high day temperature on pollen tube growth, soluble carbohydrate content, and energy levels of the pistil on the day of anthesis; the second objective was to quantify the effect of heat stress on subtending leaf physiology.

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RESEARCH DESCRIPTION

Two consecutive experiments were conducted to evaluate the effects of heat stress on reproductive development and source leaf activity in *Gossypium hirsutum* L. Experiments were initiated in January and repeated in April 2008 using the cotton cultivar cv. ST4554 B2RF planted in two-liter pots and placed in two walk-in growth chambers (Model PGW 36; Controlled Environments Limited, Winnipeg, Canada) at the Altheimer Laboratory, Arkansas Agricultural Research and Extension Center, Fayetteville, Ark., under 30/20°C day/night temperature regimes. Plants were grown under a 12/12 hr photoperiod at a 500 $\mu\text{mol m}^{-2} \text{s}^{-1}$ photosynthetically active radiation (PAR) and were watered daily with half-strength Hoagland's solution.

At approximately one week prior to flowering, plants were randomly transferred from one growth chamber to the other, and the day temperature in one of the growth chambers was gradually increased at a rate of 2°C/day until a 38/20°C day night temperature regime had been reached. Only flowers and subtending leaves between main stem nodes 5 and 10 in the first fruiting position along a sympodial branch were analyzed. Because there was no significant effect of experiment date on any of the parameters measured, data were pooled from the two consecutive experiments. Pistils used for pollen tube growth analysis were collected 24 h after anthesis and stored in formalin-acetic acid-alcohol (FAA) for future microscopic evaluation. All other pistils were collected at midday (1200 to 1300 h) and stored at -80°C for subsequent ATP analysis or dried at 47°C for three days for soluble carbohydrate determination.

Pollen tubes were observed in ovules using UV microscopy, and pollen performance was expressed as the number of ovules in an ovary containing a clearly distinguishable pollen tube (fertilized ovules) divided by the total number of ovules in each ovary. Soluble carbohydrates were quantified at 340 nm using a microplate reader and glucose assay reagent after all soluble carbohydrates in the sample extract had been enzymatically converted to glucose. ATP content in pistils was quantified using a luminometer and the firefly luciferase assay, where light production by luciferase is directly proportional to the ATP content of the sample. Photosynthesis of subtending leaves was determined using an LI-6200 portable photosynthesis system. Chlorophyll content was estimated spectrophotometrically, and maximum quantum yield was quantified using a portable fluorometer.

RESULTS

Pollen tube growth declined significantly under high day temperature. For example, the pollen tube/ovule ratio was 32.9% lower under the 38/20°C day/night temperature regime than under the 30/20°C day/night temperature conditions ($P < 0.0001$; Fig. 1A). High day temperature resulted in significant declines in total soluble carbohydrate and ATP concentrations in cotton pistils. Heat stress resulted in a 20.3% decline in total soluble carbohydrate content (Fig. 1B), and ATP concentrations in pistils exposed to heat stress were approximately 55% lower than in pistils maintained at optimal temperature conditions throughout the sampling period ($P = 0.0003$; Fig. 1C).

High day temperatures resulted in a significant reduction in net photosynthesis of leaves. Net CO₂ fixation rates under high day temperature conditions (8.9 μmol CO₂ m⁻² s⁻¹) were approximately 16.8% lower than fixation rates (10.7 μmol CO₂ m⁻² s⁻¹) observed for subtending leaves grown under optimal day temperature conditions ($P < 0.0001$; Fig. 2A). Total chlorophyll content was also significantly reduced in subtending leaves exposed to heat stress, where heat stressed leaves exhibited a 11.3% reduction in total chlorophyll content relative to the control ($P < 0.0001$; Fig. 2B). Significant declines ($P < 0.0001$) in maximum quantum yield (3.83%; Fig. 2C) were observed for leaves exposed to high day temperature relative to optimal day temperature conditions.

DISCUSSION AND PRACTICAL APPLICATION

Decreased *in vivo* pollen tube growth was a major cause of low reproductive success, as evidenced by the decline in the pollen tube/ovule ratio (Fig. 1A). Lower carbon fixation rates by heat-stressed subtending leaves (Fig. 2) decreased source strength and reduced soluble carbohydrate allocation to developing flowers as evidenced by lower soluble carbohydrate contents in heat stressed pistils relative to pistils exposed to optimal day temperatures (Fig. 1B). Because pollen tube growth declined concomitantly with carbohydrate and ATP content in cotton pistils (Figs. 1A-C), we conclude that the energy requirements of growing pollen tubes cannot be sufficiently met under heat stress. Our conclusions are substantiated by the fact that *Arabidopsis* mutants exhibiting thermostable photosynthesis also yield a much higher number of seed under heat stress than thermosensitive variants (Kurek et al., 2007). These findings suggest that selection of cultivars with greater thermotolerance of the photosynthetic apparatus might be an important method for decreasing heat stress-induced year to year variability in yield.

ACKNOWLEDGMENTS

Support for this research was provided by Cotton Incorporated.

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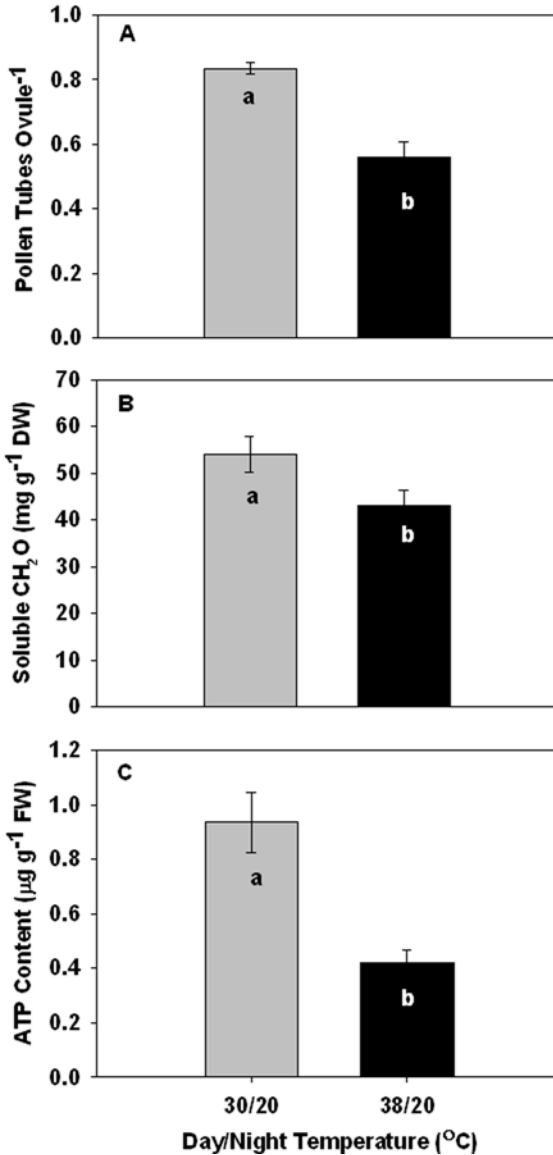


Fig. 1. Pollen tube/ovule ratio, soluble carbohydrate, and ATP contents of *G. hirsutum* pistils exposed to high (38/20°C) day temperatures. All values are means \pm standard error ($n = 15$), and values sharing a common letter are significantly different (Student's *t*-test; $P < 0.05$).

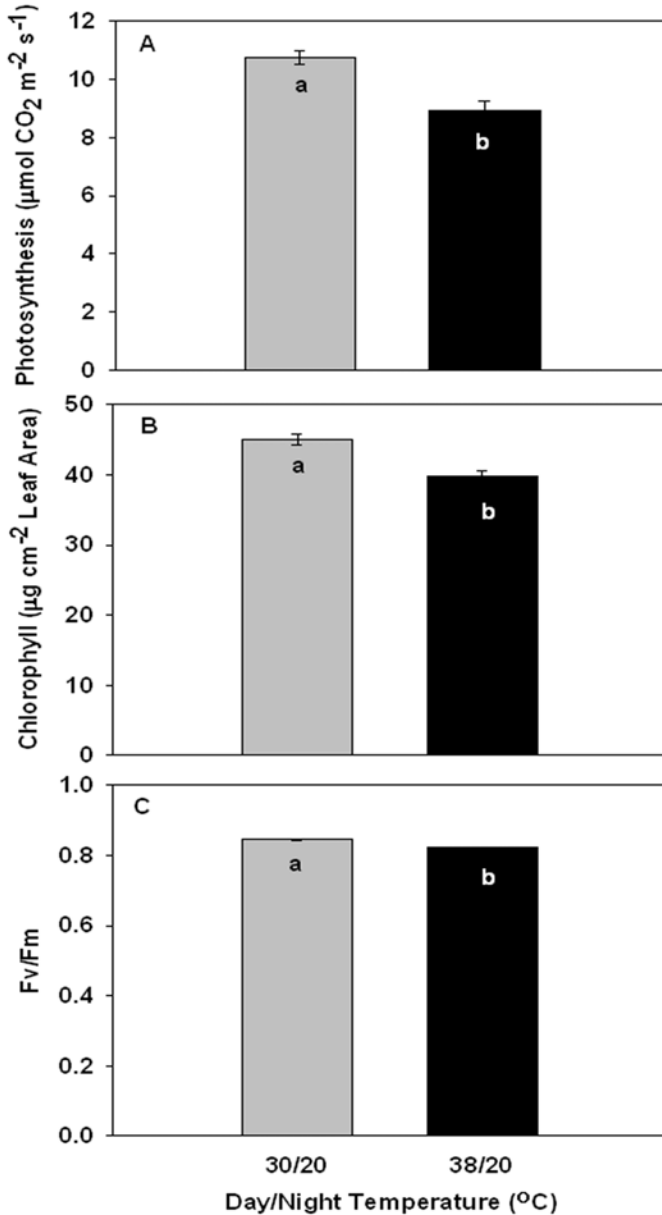


Fig. 2. Photosynthesis, chlorophyll content, and quantum yield of *G. hirsutum* leaves under normal (30/20 $^{\circ}\text{C}$) and high (38/20 $^{\circ}\text{C}$) day temperature regimes. All values are means \pm standard error (n = 42), and values sharing a common letter are significantly different (Student's t-test; P < 0.05).

Effect of 1-Methylcyclopropene on Growth and Biochemistry of Heat-Stressed Cotton Grown in a Controlled Environment

Diana K. Storch and Derrick M. Oosterhuis¹

RESEARCH PROBLEM

Although cotton is often touted as a heat-loving plant, periods of hot weather that coincide with the reproductive phase of development may cause crop stress. Heat stress in cotton manifests as excessive boll shedding (Reddy et al., 1992), decreased photosynthesis (Bibi et al., 2008), decreased yield, and decreased fiber quality (Rahman et al., 2007). Climatic records show a small but steady upward slope in overall Arkansas August temperatures on top of extreme year-to-year variability. The synthetic plant growth regulator, 1-methylcyclopropene (1-MCP), may be useful in ameliorating temperature stress to improve cotton yields.

BACKGROUND INFORMATION

1-MCP is a competitive inhibitor of the plant senescence hormone, ethylene (Sisler and Serek, 1999). In post-harvest scenarios it has been successfully used to prevent fruit ripening. 1-MCP has been shown to prevent fruit shedding in cherry tomatoes (Beno-Moualem et al., 2004). Our group has shown that 1-MCP application results in a numerical yield increase in field-grown cotton (Kawakami et al., 2006), and that 1-MCP is able to ameliorate oxidative stress in cotton plants grown in the growth chamber (Kawakami et al., 2006).

RESEARCH DESCRIPTION

The dual growth chamber study was conducted at the University of Arkansas Altheimer Laboratory in Fayetteville, Ark. The cotton (*Gossypium hirsutum* L.) cultivar STBR4554F was planted in 2-liter pots of Sunshine Mix potting soil and watered daily

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with half-strength Hoagland's nutrient solution. The growth chambers were set for 12 hour photoperiods, a temperature regime of 30/20°C (day/night), and relative humidity of $\pm 60\%$. Treatments consisted of: (T1) Untreated control; (T2) 1-MCP at 10g ai/ha applied at first flower (FF); (T3) A heat-stress of 38/20°C day/night temperature applied one week prior to FF; and (T4) Heat-stress begun 1 week prior to FF plus 1-MCP at 10 g ai/ha applied at FF. All 1-MCP treatments were sprayed with a backpack CO₂ sprayer calibrated to deliver 187 L/ha. The adjuvant AF-400 was added to the spraying solution at a rate of 0.375% v/v.

ATP extraction and protein extraction for antioxidant and malondialdehyde (MDA) content were performed on ovaries harvested during the four-day period after 1-MCP application. Growth analysis was conducted at the nine-week termination point of the experiment, 18 days after 1-MCP application.

RESULTS AND DISCUSSION

In this study 1-MCP had a significant effect on plant height (Fig. 1), indicating some curative effect on heat-stressed cotton plants. In addition, 1-MCP application corresponded to numerical increases in superoxide dismutase activity and NADPH oxidase activity in both normal and heat-stressed cotton plants (Table 1). NADPH oxidase and superoxide dismutase are both important enzymes involved in cell growth and expansion. Glutathione reductase activity and malondialdehyde concentration did not follow the expected trend (Table 1), therefore further study will be used as a check. It was found that 1-MCP led to a small numerical increase in both leaf area (Fig. 2) and above ground dry matter (Fig. 3) in both normal and high temperature environments. These findings indicate the growth-promoting potential of 1-MCP.

PRACTICAL APPLICATION

In conclusion, 1-MCP was shown to have an effect on the growth and biochemistry of heat-stressed cotton grown in controlled environments. However, extrapolation of these findings to field conditions is needed. This information is potentially useful for future living and farming in controlled environments such as environmentally controlled urban farms (Web Japan, 2005). One might suppose that in an actual greenhouse, application of 1-MCP might be useful to counteract the ill effects of plants due to buildup of heat and ethylene.

ACKNOWLEDGMENTS

Support for this research was provided by AgroFresh.

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Table 1. Effect of high temperature and 1-MCP on antioxidant and malondialdehyde levels in cotton ovaries within four days of 1-MCP application/FF.

Treatment	Glutathione reductase	Superoxide dismutase	NADPH oxidase	Malondialdehyde
	------(units/gFW)-----			(nmol/gFW)
T1	11.91 a ^z	53.50 a	0.00613 b	0.7161 a
T2	26.22 a	144.71 a	0.00720 b	0.6922 a
T3	31.67 a	92.82 a	0.01201 ab	0.9492 a
T4	30.24 a	118.17 a	0.01418 a	1.0656 a
LSD (0.05)	NS	NS	0.0084	NS

^z Numbers in a column followed by the same letter are not significantly different (P=0.05).

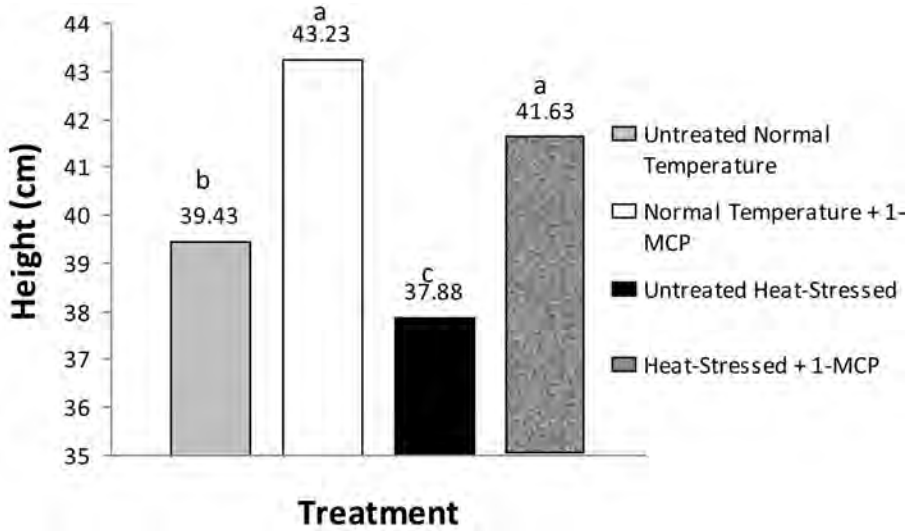


Fig. 1. Effect of high temperature and 1-MCP on plant height of nine-week-old cotton plants grown in a controlled environment. Columns with the same letter are not significantly different ($P=0.05$).

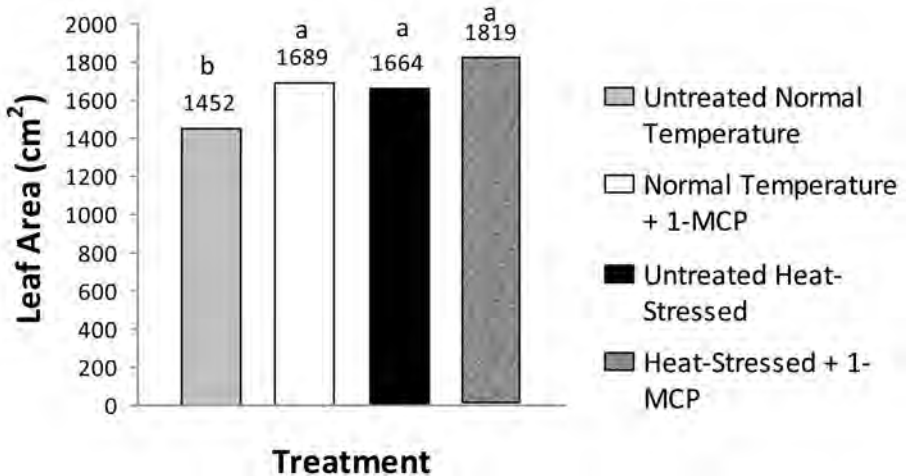


Fig. 2. Effect of high temperature and 1-MCP on leaf area of nine-week-old cotton plants grown in a controlled environment. Columns with the same letter are not significantly different ($P=0.05$).

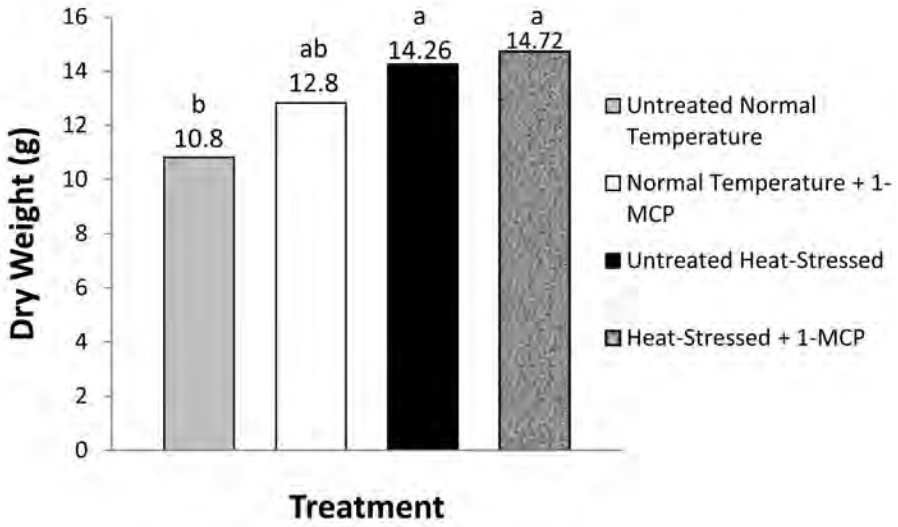


Fig. 3. Effect of high temperature and 1-MCP on above ground dry matter of nine-week-old cotton plants grown in a controlled environment. Columns with the same letter are not significantly different ($P=0.05$).

Effect of 1-Methylcyclopropene on the Biochemistry and Yield of Field-Grown Cotton

Diana K. Storch, Derrick M. Oosterhuis, and Eduardo M. Kawakami¹

RESEARCH PROBLEM

One of the major concerns of cotton farmers and the cotton industry is extreme year-to-year variability in yield (Lewis et al., 2000). Variability in cotton yield is mainly associated with environmental stress, of which temperature and drought appear to play a major role. When plants are stressed they produce ethylene, which normally acts as an endogenous senescence phytohormone. Ethylene is also well known for its role in the regulation of the fruit abscission process in cotton (Guinn, 1982). The current project was designed to evaluate the possible use of 1-methylcyclopropene (1-MCP) to alleviate the adverse effect of environmental stresses on square and boll set, and thereby reduce year-to-year variability and allow the cotton crop to yield closer to its potential.

BACKGROUND INFORMATION

Among all stress factors, temperature and drought appear to play the most significant roles in decreasing crop yields in the world. Plants under stress exhibit low photosynthesis levels and changes in the carbon source-sink relationships, which result in decreased dry matter production (Geiger and Servaites, 1991). A common response of plants under stress is increased ethylene synthesis (Abeles et al., 1992). Ethylene is an endogenous phytohormone associated with senescence, abscission, and the pollination processes (Abeles et al., 1992). In cotton, ethylene is well known for its role in the regulation of the abscission process in fruit (Guinn, 1982), which is initiated by the formation of the abscission layer that results in fruit shed (Lipe and Morgan, 1973).

1-MCP is an inhibitor of ethylene action that has been widely used to improve shelf life and quality of agricultural products. This product has also been used by scientists to make advances in understanding the role of ethylene in plants. At room temperature and pressure, the 1-MCP molecule is a gas with a weight of 54 g and a formula of C_4H_6 . 1-Methylcyclopropene has been shown to occupy the ethylene receptors such that eth-

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ylene cannot bind and initiate action (Sisler and Serek, 1999). The affinity of 1-MCP for the receptors is approximately 10 times greater than that of ethylene. In addition, compared with ethylene, 1-MCP is active at much lower concentrations. Also 1-MCP was reported in some species to decrease ethylene biosynthesis through feedback inhibition (Blankenship and Dole, 2003).

The objective of this study was to determine the effect of the anti-ethylene action compound 1-methylcyclopropene (1-MCP) on the physiology and yield of cotton grown in field conditions. In 2006 and 2007 1-MCP showed an ability to increase seedcotton yield (Kawakami et al., 2006, 2007). We hoped to confirm those findings with another season's worth of data.

RESEARCH DESCRIPTION

2008 was the third year that this experiment was conducted. The field study was conducted at the University of Arkansas Division of Agriculture's Lon Mann Cotton Research Station in Marianna, Ark., and also at the Arkansas Agricultural Research and Extension Center in Fayetteville. Both experiments were planted in mid-May using the cotton (*Gossypium hirsutum* L.) cultivar DP444BG/RR. Fertilization was according to pre-season soil tests and recommended rates. Weed and insect control were performed according to state recommendations. The plot size was 4 rows by 7 or 15 m (Fayetteville or Marianna, respectively), with a row spacing of 0.96 m and plant density of 10 plants/m. The experiment was arranged in a randomized complete block design with six replications. Treatments consisted of: (T1) Untreated control, (T2) 1-MCP at 10 g ai/ha at first flower (FF), (T3) 1-MCP at 10 g ai/ha at FF and FF + 2 weeks, and (T4) 1-MCP at 10 g ai/ha at FF and every four days for about two weeks. All 1-MCP treatments were sprayed with a backpack CO₂ sprayer calibrated to deliver 187 L/ha. The adjuvant AF-400 was added to the spraying solution at a rate of 0.375% v/v.

The yield parameters, number of bolls, boll weight, seedcotton yield, and lint yield were calculated from a one-meter length row of hand-picked cotton for each plot. Fiber samples were sent to the Louisiana State University fiber laboratory for HUI quality analysis. Developing first position cotton bolls were collected from node 6 from each plot for each week of the experiment. ATP extraction and protein extraction for antioxidant and malondialdehyde (MDA) content was performed on developing seeds, fibers, and capsule wall from the harvested bolls.

RESULTS AND DISCUSSION

In this study 1-MCP treatment had a significant effect on fiber elongation in the Fayetteville field (Fig. 1). This demonstrated that 1-MCP application may improve fiber quality. There was no significant effect of 1-MCP treatment on seedcotton production or other components of yield (Table 1). In general T3 showed a numerically higher yield, and in Fayetteville, T4 showed the highest numerical seedcotton and lint yields (Table 1). T4 also showed a numerically higher level of NADPH oxidase (NOX) activity (Table 2). However there were no significant differences between the 1-MCP treatments and the control in Tables 1 and 2.

PRACTICAL APPLICATION

In conclusion, 1-MCP did not have a significant effect on the yield or antioxidant content of field-grown cotton. However, 1-MCP proved to have a positive effect on the quality of cotton fiber. Future research will further elucidate the mechanism and best method of utilize the potential of 1-MCP to positively impact yields. More frequent applications of the product during the flowering period are being considered.

ACKNOWLEDGMENTS

Support for this research was provided by AgroFresh.

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Table 1. Effect of 1-MCP on seedcotton yield, lint yield, seeds per hectare, boll number, and boll weight in Marianna (Mar) and Fayetteville (Fay), Arkansas.

Treatment	Seedcotton		Lint		Seeds		Bolls		Boll weight	
	Mar	Fay	Mar	Fay	Mar	Fay	Mar	Fay	Mar	Fay
	(kg/ha)		(no/ha)		(g)					
T1	2856 ab ^z	3996 a	1251 a	1650 a	1588 a	2341 a	779,514 a	1,068,750 a	3.69 a	4.16 a
T2	3248 a	3280 a	1336 a	1344 a	1714 a	1918 a	772,569 a	1,013,020 a	4.32 a	3.85 a
T3	2810 b	3649 a	1223 a	1508 a	1566 a	2347 a	746,528 a	1,088,541 a	3.76 a	3.78 a
T4	^y	4041 a	1658 a	1658 a	2252 a	2252 a	1,148,437 a		3.98 a	
LSD (0.05)	0.0476	NS ^x	NS	NS	NS	NS	NS	NS	NS	NS

^z Numbers in columns followed by the same letter are not significantly different at the $\alpha = 0.05$ level.

^y Treatment not included at this location.

^x NS = not significant (P=0.05).

Table 2. Effect of 1-MCP on in Marianna (Mar) and Fayetteville (Fay), Arkansas.

Treatment	Glutathione reductase		Superoxide dismutase		NADPH oxidase		Malondialdehyde	
	Mar	Fay	Mar	Fay	Mar	Fay	Mar	Fay
	(units/gFW)		(units/gFW)				(nmol/gFW)	
T1	31.9 a ^z	23.87 a	167.58 b	179.40 a	0.0013 a	0.0014 a	9.70 a	8.45 a
T2	24.47 a	34.64 a	294.72 a	276.90 a	0.0012 a	0.0008 a	11.74 a	8.72 a
T3	33.19 a	29.54 a	251.45 ab	316.77 a	0.0014 a	0.0010 a	9.96 a	9.98 a
T4	^y	18.56 a	200.11 a	200.11 a	0.0015 a	0.0015 a	9.54 a	
LSD (0.05)	NS ^x	NS	0.0473	NS	NS	NS	NS	NS

^z Numbers in columns followed by the same letter are not significantly different at the $\alpha = 0.05$ level.

^y Treatment not included at this location.

^x NS = not significant (P=0.05).

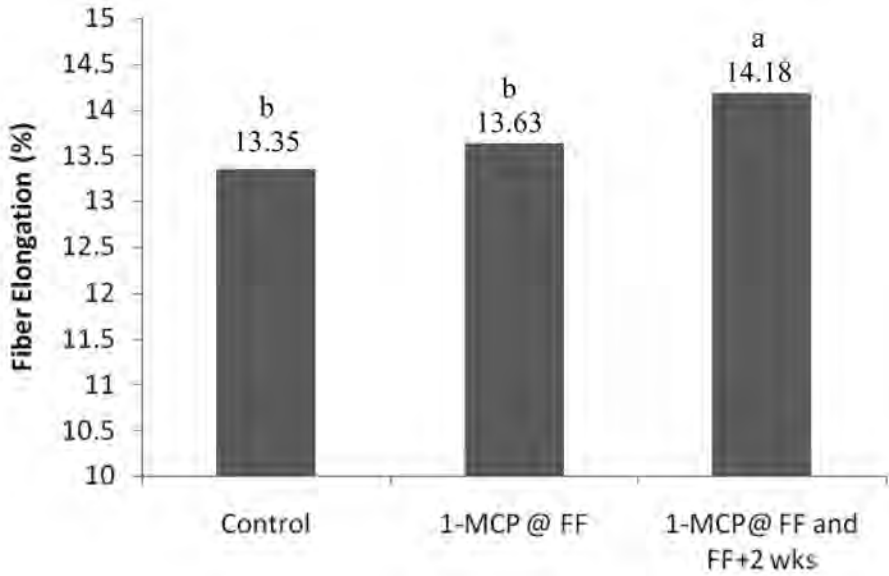


Fig. 1. Effect of 1-MCP treatment on fiber elongation in Fayetteville, Ark. Columns with the same letter are not significantly different at the $\alpha = 0.05$ level.

Effects of Urea with NBPT and DCD on the Yield of Field-Grown Cotton

Eduardo M. Kawakami, Derrick M. Oosterhuis, and John L. Snider¹

RESEARCH PROBLEM

Nitrogen (N) fertilization is one the most expensive agricultural practices and crops are known to recover only 30 to 35% of the N fertilizer applied (Constable and Rochester, 1988; Daberkow et al., 2000). Recently, attention has been focused on studies to measure and maximize plant N use efficiency. A practice commonly recommended to improve N fertilizer use efficiency is the addition of urease and/or nitrification inhibitors into N fertilizers. Urease inhibitors delay hydrolyzes of urea fertilizer and thereby diminish ammonia volatilization losses, and nitrification inhibitors hinder the conversion of ammonium to nitrate lowering N loss by leaching. Numerous studies have been done with urease and nitrification inhibitors in different crops; however, there has been limited work done with cotton, particularly on the effects on plant growth parameters and N assimilation physiology.

BACKGROUND INFORMATION

Urea fertilization is known to be susceptible to NH_3 volatilization losses and depending on fertilizer practices, soil type, and environmental conditions this loss can reach values of 50% of the total N applied (Harisson and Webb, 2001; Cai et al., 2002). One approach for reducing potential losses of N in urea fertilization is to reduce urea hydrolyzes by inhibiting urease activity. Urease is an enzyme that catalyzes the hydrolysis of urea into carbon dioxide and ammonia. Inhibiting urease, the urea fertilizer could percolate or be incorporated into the soil before hydrolysis to NH_3 and be retained in the soil colloids thereby reducing losses of gaseous N. A well known urease inhibitor is NBPT [N-(n-butyl) thiophosphoric triamide]. The main advantage of NBPT is the high efficiency in inhibiting urease at low concentration in a wide variety of soils (Vittori et al., 1996; Rawluk et al., 2001).

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Utilization of nitrification inhibitors has the objective of reduce nitrate leaching losses by retaining the applied N in the ammoniacal form, which is retained in the Cation Exchange Capacity of the soil (Reidar and Michaud, 1980). Dicyandiamide (DCD) is a well known nitrification inhibitor studied in a wide range of crops. The DCD inhibits *nitrosomonas* bacteria stopping the oxidation of NH_4^+ to NO_2^- (Ambergern, 1989). Inhibition of *nitrosomonas* is mediated by the reaction of the C-N group of DCD with sulfhydryl or heavy metal groups of the bacteria's respiratory enzymes (Ambergern, 1989). The objective of this research was to evaluate the effect of sidedress application of urea with NBPT and DCD at the pinhead-square stage of cotton, on the yield parameters: boll size, boll number, seedcotton yield, and lint yield.

RESEARCH DESCRIPTION

The field study was conducted in 2008 at the University of Arkansas Division of Agriculture's Lon Mann Cotton Research Station at Marianna, Ark., in a Captina silt loam (Typic fragidult) soil. The cotton (*Gossypium hirsutum* L.) cultivar ST4554B2RF was planted on 22 May and harvested on 15 October. The experiment was uniformly fertilized following pre-season soil tests and state recommended rates, except for N, which was applied according to the treatments. Weed and insect control was performed according to state recommendations. Mepiquat chloride was applied as needed to control vegetative growth. At the pre-plant stage all plots received 45 kg N/ha provide by urea and at the pinhead-square N application was according to the following the treatments: (T1) unfertilized control; (T2) urea fertilization, (T3) urea with NBPT fertilization, (T4) urea with NBPT and DCD fertilization. The fertilizer treatments were side-dressed with 30 kg N/ha. The plot size was 4 rows by 50 ft and a randomized complete block design with 5 replications was used to conduct the experiment. Statistical analysis was conducted using JMP software and treatments differences were detected using LSD ($\alpha = 0.05$) with probability lower than 0.1.

The yield parameters, boll size, boll number, seedcotton yield, and lint yield were calculated from a one meter length of row, hand-picked cotton.

RESULTS AND DISCUSSION

The results showed significant differences on seedcotton yield ($P=0.065$) and fiber yield ($P=0.064$), but no statistical differences were observed in the measurements of boll size ($P=0.57$) and boll number ($P=0.42$). Seedcotton yield data showed that the treatment 4 exhibited the highest yield significantly different than treatment 1 ($P=0.02$) and treatment 3 ($P=0.03$) but not different from treatment 2 ($P=0.23$) (Fig. 1). In addition no statistical differences were observed among the treatments 1, 2, and 3 (Fig. 1). The data of fiber yield was similar to the seedcotton yield, with superior fiber yield of treatment 4 compared to treatments 1 ($P=0.03$) and 3 ($P=0.02$); and no differences were detected between treatments 1, 2, and 3 (Fig. 2).

Numerical analysis of boll number measurements showed that treatment 4 had a higher number of bolls than treatments 1, 2, and 3 (Fig. 3), and that treatment 2 was

superior than treatments 1 and 3 (Fig. 3). Moreover the boll size data indicated that all treatments that received N application (T2, T3, and T4) exhibited a numerical increase in boll weight compare with the unfertilized control (T1) (Fig. 4).

Application of urea with NBPT + DCD (T4) was not significantly different than urea alone (T2) on yield production, however a numerical increase of 145 kg/ha of fiber was observed when urea with NBPT + DCD was applied. This result was obtained by a combination of a numerical gain in the number of bolls and boll weight with use of NBPT + DCD. The application of urea with NBPT (T3) did not show a positive effect on yield compared to urea alone (T2). In addition the statistical difference between T4 and T3 indicated that utilization of DCD has a greater potential to increase cotton yield than using NBPT.

PRACTICAL APPLICATION

In conclusion, the N fertilization of urea with NBPT and DCD did not show a statistical difference compared to urea alone. However, the application of urea with NBPT + DCD had a numerically positive effect on seedcotton and fiber yields. Additional research is needed to test the effect of NBPT and DCD on cotton yields.

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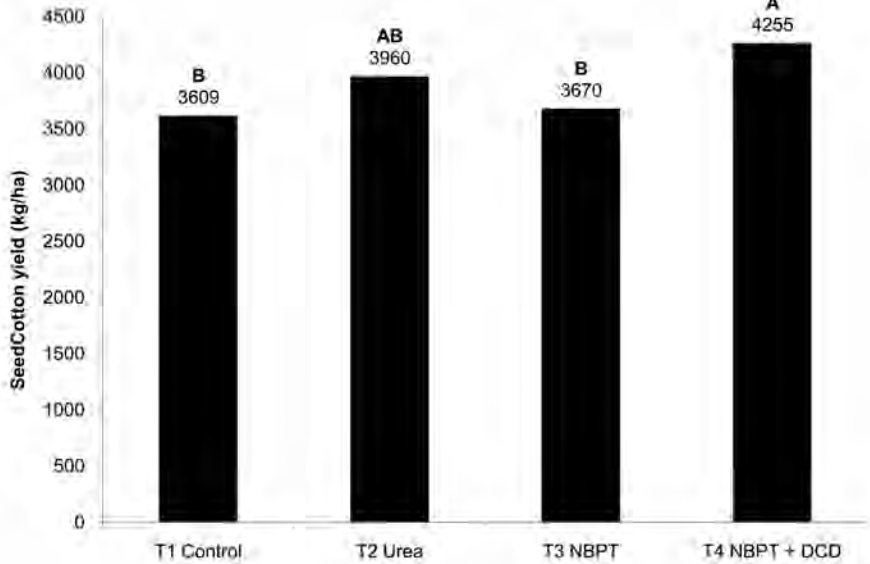


Fig. 1. Effect of urea with and without NBPT and DCD on seedcotton yield. Columns with the same letter are no significantly different ($P < 0.1$).

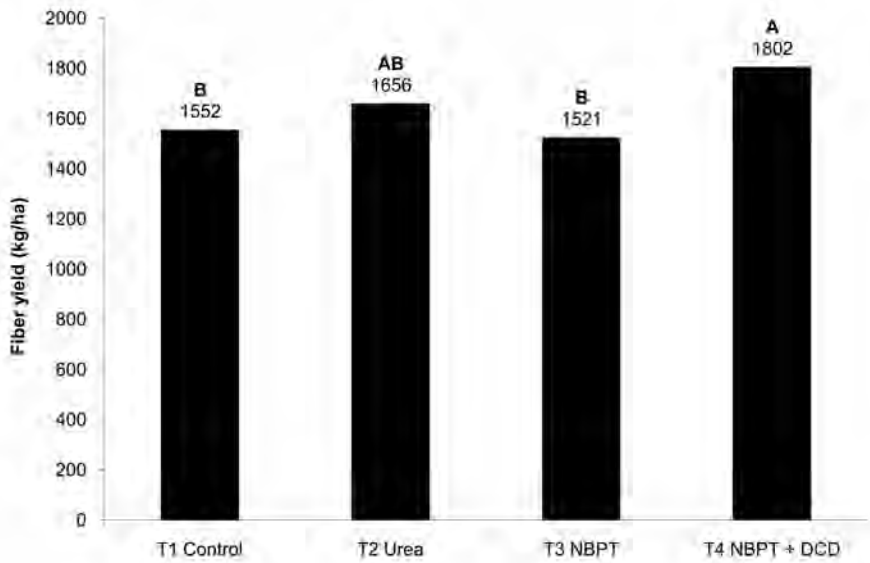


Fig. 2. Effect of urea with and without NBPT and DCD on cotton fiber yield. Columns with the same letter are no significantly different ($P < 0.1$).

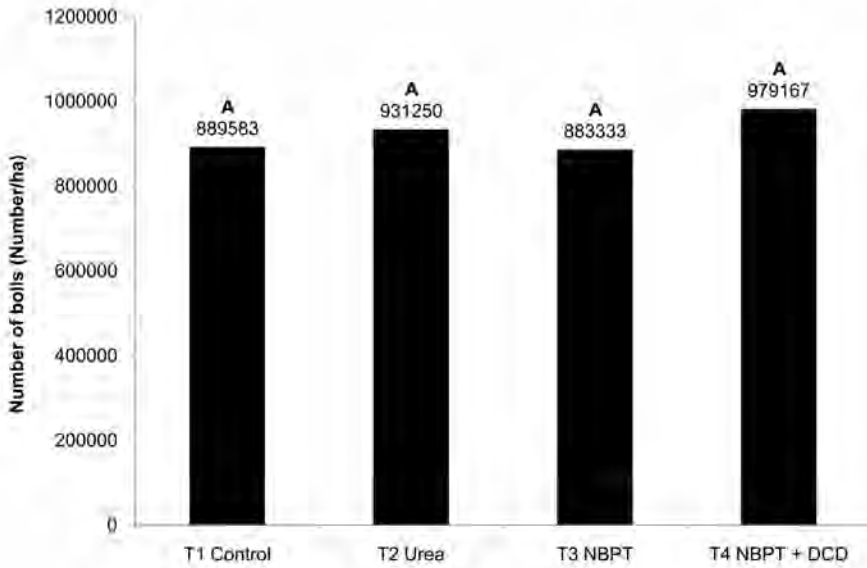


Fig. 3. Effect of urea with and without NBPT and DCD on number of cotton bolls. Columns with the same letter are no significantly different ($P < 0.1$).

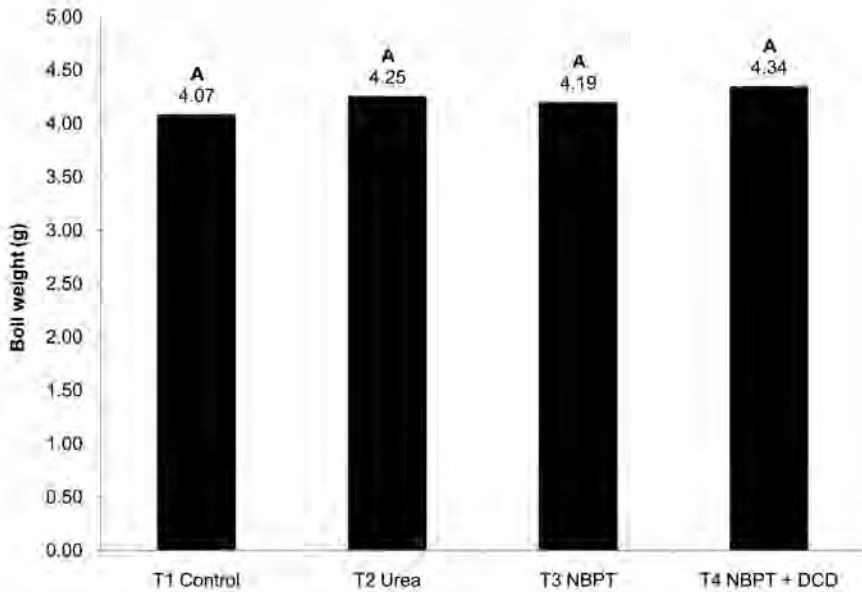


Fig. 4. Effect of urea with and without NBPT and DCD on number of cotton bolls. Columns with the same letter are no significantly different ($P < 0.1$).

Effect of Organic and Inorganic Source and Rates of Nitrogen on Seedcotton Yield at Two Locations

Morteza Mozaffari, Nathan A. Slaton, Larry A. Fowler, and Fred M. Bourland¹

BACKGROUND INFORMATION

Nitrogen (N) is the nutrient that most often limits cotton (*Gossypium hirsutum* L.) yield in Arkansas. In recent years, record high synthetic fertilizer prices coupled with desire for improving soil quality have rekindled interest in using various organic by-products as alternative fertilizer sources. Fresh poultry litter (FPL), pelleted poultry litter (PPL), and heat-dried, pelleted biosolids (marketed under the trade name Top Choice Organic or TCO)² are now available to Arkansas producers. Unfortunately, there is very little information on crop and soil response to TCO, FPL, or PPL under the production systems common to eastern Arkansas.

RESEARCH PROBLEM

The specific objective of this project was to evaluate cotton yield response to FPL, PPL, TCO, and urea-N fertilizer on two Arkansas Soils.

RESEARCH DESCRIPTION

Replicated field experiments were conducted at two locations. The experimental sites included a Sharkey clay at the University of Arkansas Division of Agriculture's Northeast Research and Extension Center in Mississippi County (MSG82) and a Dundee silt loam at the Judd Hill Plantation Cooperative Research Farm in Poinsett County (POG82). Prior to application of any soil amendment a composite soil sample (8 to 10 cores) was collected from the 0- to 6-in. depth of each replication. Selected soil chemi-

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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.

cal and physical properties were measured by standard methods used at the Division of Agriculture Soil Testing and Research Laboratory in Marianna and are listed in Table 1. The research areas were fertilized with KCl (0-0-60) and triple superphosphate (0-46-0) to supply 120 lb K_2O and 46 lb P_2O_5 /acre, respectively.

Each study was arranged as a randomized complete block design with a factorial arrangement of four N-fertilizer sources (FPL, PPL, TCO, and urea) and five N rates plus a no-N control. Each treatment was replicated five times. Each N source was applied at 30, 60, 90, 120, and 150 lb total N/acre (Table 2). Sub-samples of each organic-N source were analyzed by the University of Arkansas Agricultural Diagnostic Laboratory and each organic N source was applied based on the total N analysis listed in Table 3.

Nitrogen treatments were hand applied onto the soil surface and incorporated with a Do-All before planting. Cotton (*Gossypium hirsutum* L.) cultivar Stoneville 4554B2RF was planted on 7 and 21 May at the two sites. Conventional tillage and pest management practices were followed. The center two rows of cotton in each plot were harvested with a spindle-type picker. Analysis of variance (ANOVA) was performed using the GLM procedure of SAS. Sites were analyzed separately.

RESULTS AND DISCUSSION

Properties of Soil Amendments and Soil

Total N content of organic N sources, on as-is basis, ranged from 2.36% for FPL to 6.28% for TCO and organic N was the predominant form of N (Table 3). Top Choice Organic biosolid had the highest total P and C contents and the lowest moisture, total K, and C/N ratio. Analysis of soil samples collected before application of treatments, indicated that the soil texture at POG82 was loam and at MSG82 was clay (Table 1).

Seedcotton Yield

The N source by N rate interaction had no significant influence on seedcotton yield at either site (Table 4). Averaged across N sources, N rate significantly increased seedcotton yield at MSG82, but not at POG82. At the MSG82 location, averaged across all N sources, seedcotton yield ranged from 1228 to 3279 lb/acre and increased numerically and often significantly with increasing N-rate. When averaged across all N sources, application of 90 to 120 lb total-N/acre produced maximum seedcotton yields (Table 4). Although the interaction was not significant, data for MSG82 suggest that 90 lb urea-N/acre produced maximum seedcotton yields of about 3,000 lb/acre. In contrast, application of 150 lb total N/acre as FPL and TCO failed to increase yields above 2000 and 2500 lb/acre, respectively. Lack of response to N fertilizer rate at POG82 was somewhat unexpected, but we observed visual symptoms consistent with mild verticillium wilt across the field during the growing season.

Compared with the no-N control, all N sources, averaged across N rates, significantly increased seedcotton yields which ranged from 1228 to 2667 lb/acre at MSG82. At MSG82, seedcotton yields were greatest when urea was the N source, intermediate for cotton receiving TCO, and lowest for cotton receiving FPL and PPL (Table 5). Cotton

yield results from each N rate and N source combination at POG82 (Table 5) suggest that cotton yields tended to decline as urea-N rate increased, but remained relatively constant across TCO-, FPL-, and PPL-N rates.

PRACTICAL APPLICATION

Fresh poultry litter, PPL, and TCO appear to have utility as low-grade macronutrient fertilizers for cotton production in Arkansas. The results of this one-year study on two representative soils in eastern Arkansas suggest that all N-fertilizer sources significantly increased seedcotton yield. However, on soils that require significant amounts of N to produce maximal yields, such as MSG82, the organic-N sources (TCO, FPL, and PPL) failed to produce seedcotton yields comparable to urea. Thus, the results from MSG82 suggest that TCO, FPL, and PPL can be used to provide some proportion of the cotton crop's N requirement and perhaps recommended amounts of P and/or K.

ACKNOWLEDGMENTS

This research was supported with a gift from MANCO Fertilizer Inc. We also express our gratitude to the staff of the University of Arkansas Northeast Research and Extension Center and Judd Hill Foundation for their assistance. We also thank Mr. Chris Tharp for donating the fresh chicken litter used in this experiment.

Table 1. Selected soil chemical property and soil particle size means (0- to 6-in. depth) of soil samples taken before applying any soil amendments in a study evaluating the effects of N source and rate on cotton yield on a Sharkey clay (MSG82) and a Dundee silt loam (POG82) in Arkansas during 2008.

Site ID	Soil pH ^z	SOM ^y	Soil Mehlich-3-extractable nutrients										Soil particle size		
			NO ₃ -N ^x	P	K	Ca	Mg	Mn	Cu	Zn	Sand	Silt	Clay	Texture	
MSG82	6.6	2.4	4	71	225	3572	685	79	4.2	5.7	25	26	49	Clay	
POG82	6.3	2.0	9	78	143	1424	215	112	1.1	4.2	52	42	16	Loam	

^z Soil pH was measured in a 1:2 (weight:volume) soil-water mixture.

^y SOM, soil organic matter determined by weight loss on ignition.

^x NO₃-N measured by ion-specific electrode.

Table 2. Total N and product application rates for urea, two different fresh poultry litter (FPL) sources, pelleted poultry litter (PPL), and Top Choice Organic (TCO) biosolid used in fertilization of cotton experiments in Mississippi (MSG82) and Poinsett (POG82) counties in Arkansas during 2008.

N rate (lb N/acre)	Urea	Amendment rate				
		FPL (POG82)	FPL (MSG82)	PPL	TCO	
30	65	1,035	1,111	840	478	
60	130	2,069	2,222	1,681	955	
90	196	3,103	3,333	2,521	1,433	
120	261	4,138	4,444	3,361	1,911	
150	326	5,172	5,555	4,202	2,389	

Table 3. Selected chemical property means (n = 4-8) for two fresh poultry litter sources (FPL), pelleted poultry litter (PPL), and Top Choice Organic (TCO) biosolid used in N-fertilization trials conducted in Mississippi (MSG82) and Poinsett (POG82) counties during 2008.

N source	n	pH	Moisture	Total nutrient content (as is)					Inorganic N content		
				C	N	P ^z	K ^y	Ca	NO ₃ -N	NH ₄ -N	
FPL (MSG82)	4	8.4	36	24.2	2.36	0.98	1.77	1.58	229	5853	
FPL (POG82)	4	8.5	34	22.3	2.95	1.85	3.09	2.55	92	5346	
PPL	6	7.4	14	28.1	3.57	1.33	3.04	2.18	1530	2632	
TCO	8	5.9	7	36.7	6.28	2.23	0.38	2.24	259	2075	

^z lb P₂O₅/ton = % total P on "as-is" basis multiplied by 20 x 2.29.

^y lb K₂O/ton = % total K on "as-is" basis multiplied by 20 x 1.2.

Table 4. Seedcotton yield as affected by fresh poultry litter (FPL), pelleted poultry litter (PPL), Top Choice Organic (TCO) biosolid, and urea each applied at five total-N rates to a Sharkey clay (MSG82) and a Dundee silt loam (POG82) in Arkansas during the 2008.

Total-N rate (lb N/acre)	MSG82					POG82				
	N source		N source			N source		N source		
	FPL	PPL	TCO	Urea	means	FPL	PPL	TCO	Urea	means
0										
30	1501	1538	1601	1922	1647	3414	3586	3778	3605	3228
60	1569	1656	1678	2352	1786	3704	3468	3613	3414	3550
90	1734	1772	2285	3073	2100	3793	3693	3464	3309	3565
120	1655	1920	2181	2929	2172	3428	3668	3257	3499	3463
150	1945	1847	2535	3279	2379	3638	3837	3521	3108	3526
MSD 0.10 ^z	interaction was NS					interaction was NS				
p value	interaction = 0.1691					interaction = 0.1701				
					<0.0001					0.8141

^z Minimum Significant Difference (MSD) as determined by Waller-Duncan Test at P = 0.10. NS = not significant at P = 0.10.

Table 5. Seedcotton yield as affected by fresh poultry litter (FPL), pelleted poultry litter (PPL), Top Choice Organic (TCO) biosolid, and urea, averaged across five total-N rates, and compared to the no-N control (None) applied to a Sharkey clay (MSG82) and a Dundee silt loam (POG82) in Arkansas during 2008.

N source	MSG82	POG82
	-----Seedcotton yield (lb/acre)-----	
None	1228	3228
FPL	1670	3595
PPL	1755	3650
TCO	2036	3527
Urea	2667	3387
MSD at 0.10 ^z	232	260
<i>p</i> value	<0.0001	0.0693

^z MSD, Waller Duncan minimum significant difference.

Effect of Potassium Fertilization on Seedcotton Yield in Arkansas

Morteza Mozaffari and Nathan A. Slaton¹

BACKGROUND INFORMATION

Cotton (*Gossypium hirsutum* L.) plant demand for potassium (K) is particularly high during fruit development and K deficiency can seriously limit cotton yield potential (Oosterhuis et al., 2003). Information on cotton response to K fertilization under current production practices will aid in developing agronomically sound K-fertilizer recommendations.

RESEARCH PROBLEM

The objective of this experiment was to evaluate the effect of K-application rate on seedcotton yield and Mehlich-3 extractable soil K for a modern cotton cultivar grown using production practices common to Arkansas.

RESEARCH DESCRIPTION

The 2008 growing season was the fifth year of a replicated, continuous K-fertilization experiment on a Convent silt loam at the University of Arkansas Division of Agriculture's Lon Mann Cotton Research Station in Marianna, Ark. Prior to 2008, the experimental design was a randomized complete block arranged in a split-plot structure where cotton cultivar was the main-plot factor and K rate (0, 30, 60, 90, 120, and 150 lb K₂O/acre) was the sub-plot factor. However, during the first four years of study, the cultivar by K-fertilizer rate interaction never significantly affected seedcotton yield or post-harvest, soil-test K. Therefore, in 2008, cultivar was removed as an experimental treatment resulting in a simple randomized complete block design of six K-rates (0, 30, 60, 90, 120, and 150 lb K₂O/acre) with each K rate replicated eight times. The same K-rates were applied to the same plots, a practice established and followed since 2004. Each individual plot was 43 ft long and 12.5 ft wide allowing for four rows of cotton

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with 38-in. wide row spacings. Prior to application of any soil amendments six soil cores were collected from the 0- to 6-in. depth of each plot and composited. The same procedure was followed in the fall after cotton harvest. Soil samples were analyzed for important chemical and physical characteristics by the standard methods used at the University of Arkansas Soil Testing Laboratory in Marianna.

On 12 May 2008 urea (46-0-0) and triple superphosphate (0-46-0) were broadcast applied to supply 60 lb N and 46 lb P_2O_5 /acre, respectively. All K-fertilizer treatments were broadcast on the same day and incorporated with a Do-All. An additional 50 lb N/acre as urea was broadcast onto all plots on 8 July. Cotton cultivar Stoneville 4554B2RF was seeded into a conventionally tilled seedbed on 22 May, emerged on 1 June, and pests were managed using recommended practices. Cotton was irrigated as needed using the University of Arkansas Division of Agriculture Irrigation Scheduler program. Cotton was harvested with a spindle-type mechanical picker on 4 November. Analysis of variance was performed to evaluate the effect of annual K application rate on seedcotton yield and soil-test K using the PROC GLM procedure of SAS. Significant treatment means were separated by the Waller-Duncan minimum significant difference (MSD) test when appropriate ($P=0.10$).

RESULTS AND DISCUSSION

Averaged across soil samples collected before seeding the average soil pH was 6.8 and Mehlich-3 extractable P was 60 ppm (Above Optimum, Table 1). Previous annual K-fertilizer application rate had significantly influenced preplant soil-test K producing mean soil-test K values ranging from 93 to 143 ppm K (Table 2). Soil-test K increased as annual K-fertilizer rate increased with the annual K rates of 0 to 120 lb K_2O /acre being interpreted as Medium and the highest K rate (150 lb K_2O /acre) having an Optimum soil-test K level. Post-harvest soil-test K was also significantly influenced by annual K-fertilizer rate with mean values ranging from 82 to 125 ppm (Table 2). Annual K-fertilizer application rate significantly increased seedcotton yield in 2008 (Table 2). Potassium application rates >30 lb K_2O /acre significantly increased seedcotton yields compared to the no K control. The greatest yield was produced with the highest annual K-fertilizer rate.

PRACTICAL APPLICATION

Annual K fertilization rate significantly increased seedcotton yield in 2008. Current soil-test based recommendations would have recommended 60 lb K_2O /acre be applied to soil from all annual K rates except the highest annual rate (150 lb K_2O /acre), which would have received a recommendation for 40 lb K_2O /acre to aid in maintaining an Optimum soil-test K level. The highest annual K rate also produced the greatest seedcotton yield suggesting that more short- and long-term research is needed to better define soil-test based K-fertilizer recommendations for cotton. Data collected during

the past five years suggests that K-fertilization is an important component of cotton fertilization and may be essential for maximizing cotton yield potential.

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Table 1. Selected soil chemical and physical property means (0- to 6-in. depth) for soil samples taken before adding any fertilizer for a cotton K-fertilization trial conducted during 2008 on a Convent silt loam at the Lon Mann Cotton Research Station in Marianna, Ark.

Location	Soil		Mehlich-3 extractable nutrients							Particle size analysis			
	Soil pH ^z	NO ₃ -N ^y	P	K	Ca	Mg	Mn	Cu	Zn	Sand	Silt	Clay	Texture
LEG87	6.8	15	60	115	2169	314	165	1.3	2.1	14	63	23	Silt loam

^z Soil pH was measured in a 1:2 (weight:volume) soil-water mixture.

Table 2. Mean Mehlich-3 soil-test K concentrations in spring (preplant) and fall (post-harvest) 2008 and seedcotton yield as affected by annual K-fertilizer rate during the fifth year (2008) of a continuous-cotton, K-fertilization trial conducted on a Convent silt loam at the Lon Mann Cotton Research Station in Marianna, Ark.

Annual K-fertilizer rate (lb K ₂ O/acre)	Mehlich-3 soil-test K		Seedcotton yield (lb/acre)
	Preplant	Post-harvest	
	----- (ppm) -----		
0	93	82	2973
30	100	87	3244
60	110	96	3457
90	114	104	3696
120	126	108	3937
150	143	125	4317
MSD ^z 0.10	9	8	283
P value	<0.0001	<0.0001	<0.0001

^z Minimum significant difference at P=0.10 as determined by Waller-Duncan Test.

Cotton Response to Phosphorus Fertilization in Arkansas

Morteza Mozaffari, Nathan A. Slaton, Josh Long, Jason Osborn, and Mike Hamilton¹

BACKGROUND INFORMATION

Improved phosphorus (P)-fertilizer recommendations will enable Arkansas cotton growers to get a sound return on their fertilizer investment and reduce the risk of potential environmental concerns over eutrophication of water supplies. Advances in production practices have increased cotton yields in Arkansas during the last three decades. Consequently, the optimum P-fertilizer rates or critical soil-test P values may have changed. Therefore, a need exists for updated information on cotton response to P fertilization with the soil conditions and cropping practices common to eastern Arkansas.

RESEARCH PROBLEM

The objective of this study was to evaluate the effect of P-fertilizer rate on seedcotton yield and soil-test P concentration on a soil commonly used for cotton production in Arkansas.

RESEARCH DESCRIPTION

A replicated field experiment was conducted on a Commerce silt loam on a commercial farm in Crittenden County, Ark., in 2008. This field has been in continuous cotton for the last three years. Before application of any soil amendments, a composite (8 to 10 cores) soil sample was collected from the 0- to 6-in. depth of each replication (n=4). Soil samples were oven dried at 65°C, crushed, extracted with Mehlich-3 solution, and the elemental concentrations were measured by inductively coupled plasma atomic emission spectroscopy. Soil particle size was determined on composite samples collected from the first and second replications using the hydrometer method (Arshad et al., 1996). Soil pH was measured in a 1:2 (weight:volume) soil-water mixture. Com-

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posite soil samples were also collected from 0- to 6-in. depth of each plot after cotton harvest and processed as described before.

Cotton cultivar Stoneville5590 was planted by the cooperating grower on 24 May 2008 into a conventionally tilled seedbed. Triple superphosphate (0-46-0) was applied to the soil surface at rates of 0, 30, 60, 90, and 120 lb P₂O₅/acre on 5 June. A blanket application of 80 lb K₂O/acre (as 0-0-60) was applied to the research area on the same date. Urea was applied by the grower to supply 100 lb N/acre in mid-June. Individual plots were 40 ft long and 10 ft wide allowing for four rows of cotton with 30-in. wide row spacings. Cultural management practices closely followed the University of Arkansas Division of Agriculture recommendations for irrigated-cotton production. Irrigation timing was managed by the cooperating grower. Plants in a 10-ft-long section of one center row were hand-picked on 20 October and used to calculate seedcotton yield.

The experiment was a randomized complete block design with four replications. Analysis of variance was performed using the GLM procedure of SAS to determine the effect of P-fertilizer rate on seedcotton yield and post-harvest, Mehlich-3 extractable P. Mean separations were performed using the Waller Duncan minimum significant difference (MSD) test at significance level of 0.10.

RESULTS AND DISCUSSION

Soil at the research site contained 33% sand, 42% silt, 25% clay, and had an average soil pH of 7.9 (Table 1). Mehlich-3 extractable P was 20 ppm, which is interpreted as 'Low' with a corresponding recommendation for cotton of 70 lb P₂O₅/acre to build soil-test P and maximize cotton yields. Cotton plants grown in soil receiving no P fertilizer appeared stunted and by harvest were visibly shorter than plants receiving P suggesting that a positive yield response to P fertilization would occur. In 2007, we also observed that cotton grown in this field responded positively to P-fertilization.

Yield ranged from 1889 to 3275 lb seedcotton/acre and, compared to the no P control, seedcotton yield was significantly increased by all rates of P fertilization (Table 2). Cotton receiving the greatest P rate produced the highest cotton yield, which was significantly greater than yields of cotton receiving ≤60 lb P₂O₅/acre. Application of 90 to 120 lb P₂O₅/acre produced maximum seedcotton yields, which were about 70% higher than cotton receiving no P.

Phosphorus-fertilizer rate also significantly increased post-harvest soil-test P (Table 2). Post-harvest soil-test P in soil receiving no P was 17 ppm compared to the test average of 20 ppm before planting. Soil-test P in soil receiving P fertilizer increased as P rate increased and ranged from 22 to 46 ppm. Application of 120 lb P₂O₅/acre increased soil-test P rating from 'Low' to 'Optimum'.

PRACTICAL APPLICATION

Application of P fertilizer significantly increased seedcotton yield in a Commerce silt loam having 'Low' Mehlich-3 extractable soil P. Current soil-test based P-fertilizer recommendations would have recommended 70 lb P₂O₅/acre and although seedcotton

yields would have been increased by this application rate yields would not have been maximized. The maximum P fertilizer rate currently recommended is 90 lb P₂O₅/acre for soils having 'Very Low' soil-test P (<16 ppm). For the past two years trials conducted in this field suggest that cotton grown in soils with 'Low' soil-test P should respond positively to P fertilization. Additional research is needed to properly correlate and calibrate the soil-test based P-fertilizer recommendations for cotton. Results from this experiment will be added to a database on cotton response to P fertilization so that recommendations can be verified and/or revised once sufficient data has been collected.

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Table 1. Selected soil chemical and particle size property means (0- to 6-in. depth) for soil samples taken before adding any fertilizer to a cotton P-fertilization trial conducted on a commercial farm in Crittenden County, Ark., during 2008.

Location	Soil		Mehlich-3 extractable nutrients						Particle size analysis				
	Soil pH ^z	NO ₃ -N ^y	P	K	Ca	Mg	Mn	Cu	Zn	Sand	Silt	Clay	Texture
LEG87	7.8	30	20	110	2294	474	125	2.9	3.8	33	42	25	loam

^z Soil pH was measured in a 1:2 (weight:volume) soil-water mixture.

^y NO₃-N measured by ion-specific electrode.

Table 2. Effect of soil applied P-fertilizer rate on seedcotton yield and post-harvest soil-test P for a trial established on a commercial farm in Crittenden County, Ark., during 2008.

P-fertilizer rate (lb P ₂ O ₅ /acre)	Seedcotton yield (lb/acre)	Post-harvest soil-test P (ppm)
0	1899	17
30	2491	22
60	2753	24
90	2805	37
120	3275	46
<i>P</i> value	0.0026	0.0009
MSD at 0.10 ^z	407	9

^z Minimum significant difference at *P*=0.10 as determined by Waller-Duncan Test.

Weed Seed Spread Through Cotton Gin Trash in Arkansas

Jason K. Norsworthy and Kenneth L. Smith¹

RESEARCH PROBLEM

Reports differ on the effectiveness of composting for removing viable weed seed from gin trash. Griffis and Mote (1978) reported that composting gin trash containing redroot pigweed, johnsongrass, purple moonflower, hemp sesbania, and pitted morning-glory resulted in complete loss of weed seeds capable of germinating, leading to the conclusion that composting is lethal to all weed seeds. Furthermore, fungal growth was observed on weed seeds contained in packets extracted from piles of gin trash, leading to further speculation that it is not likely that composted gin trash contributes to increases in weed infestations. On the contrary, Gordon et al. (2001) reported that weed seedlings commonly grow on composting piles of gin trash, and viable seeds have been found in gin trash after composting.

Weed seed content in gin trash by species and quantity is an indicator of the most problematic weeds of cotton, especially at harvest. Unfortunately, the species composition and frequency of weed seeds in gin trash are often not known. If this information were available, gin operators could make informed decisions as to “how” or “where” to dispose of gin trash. Likewise, producers would know of the potential for introduction of new weeds or increases in current weed infestations in fields where gin trash is applied. Furthermore, this information is useful for the development of species-specific, late-season, or season-long weed control programs. Late-emerging weeds can be a tremendous problem in cotton in that harvest efficiency and lint quality are reduced, especially when weeds large in size such as Palmer amaranth are present (Smith et al., 2000). Therefore, research was initiated to determine the species and density of weeds present in recently collected gin trash, the means of gin trash disposal, and the presence of weeds in gin trash that had been composted for 1 or 2 years.

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BACKGROUND INFORMATION

Disposal of gin trash can be a challenge for gin operators. Raw or composted gin trash has been applied directly to fields to increase organic matter, improve soil structure, and serve as a fertilizer for crops; applied as an amendment to recover degraded soils and enhance nutrient cycling; exploited as a weed-suppressive mulch for gardens or ornamentals; used as a substrate medium for container-grown nursery crops and ornamentals; applied to soil as a mulch to reduce erosion; used as a bedding material for dairy cattle and poultry; or fed to livestock as a raw material or pelletized product (Bader et al., 1998; Griffis and Mote, 1978; Jackson et al., 2005; Kennedy and Rankins, 2008; Tejada and Gonzalez, 2006).

Composting gin trash may raise the temperature of the material to levels sufficient to kill many weed seeds. However, lethal temperatures often do not occur near the surface of the composting pile, so some weed seeds often exist in composted materials (Gordon et al., 2001). Hence, some growers are reluctant to spread composted gin trash for fear of introducing new weeds into fields.

RESEARCH DESCRIPTION

Names of gin operators and contact information for gins in Arkansas were obtained from county extension agents in the fall of 2007. Eighteen gin operators participated in a project in fall of 2007 aimed at determining the quantity and spectrum of weed species in gin trash. Each gin operator collected samples of gin trash each day the gin was in operation. A total of 453 samples was collected.

Composted gin trash from Taylor's Gin in Gould, Ark. (Desha County), was collected from depths of approximately 0- to 12-in. and 12- to 24-in. at six locations on the compost pile. Each sample contained approximately 3 gallons of material. The only moisture received by the compost was that of rainfall. The compost pile had not been disturbed since gin trash was placed at the site in the fall of 2006.

Additionally, four gin trash samples from Grower's Gin in McGehee, Ark. (Desha County), were collected at 0- to 12-in. and 12- to 24-in. depths from two piles that had been composting since the fall of 2005 (2 years) and 2006 (1 year). Gin trash at this site was moistened on a conveyer as it exited the gin, and supplemental moisture was provided through rainfall. Piles of gin trash at the Grower's Gin are turned every three to six months to increase the rate of composting.

All samples were taken to the University of Arkansas at Fayetteville. A 0.5-gallon subsample of gin trash from each bag was mixed with an equivalent volume of commercial potting mix and placed in a tray. The gin trash was placed in a greenhouse and daily moistened. The number of weeds by species in each tray were recorded weekly for 5 weeks. The quantity of germinable seeds/ton of gin trash was calculated.

RESULTS AND DISCUSSION

Seedlings of 25 weed species were observed in the 453 gin trash samples (Table 1). Eleven of the weed species were grasses and fourteen were broadleaves. Grasses were

present in 43% of the samples compared to only 9% for broadleaves. Furthermore, the four most frequently found species were grasses: large crabgrass (19%), barnyardgrass (14%), goosegrass (13%), and red sprangletop (8%). Palmer amaranth was present in 4% of the samples, making it the most prominent broadleaf weed, ranking fifth among all weeds.

Grass weeds were found in at least one sample from all gins from which 10 or more samples were collected, except for one gin in northeast Arkansas (Table 2). Of the 295 gin trash samples collected in southeast Arkansas, 51% of the samples contained germinable grass seeds compared to 27% in northeast Arkansas.

Germinable broadleaf weed seeds were present in at least one sample from 12 gins (Table 3). Broadleaf weed seeds were present in 7% of samples from northeast Arkansas and 9% of samples from southeast Arkansas. Although the percentage of gin trash samples containing broadleaf weeds was comparable across regions, the mean quantity of broadleaf weeds in samples from northeast Arkansas was 3.8-fold greater than those from southeast Arkansas.

Germinable seeds of barnyardgrass, large crabgrass, Palmer amaranth, and prickly sida were found in the surface layer (0- to 12-in. depth) of gin trash piles that had been composting for 1 year (Table 4). Furthermore, germinable Palmer amaranth seeds were present in the surface layer of the compost pile at the Grower's Gin after 2 years of composting. Large crabgrass and Palmer amaranth plants were growing on the composting pile of gin trash from the Taylor Gin, which likely explains the higher quantity of germinable large crabgrass and Palmer amaranth seeds in the surface layer of the gin trash at this site compared with that from the Grower's Gin. Although weeds were not growing directly on the composting piles of gin trash at the Grower's Gin, fully mature barnyardgrass, large crabgrass, and Palmer amaranth plants were present adjacent to the compost piles. Considering that the compost piles at the Grower's Gin were inverted (turned) every 3 to 6 months, it seems likely that seeds found in the outer layer of the gin trash were from those plants growing adjacent to the compost pile rather than ones surviving the composting process. Wind and small rodents are plausible causes for movement of seeds to the compost piles from these adjacent plants. Additionally, the temperature of the gin trash piles at both sites at a 0- to 4-in. depth ranged from 104 to 110°F, which is not sufficient to kill weed seeds, even following prolonged exposure (Egley, 1990). This is especially true for the Taylor Gin, which did not periodically invert the compost; thus, weed seeds in the outer layer were never subjected to lethal temperatures. Furthermore, the outer layer appeared to be drier than inner layers, which has been shown to contribute to longer retention of viable weed seeds (Egley, 1990).

No germinable seeds were found deeper than 12 in. at either of the sites after 1 year of composting. The absence of germinable seeds at greater depths is consistent with previously published findings (Gordon et al., 2001). At both gins, the temperature of the compost at a 12- to 14-in. depth ranged from 142 to 145°F. Ample moisture in the inner portion of the composting pile of gin trash also likely contributed to rapid loss of seed viability.

Operators of 23 gins in Arkansas were asked, "How do you dispose of your gin trash?" The most frequent response (43% of gins) was application of the trash to crop fields during the fall or winter months. These fields were generally in cotton the same

year, but trash at some gins was applied to fields that were in soybean production. Several gins had multiple means of disposal. There were two equal means of disposal used by 39% of the gins. One was the composting of trash for a period followed by application as mulch or a soil amendment to gardens, flower beds, or crop fields. The other was feeding gin trash to cattle either directly or as a pelletized product. Trash from two of the gins (9%) was placed on covered landfills for erosion control and to encourage growth of vegetation.

PRACTICAL APPLICATION

Griffis and Mote (1978) concluded that weed seeds could not survive in composted gin trash, leading to speculation that application of composted gin trash onto production fields will not increase weed infestations. This is contrary to findings in this research where germinable weed seeds were found in composted gin trash. Hence, weed seed dispersal during gin trash disposal is obviously occurring based on the presence of germinable weed seeds in freshly collected trash as well as that composted at least 2 years. Although anecdotal, several gin operators and producers noted that Palmer amaranth rapidly became a problem in fields where gin trash was applied.

It is obvious that there are numerous weed species in gin trash, including composted gin trash, with Palmer amaranth being among the most prevalent. Therefore, movement and establishment of new glyphosate-resistant Palmer amaranth populations (Norsworthy et al., 2008a, 2008b) and other resistant weeds are a concern with disposal of gin trash. If glyphosate-resistant Palmer amaranth were to infest a field, seeds contained in debris adhering to cotton lint are likely to lead to resistance perpetuation through gin trash disposal. The herbicide-resistant weeds could also be dispersed by cattle fed weed seed-contaminated gin trash.

Users of gin trash need to be aware that the consequences of its use may outweigh positive attributes. It has been proposed that sterilization of the outer portion of the gin trash pile may be possible through use of solar techniques involving a low-cost plastic (Gordon et al., 2001). Regardless of the technique employed, it is imperative that practical, economical methods are developed to achieve a sterilized material to allow disposal of a weed-free product from gin trash.

ACKNOWLEDGMENTS

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Table 1. Weed species emerging from gin trash samples.

Common name	Samples with seed		Avg. seed quantity (seeds/ton)
	(#)	(%)	
Large crabgrass	90	(19)	3650
Barnyardgrass	68	(14)	1280
Goosegrass	61	(13)	1480
Red sprangletop	39	(8)	1230
Palmer amaranth	20	(4)	687
Broadleaf signalgrass	12	(3)	207
Annual bluegrass	8	(2)	223
Cutleaf groundcherry	6	(1)	85
Ryegrass	6	(1)	69
Bearded sprangletop	6	(1)	224
Pitted morningglory	4	(<1)	61
Eclipta	4	(<1)	33
Prickly sida	4	(<1)	154
Yellow foxtail	4	(<1)	53
Spreading dayflower	2	(<1)	16
Hemp sesbania	2	(<1)	16
Horseweed	2	(<1)	16
Redroot pigweed	2	(<1)	1110
Hairy vetch	2	(<1)	16
Johnsongrass	1	(<1)	8
Henbit	1	(<1)	8
Horse purslane	1	(<1)	8
Smooth pigweed	1	(<1)	8
Northern jointvetch	1	(<1)	8
Fall panicum	1	(<1)	8
Broadleaves (total)	40	(9)	2500
Grasses (total)	196	(43)	8320

Table 2. Grass seedlings (all species) emerging over a 5-week period from gin trash samples collected in Arkansas.^z

State	Region	County	Gin number	Samples	Percent by density					Seedlings	
					0	1-19	20-39	40-59	≥60	mean	max.
					-----(%/ton X 1000)-----					----- (no. ton)-----	
AR	NE	Craighead	1	22	100	0	0	0	0	0	0
AR	NE	Craighead	2	46	65	33	2	0	0	2910	24400
AR	NE	Craighead	3	11	91	9	0	0	0	370	4070
AR	NE	Greene	4	11	64	27	0	9	0	6280	56900
AR	NE	Lee	5	22	27	45	0	5	18	23800	110000
AR	NE	Mississippi	6	22	86	14	0	0	0	553	4070
AR	SE	Ashley	7	28	68	29	0	4	0	3920	52800
AR	SE	Chicot	8	34	12	56	15	12	6	18100	69100
AR	SE	Desha	9	38	50	39	3	3	5	9560	89400
AR	SE	Desha	10	38	50	37	8	3	3	7700	85400
AR	SE	Desha	11	36	61	33	3	3	0	4630	48800
AR	SE	Desha	12	36	47	33	3	12	6	16800	228000
AR	SE	Desha	13	40	42	42	3	0	13	19600	305000
AR	SE	Desha	14	45	62	34	4	0	0	3250	28500
AR	NE	---	---	158	73	22	1	1	3	4780	110000
AR	SE	---	---	295	49	38	5	4	4	10400	305000

^z Only gins submitting 10 or more samples are shown individually, but all samples were included for the regional evaluation.

Table 3. Broadleaf weed seedlings (all species) emerging over a 5-week period from gin trash samples collected in Arkansas.^z

State	Region	County	Gin number	Samples	Percent by density				Seedlings		
					0	1-19	20-39	40-59	≥60	mean	max.
					-----(%/ton X 1000)-----				----- (no./ton)-----		
AR	NE	Craighead	1	22	95	5	0	0	0	183	4070
AR	NE	Craighead	2	46	96	4	0	0	0	175	4070
AR	NE	Craighead	3	11	100	0	0	0	0	0	0
AR	NE	Greene	4	11	100	0	0	0	0	0	0
AR	NE	Lee	5	22	86	14	0	0	0	923	12200
AR	NE	Mississippi	6	22	81	14	0	0	5	18300	390000
AR	SE	Ashley	7	28	82	18	0	0	0	1300	16300
AR	SE	Chicot	8	34	85	9	3	0	0	2750	48800
AR	SE	Desha	9	38	97	3	0	0	0	106	4070
AR	SE	Desha	10	38	92	8	0	0	0	321	4070
AR	SE	Desha	11	36	94	6	0	0	0	228	4070
AR	SE	Desha	12	36	86	14	0	0	0	1020	16300
AR	SE	Desha	13	40	90	10	0	0	0	508	8130
AR	SE	Desha	14	45	98	2	0	0	0	89	4070
AR	NE	---	---	158	93	6	0	0	<1	2780	390000
AR	SE	---	---	295	92	8	<1	<1	0	728	48800

^z Only gins submitting 10 or more samples are shown individually, but all samples were included for the regional evaluation.

Table 4. Germinable weed seeds in cotton gin trash at two depths after one or two years of composting.

Gin name	Depth (in.)	Composting length (year)	Germinable seeds			
			Barnyardgrass	Large crabgrass	Palmer amaranth	Prickly sida
			----- (no./ton)-----			
Grower's Gin	0 to 12	1	7000	1020	1020	0
	12 to 24	1	0	0	0	0
Grower's Gin	0 to 12	2	0	0	4070	0
	12 to 24	2	0	0	0	0
Taylor Gin	0 to 12	1	678	15600	67800	678
	12 to 24	1	0	0	0	0

Use of a Model to Develop Practical Solutions for Reducing Risks of Glyphosate-Resistant Palmer Amaranth in Cotton

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RESEARCH PROBLEM

Currently, as many as five glyphosate applications are used for weed management in glyphosate-resistant cotton, which comprises approximately 98% of the cotton acreage in Arkansas (Norsworthy et al., 2007). As glyphosate use has increased, tillage use has decreased (Young, 2006), placing extreme selection pressure for glyphosate resistance on Palmer amaranth and other weeds frequently found in cotton and other cropping systems that rely almost solely on glyphosate. The value of weed management systems in glyphosate-resistant cotton that increase herbicide mode of action diversity has been recognized (Burke et al., 2005). A survey conducted in spring 2006, reported that approximately two-thirds of cotton producers in the southern United States had planted glyphosate-resistant cotton continually for 3 to 5 years (Foresman and Glasgow, 2008).

BACKGROUND INFORMATION

Palmer amaranth is one of the most common, prolific, competitive, and hence, important weeds of crops in the southern United States (Klingaman and Oliver, 1994), driving weed management decisions in cotton. Its resistance to acetolactate synthase-inhibiting herbicides (pyrithiobac, trifloxysulfuron) is widespread throughout cotton-producing areas (Heap, 2009). Because of rapid growth, Palmer amaranth quickly overtops cotton, reducing lint yield by up to 92% at a density of only 0.08 plant/ft² (Rowland et al., 1999). Often where glyphosate-resistant Palmer amaranth evolves, high population densities mean that the cotton crop must be abandoned.

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Following the emergence of glyphosate resistance in rigid ryegrass in Australia, it was recognized that widespread resistance to glyphosate could seriously impact sustainable weed management. In response to this threat, computer models were developed to simulate evolved resistance to glyphosate in rigid ryegrass under a number of cropping scenarios. In this way, glyphosate use patterns and cropping practices that increased the risks of glyphosate resistance and those that minimized selection pressure for resistance could be identified and evaluated (Neve et al., 2003a, 2003b). More recently, modeling approaches have been used to address risks of weed resistance to glyphosate in cropping systems with intensive use of glyphosate-resistant crop technology in the United States (Neve, 2008).

RESEARCH DESCRIPTION

In this paper, a previously developed model is used to explore the impacts of glyphosate resistance management strategies on risks of resistance evolution. The aim of this research is to demonstrate the benefits of reduced glyphosate use through reduced applications in single cropping seasons and increased use of residual herbicides for season-long mode-of-action diversity in Palmer amaranth control.

The model structure and parameters were described in Neve et al. (2009). For each management strategy simulated, the model is run 250 times (i.e., 250 independent fields). Stochastic elements within the model ensure run-to-run and season-to-season variability in Palmer amaranth population size and dynamics, so that for any management strategy, a range of realistic outcomes will be predicted and can be summarized to indicate the risk of glyphosate resistance.

The simulation model is used to compare the predicted rate and relative risk of glyphosate resistance under a number of contrasting weed management strategies. These strategies are based on continuous glyphosate-resistant cotton. Weed management practices are assumed to be identical in all 20 years of the simulation. Available options for Palmer amaranth control, together with efficacies, are based on field research.

Evolution of glyphosate resistance was simulated for seven weed management strategies in continuous glyphosate-resistant cotton (Fig. 1a). The 'worst-case' strategy (a) was five glyphosate applications per year. In the remaining six strategies, glyphosate use was reduced to three or four applications per year and herbicide mode of action diversity was introduced by the addition of one or a series of alternative residual herbicides. These strategies and herbicides were chosen to represent a realistic range of alternative and additional options for Palmer amaranth control in cotton.

For each strategy, the results are summarized to show the rate at which resistance evolves and the risk of resistance (percentage of runs where resistance is predicted). A population is defined as having evolved resistance to glyphosate when 20% of individuals within the seed bank are resistant.

RESULTS AND DISCUSSION

In continuous glyphosate-resistant cotton with sole reliance on glyphosate for Palmer amaranth control, glyphosate resistance is predicted in 30% of Palmer amaranth

populations after 4 years and 59% of populations after 5 years (Fig. 1). After 20 years of this program, 67% of populations are predicted to have evolved resistance, though no populations were predicted to become resistant after year 13. The worst-case strategy has predicted very widespread glyphosate resistance in Palmer amaranth in 4 to 5 years, and this seems to correlate well with field observations where resistance was first reported in Arkansas within this time frame. On this basis, our worst case strategy seems an appropriate starting point from which to consider alternative weed management strategies that will mitigate risks of glyphosate resistance.

In strategy b (Fig. 1), the directed layby glyphosate application is tank-mixed with flumioxazin. Compared to the glyphosate-only system, this strategy has little effect on the time to resistance and reduces the overall risk of resistance by only 6% (67% to 61%). This result suggests that late emerging Palmer amaranth plants may be relatively unimportant in terms of their contribution to risks of resistance, probably because they are subject to intense crop competition, produce few seeds, and are a small fraction of the total annual emergence.

In strategy c (Fig. 1), fomesafen is applied preplant and replaces the burndown glyphosate application at planting. Fomesafen has high efficacy against early-emerging Palmer amaranth plants and continued activity against later-emerging plants, ensuring some mode-of-action diversity for control of Palmer amaranth. Addition of this single herbicide has significant impacts on risks of glyphosate resistance, resulting in few predicted cases of resistance before year 6 and a reduction in the overall risk of resistance, so that resistance is predicted in only 30% of Palmer amaranth populations. In strategy d (Fig. 1) where both flumioxazin and fomesafen are applied, the predicted risk of resistance is reduced to 21%.

A key objective of glyphosate resistance management strategies must be to ensure that no, or as few as possible, plants are exposed to glyphosate alone. This can be achieved by judicious use of PRE- and POST-selective herbicides. In strategy e (Fig. 1), fluometuron is applied as a tank mixture with burndown glyphosate, and *S*-metolachlor is applied with the second POST application. Here, the risk of resistance exceeds 10% only after 7 years, and the overall risk of resistance after 20 years is less than 20%. Adequate control of Palmer amaranth populations is achieved with no glyphosate applied at the third POST timing.

In strategy f (Fig. 1), three alternative herbicides are used in conjunction with four glyphosate applications. Despite this, significant resistance is predicted after just 4 years, and cases of resistance continue to increase throughout the 20-year simulation. In this strategy, there is insufficient overall control of Palmer amaranth populations. For this reason, population sizes increase over time (years). Results from strategy f are a clear indication that it is not only important to incorporate multiple herbicide modes of action into weed management systems in glyphosate-resistant cotton, but also to consider the timing of these applications and their impact on overall levels of weed control.

With the knowledge gained from strategies a to f, we can begin to design herbicide-based weed management systems for continuous glyphosate-resistant cotton that will significantly reduce risks of glyphosate resistance in Palmer amaranth. In strategy g (Fig. 1), a residual herbicide is applied preplant, POST, and at layby to ensure that all Palmer amaranth plants receive a high level of control from both glyphosate and an

alternative mode of action. Risks of resistance are reduced significantly, with resistance predicted in only 10% of the fields. This program has reduced the risks of glyphosate resistance almost seven-fold compared to the glyphosate-only program. These benefits have been achieved by replacing the burndown glyphosate application with a preplant residual herbicide and by mixing two of the POST glyphosate applications with residual herbicides with alternative modes of action. These considerable reductions in risk of resistance have been achieved in systems that continue to grow continuous glyphosate-resistant cotton. However, our best management strategy for continuous glyphosate-resistant cotton relies on two applications of PPO-inhibiting herbicides (fomesafen and flumioxazin), and care must be taken to ensure that glyphosate-resistance management strategies do not put undue pressure on other herbicide modes of action. An alternative strategy to reduce selection for glyphosate resistance may be to modify herbicide use by growing glyphosate-resistant cotton in rotation with other crops or with cotton that is not resistant to glyphosate.

PRACTICAL APPLICATION

Three key principles dictate the success of alternative weed management systems simulated by our model: glyphosate selection pressure is reduced by reducing the number of glyphosate applications within and between years; residual herbicides expose a majority of Palmer amaranth emergence cohorts to an alternative mode of action; and finally, these management systems are highly effective in maintaining Palmer amaranth populations at low population densities in the absence of glyphosate resistance if properly timed. Rotating glyphosate-resistant cotton with corn or other cotton cultivars further reduces risk of resistance. Using effective resistance-management strategies appropriate for seasonal conditions and individual fields will reduce the risks of developing or increasing glyphosate-resistant Palmer amaranth.

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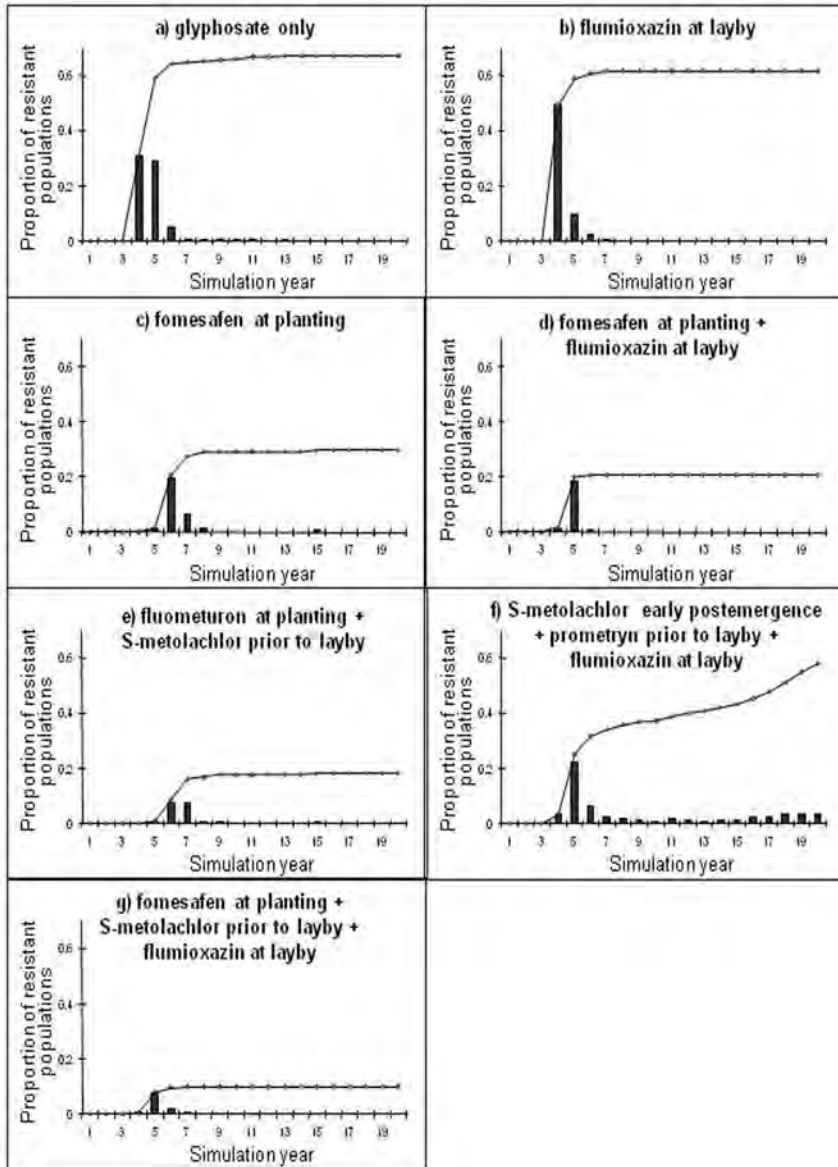


Fig. 1. The proportion of Palmer amaranth populations in which glyphosate resistance is predicted for seven weed management strategies (a-g) in continuous glyphosate-resistant cotton. In strategy a, glyphosate is applied 5 times each season. In strategies b through g, glyphosate is applied 3 to 4 times per season. For each strategy, the model is run 250 times and a population is described as resistant at the point where 20% of individuals are resistant. Bars represent the proportion of populations becoming resistant in each of the 20 years of the simulation and the line plot show the cumulative probability of resistance over that period.

The Spread and Population Genetics of Glyphosate-Resistant Palmer Amaranth in Arkansas

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RESEARCH PROBLEM

Glyphosate-resistant Palmer amaranth is spreading at an alarming rate in the southern U.S. Cases of resistance were confirmed in 19 counties in Arkansas in 2008, covering an estimated area of about 350,000 acre of cotton and soybean (K.L. Smith, Arkansas Extension Weed Specialist, unpublished data). Of the cotton acres with glyphosate-resistant Palmer amaranth, about 98,000 acre, 15% were reported to have severe infestation.

BACKGROUND INFORMATION

Palmer amaranth is an obligate outcrossing species and produces copious amounts of tiny seeds. This mating behavior, high level of fecundity, and aggressiveness promotes the rapid spread and dominance of this weed in the southern U.S. The population genetics and evolutionary structure of Palmer amaranth is expected to be complex. Understanding the patterns and processes involved in gene flow and population structure are necessary to minimize further resistance movement and population expansion.

RESEARCH DESCRIPTION

Sample Collection

Palmer amaranth populations were sampled from Crittenden, Lee, Lincoln, Mississippi, Jackson, Lawrence, Craighead, Poinsett, Lee, St Francis, and Phillips counties

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in Arkansas in 2007 and 2008. These samples were obtained from fields where Palmer escaped a glyphosate-based weed control program. The inflorescence of 20 randomly selected, mature, Palmer amaranth was collected from each field. Each plant was at least 100 ft apart. In some locations, soil samples were collected to study the genetic diversity of plants that can be recovered from the seed bank versus those that survived glyphosate applications in the same field. Field history was obtained whenever available. The plant parts were air-dried and threshed to recover seeds.

AFLP DNA Fingerprinting

DNA fingerprinting was initiated using amplified fragment length polymorphism (AFLP) technique. Leaf tissues were collected from 7 to 12 individuals of 5 Palmer amaranth populations after confirmation of glyphosate resistance. Leaf tissues were also collected from at least 20 individuals per population of glyphosate-resistant Palmer from North Carolina (1) and South Carolina (2). DNA fingerprinting was initiated on three Arkansas populations, two South Carolina populations, and 1 from North Carolina. Eight primer pairs, which were most informative for tall waterhemp, were used.

Sequencing of the EPSPS Gene

Two populations (AR-Grady, resistant, and CL86, susceptible) are being used as test populations for the EPSPS gene amplification. Total RNA was extracted from young leaf tissues of individual plants from AR-Grady and CL86 populations. cDNA was synthesized from total RNA and used for EPSPS gene amplification by polymerase chain reaction (PCR). Three batches of degenerate primers were designed based on the conserved EPSPS regions of other species including: Cotton (EU123855.1), tall waterhemp (AY545657.1), Italian ryegrass (DQ153168), rigid ryegrass (AF349754), and goosegrass (AJ417033.1; AY157643). The gene fragments amplified by the degenerate primers were aligned with the EPSPS gene sequence of *Amaranthus rudis*. The gene fragments generated were used to design specific primers to amplify overlapping long segments of the EPSPS gene. Thirteen specific primer pairs were tested. Four of these were designed to amplify 1100- to 1600-bp fragments. The extra-long PCR procedure was used. Attempts to amplify the gene in one long piece were unsuccessful thus, an equivalent primer pair that was optimized for the Georgia population was tested for Arkansas population and produced the longest fragment. The primer pair was then used for subsequent sequencing activities. The sequence of the long fragment showed more than one EPSPS allele in one plant. The amplified fragment was cloned to segregate the alleles. Six EPSPS clones were sequenced per plant. All EPSPS sequences were analyzed using Sequencer and further sequence analysis was done using the Bioedit software and multiple sequence alignment software, CLUSTALW. Nucleotide and amino acid polymorphisms were analyzed.

RESULTS AND DISCUSSION

AFLP DNA Fingerprinting

The primer pairs selected amplified 398 to 824 DNA fragments per primer pair and 330 to 595 DNA fragments per plant. The populations AR-7 and AR-Grady consisted of only 5 individuals per population so additional plants will be fingerprinted for these populations and more populations will be analyzed from Arkansas, with time.

EPSPS Sequencing and Analysis

Degenerate primers AmpaF1-I/R1-I, AmpaF2-Ia/R2, AmpaF3/R3, and AmpaF4/R4 amplified three fragments of the gene ranging in size from 290 to 800 bp (Fig. 1) while F1-A/R1-A, F3-B/R3-B, F4-A/R4-A, and F6-B/R6-B amplified four gene fragments of about 220 to 800 bp. Of the 13 Palmer amaranth specific primer pairs tested, only three (Mid1EPSF/R, Mid2EPSF/R, and Mid3EPSF/R) had amplification products of 212, 240, and 248 bp, respectively (Fig. 2). Four of the primer pairs optimized for the Georgia population, EPSF1/R8, EPSF6/R6, EPSF7/R7, and EPSF5/R6 produced 162-, 278-, 152-, and about 1600-bp fragments, respectively for Palmer amaranth. The short fragments fell in the same regions that were already amplified by the degenerate primers; however, the long fragment was most useful because it generated about 85% of the total EPSPS sequence based on *A. rudis*. The information obtained so far revealed that the Palmer amaranth EPSPS is 90% identical to that of *A. rudis* (waterhemp) with respect to the amino acid sequence. There is significant variation in the EPSPS sequence of these two species. There are polymorphisms between individuals within each Palmer amaranth population. Thus far, a minimum of two and maximum of four EPSPS alleles were identified per plant.

In the resistant population, GR9 has 3 EPSPS alleles with 95 to 99% identity at the nucleotide level; while GR6 had three alleles with 96 to 99% identity in nucleotide composition. One allele was sequenced from GR4. In the susceptible population, CL5 had four alleles. Only 87 to 90% of the amino acid sequences of these clones were identical. CL10 had two alleles. The identity in nucleotide sequence of GR9, GR6, and GR4 ranged from 96 to 99% and the amino acid sequence identity was 87 to 90%. The same degree of genetic diversity was observed among the CL86 plants. Considering all alleles sequenced, the Grady population from Arkansas and the CL86 population from South Carolina were polymorphic in 37 amino acid positions. There is substantial genetic distance between these two populations owing to localized evolutionary forces that would be different between the two sites of origin. Moreover, Ka/Ks profiles differ between the CL-86 and the Grady population near ~800bp and ~1250 bp (Fig. 3). CL86 has higher peaks at ~800 and ~1250 bp than the Grady implying that the susceptible population is more diverse and that the resistant population is undergoing positive selection pressure.

In terms of amino acid sequence, the resistant population (AR-Grady) showed six potential EPSPS isoforms. We do not know how many of these EPSPS variants produce a functional protein. Further experiments are needed to determine that. The obligate outcrossing nature of Palmer amaranth is indicated in the diversity of this target

gene, which is undergoing intense selection. There were seven amino acid mutations observed in the resistant population that were not observed in any of the EPSPS variants in the susceptible population (Table 1). The amino acid positions were numbered based on the *A. rudis* sequence, starting from the start codon. None of these mutations were found in the glyphosate-resistant rigid ryegrass (*Lolium rigidum*) of Australia (Wakelin and Preston, 2006) nor in the glyphosate-resistant goosegrass (*Eleusine indica*) from Malaysia (Baerson et al., 2002) (Fig. 4). In the case of rigid ryegrass in Australia, only one of seven glyphosate-resistant populations sequenced harbored a mutation that was implicated in glyphosate resistance. The rest showed EPSPS mutations, but their mechanism of resistance involved differential absorption/translocation of glyphosate (Wakelin and Preston, 2006). Sequence information from more Palmer amaranth plants is needed to determine if target site mutation is one of the mechanisms of resistance in glyphosate-resistant populations from Arkansas.

PRACTICAL APPLICATION

Understanding how resistance has evolved and spread among populations of Palmer amaranth would help in the development of strategies to minimize its destructive impact.

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Table 1. Summary of amino acid mutations in the glyphosate-resistant Palmer amaranth population from Arkansas relative to the susceptible population from South Carolina. The amino acid positions were numbered based on the *A. rudis* sequence starting from the start codon.

Plant code	Allele	Amino acid mutations
AR-GR9	Clone 1	Gly231Asp, Met334Thr
AR-GR9	Clone 2	Val249Ala
AR-GR9	Clone 3	Leu90Pro, Deletion at 226, Deletion at 232
AR-GR6	Clone 3	Gly231Val, Asn351Ser
AR-GR4	Clone 1	Lys362Glu

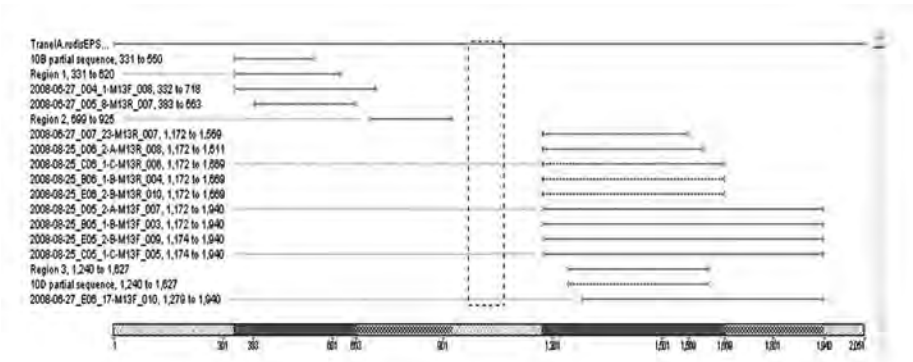


Fig. 1. Schematic alignment of Palmer amaranth EPSPS gene fragments amplified using degenerate primers designed in the Burgos laboratory. The reference sequence was provided by Dr. Patrick Tranel, Univ of Illinois, Champaign-Urbana.

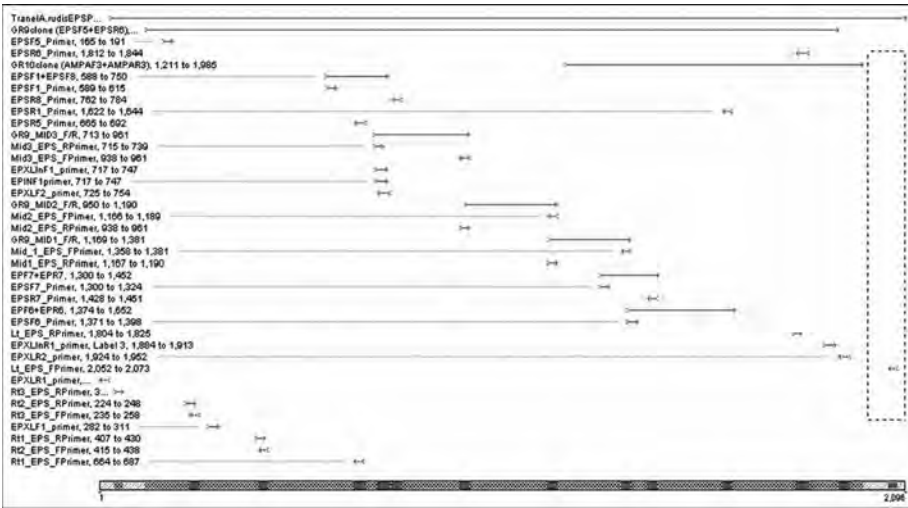


Fig. 2. Schematic view of primers and amplified EPSPS fragment alignment with respect to tall waterhemp (*Amaranthus rudis*), courtesy of Dr. Patrick Tranel, Univ. of Illinois, Champaign-Urbana. Some fragments not included.

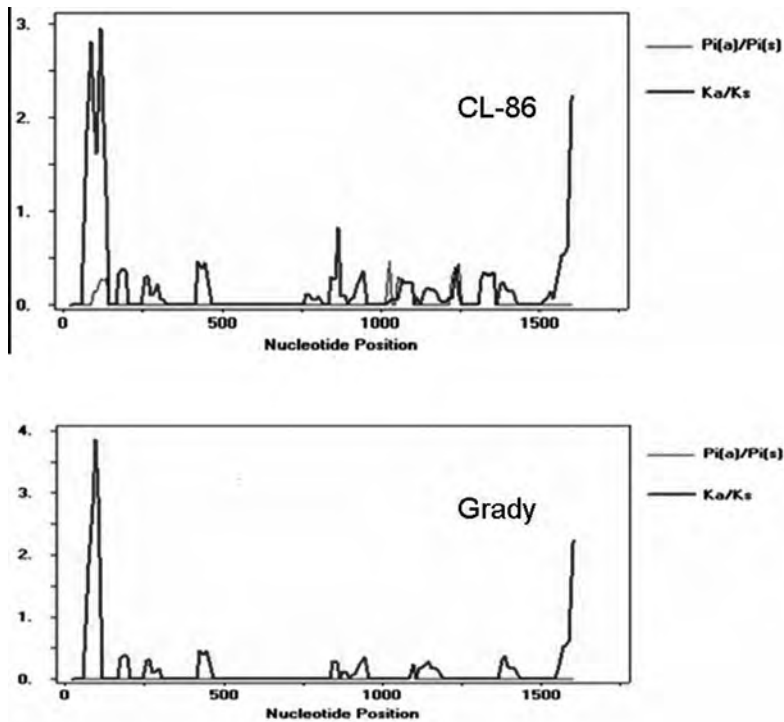


Fig. 3. Nucleotide comparison of Grady and CL86 populations in Ka/Ks profiles.

	170	18
Goosegrass R	FLGNAGTAMRSLTAAV	
Goosegrass S		P
GR9 clone1		P
GR9 clone2		P
GR9 clone3		P
GR6 clone1		P
GR6 clone2		P
GR6 clone3		P
GR4 clone1		P
CL5 clone1		P
CL5 clone2		P
CL5 clone3		P
CL5 clone4		P
CL8 clone1		P
CL10 clone1		P
CL10 clone2		P

Fig. 4. Possible mutation site in glyphosate-resistant Palmer amaranth relative to glyphosate-resistant goosegrass. The resistant Palmer amaranth population did not harbor the mutation found in the glyphosate-resistant goosegrass population.

Economic Analysis and Field Efficacy of Dual-Toxin Bt Cottons in Arkansas – A Two-Year Summary

D. Scott Akin, A. Flanders, Gus M. Lorenz, and Glenn E. Studebaker¹

RESEARCH PROBLEM

Bollworm and tobacco budworm pest management represents a significant but necessary investment for Arkansas cotton growers. The original Bollgard® technology has provided excellent control of tobacco budworm and suppression of bollworm. Bollgard II® and WideStrike® both appear to provide improved control of bollworm and other lepidopteran pests (e.g., loopers, armyworm spp.), but little is known about their potential economic benefit to cotton producers. The objective of this study was to determine the value of second-generation Bt cottons compared to Bollgard and non-Bt cottons.

BACKGROUND INFORMATION

Economic studies have demonstrated the value of Bollgard cotton under a variety of environmental and insect pressure conditions (Mullins and Mills, 1999). Since Bollgard cotton requires fewer insecticide applications for target lepidopteran pests (Layton et al., 2003), direct economic benefit can be attained. Also, natural enemies that are normally suppressed by a number of synthetic foliar insecticides are preserved, resulting in fewer occurrences of secondary pest outbreaks (Van Tol and Lentz, 1998). While the economic advantages of Bollgard cotton compared to non-Bt cotton has been apparent, the relative economic advantage of dual-toxin Bt cottons in Arkansas is relatively unknown.

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RESEARCH DESCRIPTION

Experiments were conducted in at Trumann, Hooker, and Kelso, Ark., in 2007 and 2008 to evaluate the value of stacked-gene Bt cottons to Arkansas cotton producers under typical grower conditions. Insect protection traits in each trial included conventional (non-Bt), Bollgard (Cry1Ac), Bollgard II (Cry1Ac + Cry2Ab), and WideStrike (Cry1Ac + Cry1F). Each experiment contained one variety representing each Bt technology and a non-Bt. These trials were treated on an as-needed basis (based on U of A thresholds) for all caterpillar pests. Technology fees (insect protection traits only), foliar insecticide applications, and yield data were used for economic analysis. Plot size was 16 rows by 200 ft at Kelso, 12 rows by 50 ft at Hooker, and 24 rows by 100 ft at Trumann. Data were collected from random samples of 25 terminals, 25 squares, 25 blooms, and 25 bolls at Hooker and Trumann. At Kelso, 50 of each structure were visually examined for presence of caterpillars and associated damage. Yield data were collected with the respective grower's commercial picker. A boll buggy equipped with weigh sensors was used to determine pounds of seed cotton. Grab samples were collected from the boll buggy and ginned for turnout data to determine lint yield. Plots were set up in a randomized complete block design with 4 replications. Larval counts, associated damage, and yield were collected. Economic analysis was also performed. Data were analyzed using Agronomic Research Manager 8 (Gylling Data Management) for individual trials, and SAS 9.1 (SAS Institute) for cursory analysis of combined data.

RESULTS AND DISCUSSION

In order to evaluate the statewide advantages of available Bt trait packages in cotton, all three locations (both years) were combined for mean seasonal damage, mean seasonal larvae, and seed cotton yield. There was no significant difference in lint yield across all varieties (Fig. 2). For mean seasonal damage (Fig. 1), Bollgard varieties were not significantly different from conventional or Bollgard II or WideStrike. However, both dual-toxin Bt cottons did sustain less damage than the conventional non-Bt when averaged over both years and all locations. Larval numbers were reduced by the presence of any Bt event in all trials compared to the conventional varieties (Fig. 1).

Economic Analysis

Data from experimental plots were evaluated for economic returns by applying appropriate commodity and input prices. A partial budgeting method was utilized in which only relevant input costs differences between technologies was included. Costs differences for insect resistance technology were seed costs (including technology fees) and insecticide applications. Revenue is determined by applying plot yields to a price of \$0.56/lb. This was the expected price of cotton that includes market price and the loan deficiency payment. Stochastic analysis of experimental data provided average net economic returns and probability distributions of seed technologies. Utilizing the empirical distribution of Simetar led to statistical analysis without imposing an assumed probability distribution such as a normal distribution (Richardson et al., 2006).

The empirical distribution generated a probability distribution based on experimental data results. Net revenue for each plot was calculated by multiplying yield and cotton price. Seed costs and insecticide expense, including aerial application, for each plot were then deducted from gross revenue. Seed costs and insecticide expenses were derived from cotton production budgets developed by the University of Arkansas (Stiles and Barber, 2008).

Table 1 reports averages of 500 simulations for each insect resistance technology. WideStrike and Bollgard exhibited the largest yields and revenue in this particular study. Seed costs included technology fees and were identical for each technology over all respective plots. Insecticide expenses included chemical cost and aerial application. Reported expenses were averages for all plots of a technology which had no expenses in some cases. Plots with no insecticide resistance technology had the greatest insecticide expense that averaged \$16.53/acre. WideStrike had the greatest net revenue per acre that was \$4.85 more than Bollgard.

Figure 3 shows the cumulative distribution functions (CDF) for each technology. The CDF indicates the probability that net revenue is equal to or less than a net revenue value on the horizontal axis. Comparing the CDF of WideStrike and Bollgard shows that while they have averages that are similar, Bollgard has a significant probability of net revenue that is lower than WideStrike. The coefficient of variation in Table 1 for Bollgard II suggests that it has less variability than other technologies. Comparing Figure 5 and Figure 6 indicates that this reduced variability occurs at probabilities with high net revenues. Thus, while Bollgard II and WideStrike have similar probabilities of realizing low net revenues, Bollgard II does not have the likelihood of achieving the high net revenues of WideStrike.

PRACTICAL APPLICATION

Results from these trials suggest that when considering overall yield, the type of transgenic Bt cotton was not as important as the variety itself. This is likely due to the overall lack of heliothine pressure at all 3 locations during both years. There are obvious advantages to the dual-gene products such as Bollgard II and WideStrike for control of lepidopteran pests, but this advantage does not necessarily translate to higher yields, especially in the absence of lepidopteran pests. That said, dual-toxin Bt cottons may prove to be more valuable than single-toxin technology during a year that may undergo heavier bollworm flights, or perhaps even a significant fall armyworm or looper migration.

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Table 1. Average yield, revenue, seed costs, insecticide expense, net revenue, and coefficient of variation from stochastic simulation, by insect technology.

Technology	Yield ------(lb)-----	Revenue	Seed cost	Expense	Net revenue	C.V. (%)
None ^z	1,047	586.49	75.84	16.53	494.22	25.7
Bollgard ^y	1,118	625.86	80.12	2.28	543.23	21.8
Bollgard II ^z	1,094	612.84	97.52	0.00	515.35	13.1
WideStrike ^z	1,150	643.93	93.31	2.28	548.08	18.8

^z With Roundup Ready Flex Technology.

^y With Roundup Ready Technology.

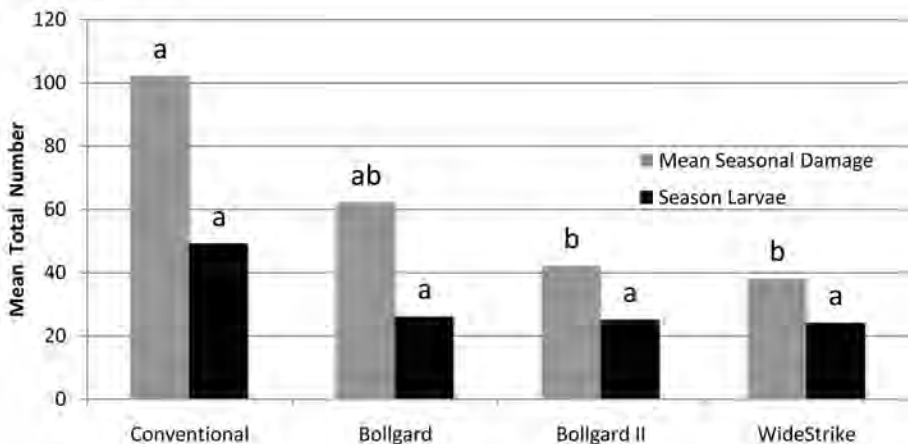


Fig. 1. Mean seasonal damaged structures and mean seasonal larvae in 2007-2008 large plot Bt cotton economic trial (all locations) (SAS, 1998).

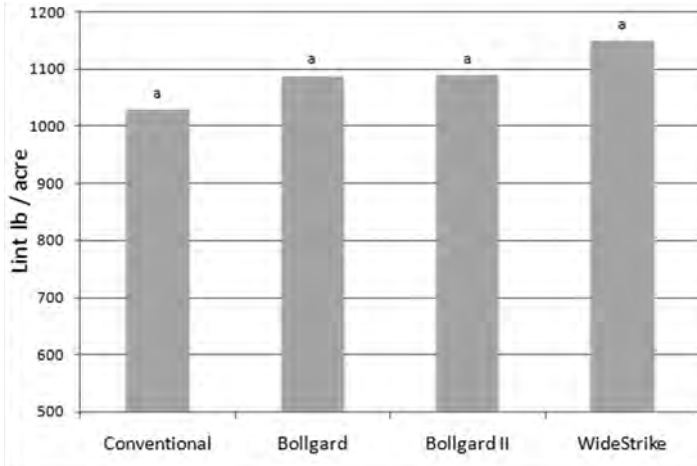


Fig. 2. Yield (lb lint/acre) in 2007-2008 large plot *Bt* cotton economic trial (all locations) (SAS, 1998).

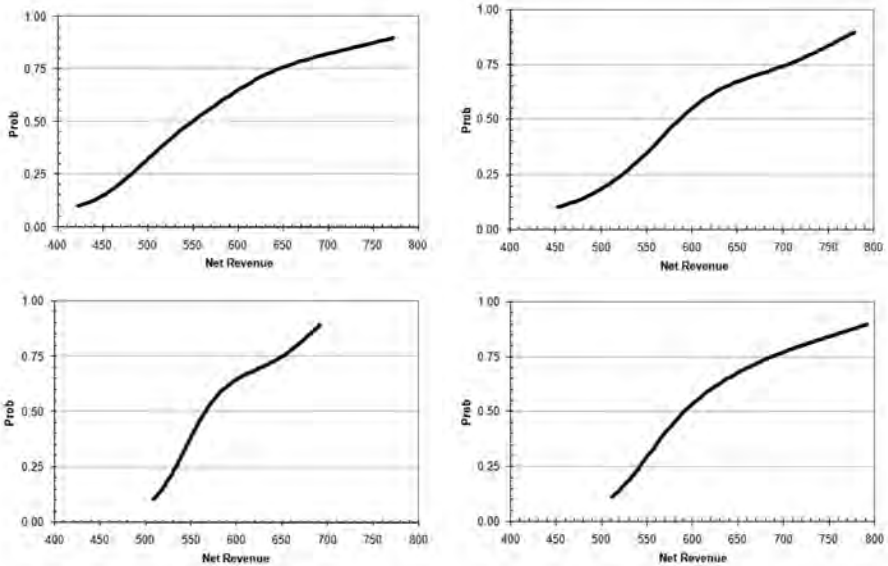


Fig. 3. Cumulative distribution function of net revenue with (a) no insect technology, (b) Bollgard, (c) Bollgard II, and (d) WideStrike.

Effects of Alternative Seeding Patterns, Seeding Rate, and Seeding Configuration on Yield in a Cotton Production System

Tom Barber, Fred M. Bourland, Daniel O. Stephenson, and Jarett Chapman¹

RESEARCH PROBLEM

With the climbing costs of cotton production, producers must ensure optimal returns on their cotton crops in order to make a profit. The groundwork for a high yielding crop has to start with an accurate and efficient planting system to ensure an optimal stand. However, there are a variety of new systems and techniques to incorporate compared to the conventional system that has been used for so long. These new seeding patterns and rates may help stand consistency and may lower cost of seed due to lower seed rates. This study was conducted to elucidate optimal cotton seeding configurations and rates that will maximize plant health and yield in three cotton seeding patterns.

BACKGROUND INFORMATION

Field studies were conducted at the Northeast Research and Extension Center in Keiser and the Lon Mann Cotton Research Station in Marianna. Soil at Keiser and Marianna was a Sharkey silty clay and a Calloway silt loam, respectively. Cotton was seeded at both locations with a John Deere 1700 MaxEmerge Vacuum planter equipped with a SeedStar hydraulic variable-rate seed drive (38-in. single row and 15-in. twin row) and a Monosem Precision NG Twin row Vacuum planter equipped with a Rawson Hydraulic variable-rate seed drive (7.5-in. twin row). Both planters are equipped with variable-rate seed drives to emulate the planters used by producers who wish to vary their seeding rates within a specific area.

Cotton (*Gossypium hirsutum* L.) cultivar Stoneville 4554 B2RF was seeded in all planting patterns, seeding rates, and configurations, on 20 May at Marianna and 21 May at Keiser, at a depth of approximately 0.75-in. Pest and crop management strategies were based on Arkansas Cooperative Extension Service recommendations.

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At both locations, conventional tillage and furrow irrigation was used. Raised beds were prepared in the spring by using a standard 38-in. hipper-bedder at Keiser. The hipper-bedder necessitated the use of a Do-All to level the raised beds; therefore, just prior to planting, beds were leveled (knocked-down) twice resulting in a 20-in. wide bed to allow for planting of the three row spacings. At Marianna, land was prepared by using a 38-in. hipper-roller in the spring and just prior to planting. Following the use of the hipper-roller, bed leveling was not required because the hipper-roller provided a 20-in. wide bed.

Cotton emerged on 25 May and 26 May at Marianna and Keiser, respectively. Mixed fertilizer (P and K) was applied per soil sample results at each location. Nitrogen (N) was applied as a two-way split at both locations. At Keiser, 50 lb N/acre (Agrotain-treated urea) was applied on 1 June and 5 July; and 45 lb N/acre (Agrotain-treated urea) was applied on 31 May and 28 June at Marianna. Cotton was defoliated with two applications of a tank-mixed combination of ethephon, thidiazuron, and tribufos at both locations in October. Cotton was harvested in late October using a John Deere 9930 cotton harvester that is modified with spindle-harvester heads equipped to harvest 15-in. twin-row cotton.

RESEARCH DESCRIPTION

A randomized complete block arranged as a split-plot experimental design was implemented at both locations. Main-plots consisted of three cotton seeding patterns (all seeded atop a 38-in. bed): (1) single rows evenly spaced 38-in. apart; (2) twin rows spaced 7.5-in. apart, with each set of twin rows separated by 38-in.; and (3) twin rows spaced 15-in. apart, with each set of twin rows separated by 38-in. Split-plots consisted of five cotton seeding rates (seeds per acre): (1) 35,000, (2) 45,000, (3) 55,000, (4) 65,000, and (5) 75,000.

Data collected included stand counts recorded 2 to 3 weeks after emergence (WAE), node above white flower (NAWF) counts collected in late-July, percent open boll collected in mid-September, plant structure and cotton boll distribution via plant mapping collected just prior to harvest, seed cotton yield, cotton lint yield, trash and seed percentages, seed and lint indices, seed per acre, and high volume instrument (HVI) measurement of cotton fiber length, uniformity, strength, and micronaire. Data were subjected to ANOVA using PROC MIXED with SAS with replication as a random variable. Main effect and interaction means for cotton seeding pattern and seeding rate were separated with Fisher's protected LSD at $P \leq 0.05$.

RESULTS AND DISCUSSION

Analysis indicated an interaction of location with planting pattern and seeding rate that was significant for percent plant survival; therefore, data were separated by location and reanalyzed. Plant stand data indicated that the overall actual plant survival averaged over seeding pattern and rate was 78 and 97% at Keiser and Marianna, respectively. Plant survival percentages for the main effect of planting pattern and seeding

rate are shown in Table 1. Decreased overall plant survival at Keiser was most likely due to the soil type and extended cool wet weather at planting. Seeding rates of 65,000 and 75,000 seeds/acre resulted in significantly lower plant survival ranging from 70 to 81% at both locations Table 1. Plant mapping data were averaged over location and indicated that the number of monopodial (vegetative) branches were significant across row patterns and seeding rate, but ranges were small, 1.4 to 2.3. Other plant structure variables such as number of sympodial (fruiting) branches (S), number of the highest sympodium with a boll in the first position (ES), were greater for 7.5-in. twin row than other row planting patterns across locations (Table 2). Plant mapping also indicated that these variables were greater for the lowest seeding rate, 38,000 seeds/acre, across locations. There was no significant difference in regards to NAWF, internode lengths, plant heights, and maturity at either location. When data were averaged for plant height, the main effects of location were significant, plants at Keiser were significantly shorter (30 in.) than those at Marianna (38 in.).

Total bolls per plant (TB) were significant for row spacing and seeding rate (Table 3). Generally, as the seeding rate increased total bolls per plant significantly decreased. The highest total bolls/plant (15) were recorded with 7.5-in. twin row cotton planted at 35,000 seeds/acre. Yield variables such as boll retention in the first (BR1), second (BR2), and the sum of the first and second positions on the lowest five sympodia (EBR) were combined over location and found significant for seeding rates, but not row spacing (Table 4). Generally, the lower seeding rates had significantly increased fruit retention on first and second positions than higher seeding rates. These data indicate that as seeding rate (ultimately plant density) increases, cotton plants have less branches and total bolls/plant; however, cotton seeded to achieve a high density of plants may have a greater number of bolls in the first position. This scenario is similar to ultra-narrow-row cotton (cotton seeded in consistently spaced 7- to 10-in. rows), in which the goal is to have short plants that typically produce one to two bolls in the first position. On the other hand, as seeding rate decreases, higher fruit retention was observed with first and second position fruit, which explains the cotton plant's ability to compensate for lower populations.

Cotton lint yield was calculated by lint percentages, taken from a 10-saw microgin. Lint yield combined over locations for seeding rate and row spacing was not significant. Although general trends revealed increased yield when higher seeding rates were used in conjunction with twin 7.5- or 15-in. row spacing. Higher total fruit was recorded in 7.5-in. twin row plots; however, no significant difference in lint yield was observed between planting patterns at either location or among seeding rates (Table 5). A general trend at the Keiser location indicated that higher seeding rates and narrow row spacing may perform better on clay type soils. HVI analysis of cotton lint samples from Keiser and Marianna provided measurements of cotton fiber length, uniformity, strength, and micronaire (data not shown). Analysis indicated that differences in fiber length, uniformity, strength, and micronaire existed only between locations. Planting pattern and seeding rate did not influence these variables at either location. At Keiser, fiber length, uniformity, strength, and micronaire were 1.10, 84.4, 30.6, and 4.2, respectively. Fiber length, uniformity, strength, and micronaire were 1.2, 84.5, 29.4, and 4.8, respectively, at Marianna. These fiber qualities were all within the normal range.

Preliminary results from the second year of this study indicate that planting pattern and seeding rate could influence cotton growth and yield. Additionally, these differences are affected by location of experiment, which may be attributed to soil type and environment. Due to the variation observed among planting patterns and seeding rates at both locations over a two year period, research needs to be continued in the following year to elucidate the affect of alternative planting patterns and seeding rates in cotton.

PRACTICAL APPLICATION

There may be a place to use some of these different seeding patterns and rates in cotton production. Such variables as location, soil type, planting date, environmental conditions, and most importantly, grower preferences, would all need to be taken into consideration before committing to a planting system. More research, with consideration of less variation among locations, may reveal more significant data that will provide producers with proven results of these different seeding patterns and rates.

Table 1. Percent plant survival from row spacing and seeding rate at Keiser and Marianna.

Planting pattern	Plant survival		Seeding rate	Plant survival	
	Keiser	Marianna		Keiser	Marianna
	----- (%) -----		(seed/acre)	----- (%) -----	
38-in. single row	81	96	35,000	83	100
7.5-in. twin row	78	94	45,000	86	100
15-in. twin row	75	100	55,000	79	100
			65,000	72	81
			75,000	70	73
			LSD (0.05)	14	14

Table 2. Effect of planting pattern and seeding rate on plant structure as determined by plant mapping across locations.^z

	Plant structure variables				
	M	S	ES	H2	TN
	-----(#)-----				
Planting pattern					
38-in. single row	1.4	12.2	8.2	9.0	17.4
7.5-in. twin row	1.8	13.7	9.2	10.6	18.2
15-in. twin row	2.0	12.6	9.0	9.9	18.2
LSD (0.05)	0.3	0.8	0.6	0.8	0.6
Seeding rate					
(seed/acre)					
35,000	2.3	13.4	9.8	10.3	18.8
45,000	1.9	12.5	8.9	9.5	18.0
55,000	1.6	12.4	8.5	9.3	17.8
65,000	1.4	12.1	8.5	8.9	17.6
75,000	1.4	12.0	8.2	8.7	17.5
LSD (0.05)	0.8	0.9	0.8	0.8	0.8

^z Abbreviations: M, number of monopodial branches on main axis; S, number of sympodial branches on main axis; ES, number of highest sympodium with a boll in the first position; H2, highest sympodium with two nodal positions; TN, total number of nodes on the main axis above cotyledonary node.

Table 3. Total bolls per plant averaged over location by row spacing and seeding rate as recorded from plant map data.

Seeding rate	38-in.	7.5-in. twin	15-in. twin
(seed/acre)			
35,000	10.3	15.1	10.0
45,000	8.5	8.8	8.6
55,000	7.3	8.7	7.9
65,000	7.1	6.4	7.1
75,000	6.4	7.1	6.5
LSD (0.05)	----- 1.5 -----		

Table 4. Effect of seeding rate on yield variables as determined by plant mapping across locations.^z

Seeding rate (seed/acre)	Yield variables						
	B1	B2	OB	MB	BR1	BR2	EBR
		(%)					
35,000	59.8	21.8	4.2	13.9	49.3	25.5	51.0
45,000	67.3	18.8	2.8	10.8	45.4	17.7	44.0
55,000	67.9	21.3	2.2	8.6	42.9	18.3	42.5
65,000	72.9	18.5	1.0	7.5	41.4	14.7	38.7
75,000	74.7	16.2	1.5	7.4	41.5	13.0	36.6
LSD (0.05)	5.3	3.4	1.6	3.1	3.2	4.3	4.2

^z B1, percentage of TB associated with first sympodial positions; B2, percentage of TB associated with second sympodial positions; OB, percentage of TB associated with sympodial positions outside of first and second positions; MB, percentage of TB associated with sympodia arising with monopodia; BR1, boll retention of first sympodial positions; BR2, boll retention of second sympodial positions; EBR, boll retention of first and second positions on the lowest five sympodia.

Table 5. Effect seeding rate on cotton lint yields across row configuration and main effects of both row spacing and seeding rate on cotton lint yield at Keiser and Marianna.

Row configuration	Seeding rate ^z				
	35,000	45,000	55,000	65,000	75,000
	----- (lb/acre) -----				
38-in. single row	1288	1313	1287	1375	1318
7.5-in. twin row	1204	1229	1350	1369	1379
15-in. twin row	1308	1352	1374	1385	1391
LSD (0.05)	NS	NS	NS	NS	NS
	Main effects of row spacing and seeding rate				
	Keiser		Marianna		
	Lint yield	Lint	Lint yield	Lint	
	(lb)	(%)	(lb)	(%)	
Row spacing					
38-in. single row	1024	40.0	1609	42.0	
7.5-in. twin row	982	41.0	1631	43.0	
15-in. twin row	1089	41.0	1635	42.0	
LSD (0.05)	NS	NS	NS	NS	
Seeding rate					
(seed/acre)					
35,000	983	41.2	1602	43.0	
45,000	1009	41.2	1558	43.0	
55,000	1007	41.2	1653	43.0	
65,000	1054	40.0	1642	43.0	
75,000	1106	40.0	1619	42.0	
LSD (0.05)	NS	NS	NS	NS	

^z Seeding rate data is combined over locations.

Evaluating Importance of Harvest Timing after Complete Defoliation is Achieved

Tom Barber, Frank E. Groves, and Jarett Chapman¹

RESEARCH PROBLEM

Cotton is defoliated prior to mechanical harvesting. For best harvest efficiency, cotton needs to be harvested after complete defoliation is achieved. In certain scenarios, however, this timing of harvest can be delayed due to environmental conditions such as the tropical systems that have been a factor in past years. There is no supported data as to how much yield is actually lost, or at what rate it is lost by delaying the harvest timing after complete defoliation is obtained. Another unproven factor is the yield and efficiency differences among competing cultivars due to delayed harvest timings.

BACKGROUND INFORMATION

The Cotton Incorporated State Support Committee in Arkansas recently funded a four-year project evaluating defoliation timing and relationships between timing, cotton lint yield, and fiber quality (Barber and Bowman, 2008). Results of this study indicated that the most profitable time to defoliate without reduction in yield and fiber quality was defoliation at 850 heat units after nodes above white flower=5 (NAWF5). However, over the four-year period it became apparent that cultivar selection was one of the most important factors in determining the most profitable time to defoliate cotton. Multiple cultivars were tested in the last year of the study and results indicate that the 850 heat unit timing may not work as a blanket recommendation for every cultivar. Maturity differences seem to play an important role in determining the time to defoliate without yield loss, while preserving fiber quality. Preliminary data from 2007 indicated that defoliating some cotton cultivars at 850 heat units may be too early to maximize yield. Concerns of increased micronaire are relevant when delaying defoliation applications; however, some new cultivars may not increase micronaire when defoliation is delayed to 950 or 1050 heat units after NAWF5. The purpose of this study was to evaluate three

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new BollGard II, Flex cultivars to determine the most profitable time to defoliate while maximizing yield and fiber quality parameters.

RESEARCH DESCRIPTION

Studies were initiated in 2008 at the Lon Mann Cotton Research Station at Marianna, Ark., and the Southeast Research and Extension Center at Rohwer, Ark. Plots were set up in a factorial design with two main factors represented by cultivar and defoliation timing. Plots were 4 rows by 50 ft long. Cultivars planted included DP 161 B2RF, ST 5458 B2RF, and PHY 375 WRF. Defoliation applications were based off of heat unit accumulation after NAWF 5 at 750, 850, 950, and 1050, respectively, for each cultivars evaluated. Percent open and nodes above cracked boll (NACB) were also recorded as well as total fruiting nodes at the time of application. Lint yield and quality were taken from each treatment to compare profitability. Treatments were harvested as soon as possible after defoliation applications to maintain fiber quality parameters. Large fiber quality samples were taken from each plot to gin in a commercial size research gin at Jackson, Tenn.

RESULTS AND DISCUSSION

Winds and rainfall from hurricane Gustav and Ike prevented timely applications of harvest aids at all four application timings. Rainfall totaling 18 in. accumulated throughout the months of August and September at the Southeast Research and Extension Center at Rohwer. Similar conditions prevented applications at Marianna. When field conditions allowed, 1050 heat units passed NAWF 5 were already accumulated. Therefore, no data were recorded in 2008 relevant to cultivar effects based on defoliation timing. However, due to the circumstances it was determined that harvest efficiency and timing would be evaluated from the three cultivars at each location. Therefore, 3 harvest dates were determined starting with 14 days after initial defoliation application, followed by 21 and 28 days after initial application. Plots were harvested with a plot picker to determine lost yield by cultivar due to delay in harvest after complete defoliation. Analysis of the data revealed no significant interactions between location and cultivar or harvest date; therefore, data were combined over locations and analyzed for main effects of cultivar and seeding rate. There were significant differences in cultivars when averaged over harvest timings. DP 161 B2RF was the highest yielding cultivar over ST 5458 B2RF and PHY 375 WRF with 1113, 960 and 793 lb lint/acre, respectively (Table 1). The main effect of harvest timing was also significant. The first harvest timing yielded 169 lb/acre more than the second and 406 lb/acre more than the third harvest timing (Table 1). This one-year evaluation suggests that several hundred pounds of lint can be lost by waiting 28 days past defoliation to pick cotton. Table 2 shows data presented by cultivar over harvest dates. The data suggest that one cultivar did not stand out in regards to amount lost over time. Each cultivar lost approximately 400 lb/acre at 28 days after defoliation.

PRACTICAL APPLICATION

Harvest timing and efficiency are critical variables to be considered when scheduling defoliation in cotton. As seen in the past, tropical systems can result in hundreds of pounds of cotton lost to delayed mechanical harvest after complete defoliation. These data confirm the importance of a timely and efficient harvest to prevent cotton loss.

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Table 1. Seedcotton and lint yield results by cultivar and harvest date.

Cultivar	Seedcotton	Lint yield
	----- (lb/acre)-----	
DP 161 B2RF	2929 a ^z	1113 a
PHY 375 WRF	2087 c	793 c
ST 5458 B2RF	2528 b	960 b
Harvest timing		
14 DAT ^y	3018 a	1147 a
21 DAT	2575 b	978 b
28 DAT	1950 c	741 c

^z Yields in a column with the same letter are not significantly different (P=0.05).

^y DAT = days after defoliation treatment.

Table 2. Cotton lint yield by cultivar and harvest date.

Cultivar	Harvest date		
	14 DAT ^z	21 DAT	28 DAT
	----- (lb/acre)-----		
DP 161 B2RF	1294	1152	893
PHY 375 WRF	951	855	574
ST 5458 B2RF	1196	929	757
LSD (P=0.05)	----- 139 -----		

^z DAT = days after defoliation treatment.

Achieving Profitable Cotton Production: Irrigation Initiation and Termination

Tom Barber, Robert Hogan, Jr., Mark J. Cochran, and Jarett Chapman¹

RESEARCH PROBLEM

The demand for high yielding crops while lowering input costs will always be the driving motive for research in row crop production. In an irrigated cotton-production system there are certain water management strategies that can decrease the cost of irrigating. In addition to lowering costs, some crop response may be significant due to different management systems. The objective of this study was to expand the current knowledge base regarding the timing of irrigation initiation in conjunction with COT-MAN-based irrigation termination timing for Arkansas cotton.

BACKGROUND INFORMATION

When meeting with numerous Arkansas cotton producers concerning researchable topics relating to profitability of cotton production, it was decided that economics and agronomics of irrigation management was the most important topic. Traditionally, initiation of irrigation occurs after the layby operations are completed in the field. Yet, improvements in pre-harvest management allow producers to initiate irrigation earlier. It is thought that changing the timing of irrigation initiation may also affect the timing of irrigation termination. In 2008, Arkansas harvested cotton from approximately 610,000 acres, with over 83% of those acres irrigated (NASS, 2008). Timely irrigation of cotton has shown to increase yields, making irrigation a matter of importance. Vories in 2002 (unpublished) estimated that the cost of delayed irrigation was \$106.00/acre. Stress management is important in maintaining cotton structure and fruit throughout the season. Early season environmental stresses usually come from extended periods of hot and dry weather. These conditions, especially high nighttime temperatures can lead to increased boll shed later in the season. Early irrigation is the only way to man-

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age these environmental stresses and aid the cotton plant in cooling thus increasing photosynthetic activity and productivity. In addition, timing of irrigation termination is also of significance. From an economical standpoint, the optimal termination point is defined by the last irrigation that renders an increased yield value that is greater than the irrigation costs. Knowledge of the interaction effects of irrigation initiation and termination timing are limited. The objective of this study was to expand the current knowledge bases regarding the timing of irrigation initiation in Arkansas and determine COTMAN-based irrigation termination timing for Arkansas cotton.

RESEARCH DESCRIPTION

Initiated in 2007, two Upland cotton study sites with differing soil types were selected in Desha County. Site one (Ross field) was located on silt loam soil; site two (Center field) was located on clay loam soil. Study plots extended the full length of the field. Buffer strips were established between each termination treatment to help control error. Standard grower practices were utilized throughout the study. COTMAN data (Oosterhuis and Bourland, 2008) was collected weekly. Partial budgeting and economic techniques were employed to identify yield- and profit-maximizing irrigation initiation and termination points. Three treatments were used to test the effect of irrigation initiation. Treatments were initiating irrigation prior to a traditional layby (Early Initiation), initiating irrigation after an early layby (Mid-Initiation), and initiating irrigation after a traditional layby (Late Initiation). Three treatments were used to test the effect of irrigation termination. Treatments were terminating irrigation at NAWF=5 + 300 accumulated DD60 heat units (Early Termination), terminating irrigation at NAWF=5 + 450 accumulated DD60 heat units (Mid-Termination), and terminating irrigation at NAWF=5 + 600 accumulated DD60 heat units (Late Termination). In 2008, early initiation irrigation timings occurred on 18 June, mid-initiation on 24 June, and late initiation on 3 July. Due to heavy rains, termination treatments were not relevant. NAWF=5 approximately occurred on 14 August. Cotton was harvested from both study sites the second week in October.

The experimental design of the study was a split plot design with irrigation representing main-plot treatments and irrigation termination representing subplot treatments. Cotton data were analyzed by ANOVA of ARM Research Manager (Gylling Data Management, Inc., Brookings, S.D.). In the presence of significant treatment effects ($P < 0.05$), means were separated using least significant differences.

RESULTS AND DISCUSSION

For the Ross field, cotton treated with mid-initiation resulted in the highest net returns (Table 1), however there were no significant differences in cotton lint yield or net returns with any initiation treatment. There were differences in fiber quality parameters of micronaire and fiber length. Cotton fiber tested lower micronaire and longer fiber length in treatments that were early irrigated (Table 1). Plant heights at bloom and harvest, as well as NAWF numbers were also higher with early irrigation initiation

(Table 2). The results at the clay loam site (Center field) were similar to the Ross field. Cotton lint yields and net returns were not significantly different, however differences were observed in fiber quality (Table 3). Micronaire and fiber length with early irrigation were significantly different than mid- and late-initiation timings. Micronaire in the late initiation was reported in the discount range (5.03). Physical parameters such as plant heights at bloom and harvest, NAWF, and total nodes were significantly higher with early irrigation (Table 4); however, differences were not as drastic as in the silt loam Ross field. Number of irrigations were 5, 4, and 3 for the early-, mid-, and late-irrigation initiations, respectively. Data from this trial was most likely skewed due to frequent and heavy rainfall from hurricanes in August and September.

PRACTICAL APPLICATION

Hurricanes Gustav and Ike in late August and September produced heavy rains totaling 18 in. of precipitation. Termination treatments were affected due to frequent rainfall and massive accumulations. Overall yields were most likely affected from rainfall resulting in possible yield loss as well as other factors which may skew the data set for 2008. More research will need to be performed to interpret a more accurate data set regarding irrigation termination in cotton. However, different irrigation initiation timings revealed some physical plant alterations as well as a significant difference in micronaire and fiber lengths in the early irrigations.

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Table 1. Yield, fiber quality, irrigation costs and net returns by irrigation timing on the Ross field.

Cultivar	Lint		Mic ^z	Strength	Length	Uniformity	Gross returns	Irrigation costs	Net returns
	Yield	Percent							
Early - 300	1304.38	42.95	4.70	31.37	1.19	85.00	775	93	682
Early - 450	1302.73	42.95	4.70	31.37	1.19	85.00	774	93	681
Early - 600	1320.94	42.95	4.70	31.37	1.19	85.00	785	93	692
Mid - 300	1335.57	43.24	4.90	30.53	1.19	84.93	793	84	709
Mid - 450	1319.82	43.24	4.90	30.53	1.19	84.93	784	84	700
Mid - 600	1324.75	43.24	4.90	30.53	1.19	84.93	787	84	703
Late - 300	1300.67	43.48	4.93	30.50	1.18	85.87	774	75	699
Late - 450	1292.48	43.48	4.93	30.50	1.18	85.87	769	75	694
Late - 600	1301.63	43.48	4.93	30.50	1.18	85.87	774	75	699
LSD (P=0.05)	41.0	1.677	NS	NS	NS	NS	NS	NS	NS
CV	1.8	2.36	NS	NS	NS	NS	NS	NS	NS

^z Mic = micronaire.

Table 2. Heights, NAWF, and total nodes for Ross field.

Treatment	Bloom height	Harvest height	NAWF bloom	Total nodes bloom
	----- (in.)-----			
Early - 300	28.97	41.30	8.3	13.27
Early - 450	29.63	39.00	8.4	13.00
Early - 600	28.17	42.70	8.2	13.20
Mid - 300	27.07	37.70	7.0	12.67
Mid - 450	27.30	42.70	7.3	13.07
Mid - 600	27.13	40.70	7.0	13.00
Late - 300	26.30	36.30	7.0	12.73
Late - 450	26.47	37.70	6.7	13.53
Late - 600	25.63	38.00	7.0	12.33
LSD (P=0.05)	1.02	4.52	1.2	1.10
CV	2.10	6.20	9.1	4.70

Table 3. Lint yield, turnout, fiber quality, irrigation costs, and net returns for Center field.

Cultivar	Lint		Mic ^z	Strength	Length	Uniformity	Gross returns	Irrigation costs	Net returns
	Yield	Percent							
Early - 300	1133.94	41.74	4.47	31.33	1.18	84.50	674	93	581
Early - 450	1175.20	41.74	4.47	31.33	1.18	84.50	698	93	605
Early - 600	1163.34	41.74	4.47	31.33	1.18	84.50	691	93	598
Mid - 300	1205.59	43.17	4.50	30.67	1.16	84.13	715	84	631
Mid - 450	1210.97	43.17	4.50	30.67	1.16	84.13	718	84	634
Mid - 600	1179.33	43.17	4.50	30.67	1.16	84.13	699	84	615
Late - 300	1160.05	42.26	5.03	30.67	1.16	84.70	659	75	584
Late - 450	1147.05	42.26	5.03	30.67	1.16	84.70	652	75	577
Late - 600	1162.26	42.26	5.03	30.67	1.16	84.70	660	75	585
LSD (P=0.05)	76.30	0.60	0.03	NS	0.10	NS	NS	NS	NS
CV	3.60	2.36	3.50	1.80	1.70	1.3			

^z Mic = micronaire.

Table 4. Heights, NAWF, and total nodes for Center field.

Treatment	Bloom height	Harvest height	NAWF bloom	Total nodes bloom
	----- (in.)-----			
Early - 300	26.03	40.70	8.3	13.13
Early - 450	25.97	38.70	8.3	13.60
Early - 600	24.87	36.70	8.0	13.40
Mid - 300	24.23	39.70	8.0	12.80
Mid - 450	23.33	41.70	8.0	12.93
Mid - 600	24.03	41.30	7.0	13.27
Late - 300	25.53	36.00	7.3	13.20
Late - 450	25.37	36.70	7.7	13.00
Late - 600	24.97	39.30	7.7	13.60
LSD (P=0.05)	2.9	3.04	1.14	0.73
CV	6.6	4.9	8.2	3.12

Density of Tarnished Plant Bug in Different Cotton Cultivars

Glenn E. Studebaker, Fred M. Bourland and Shawn W. Lancaster¹

RESEARCH PROBLEM

Tarnished plant bug (TPB) has risen in status as one of the most prominent pests of cotton in Arkansas. It has been ranked as the number one pest of cotton, causing the highest crop losses each year since 2004 (Williams, 2007). Insecticides are the most commonly used tool for managing TPB in cotton by growers. However, there is growing concern over the development of insecticide resistance in the TPB to some of the most commonly used insecticides such as acephate and dicrotophos. Therefore, it is important to investigate other means of managing TPB in cotton.

BACKGROUND INFORMATION

Host plant resistance is one of the main tenants of integrated pest management and can be a useful tool in managing insect pests. Recent research indicates that certain cotton cultivars are less attractive to TPB. ST4554B2RF has shown lower damage to large squares in small (2 row) plot trials in northeast Arkansas. In the early 1970s frego-bract cotton lines were found to be much less attractive to boll weevil (Mitchell et al., 1973). However, it was also discovered that these lines were very attractive to TPB (Lincoln et al., 1971). The attractiveness of frego-bract cotton may make it a potential candidate as a trap crop for managing TPB in mid-South cotton production.

The objective of this research study was to evaluate the attractiveness of a range of cotton (*Gossypium hirsutum* L.) cultivars that vary in their attractiveness to TPB in larger plots (12 rows by 75 feet). A second aspect of the research was to examine the movement of TPB from a highly attractive frego-bract variety into ST4554B2RF, a much less attractive cultivar, and evaluate the utility of frego-bract lines as a trap crop for TPB.

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RESEARCH DESCRIPTION

ST4554B2RF (low attraction to TPB), DP117B2RF (moderate attraction), SG105 (moderate), ST393 (moderate), and TX-Frego (highly attractive) cotton varieties were planted in 12 row by 75 foot plots replicated 4 times at the Northeast Research and Extension Center in Keiser, Ark., in 2007 and 2008. DP117B2RF and SG105 were only evaluated in 2007 and were not used in 2008 due to lack of availability of seed. ST393 showed similar attractiveness to SG105 and was used in 2008. Plots were arranged and analyzed in a factorial design with cultivar and threshold being the two factors. Plots were monitored weekly for TPB with a drop cloth and treated with 0.5 lbs acephate/acre according to the following thresholds:

- 1) Automatically treated each week
- 2) 3 TPB per 5 row feet
- 3) 5 TPB per 5 row feet
- 4) Untreated control

Eight row strips of TX-Frego were planted next to 12 row strips of ST4554. TPB numbers were monitored weekly at distances of 1, 7, and 12 rows over from the TX-Frego to detect movement from Frego into ST4554. All plots were taken to yield at the end of the growing season.

RESULTS AND DISCUSSION

TPB populations were much higher in 2007 than in 2008. In both years TX-frego cotton had higher numbers of TPB than the other cultivars in the untreated plots (Figs. 1 and 2). TX-frego reached the 3 TPB/5 feet treatment threshold 4 times in 2007 and 2 times in 2008 (Fig. 3). ST4554B2RF reached the 3 TPB/5 feet threshold once in 2007 and zero times in 2008 (Fig. 3). The other cultivars were in between TX-frego and ST4554B2RF (Figure 3) which correlated well with the small 2 row plot data from previous years. Yields for 2007 are reported in Table 1. There was a significant interaction between variety and threshold [Prob(F)=0.0001]. TPB had the biggest impact on yield in TX-frego in 2007. There was little impact on ST4554B2RF yield at the higher TPB thresholds. However, there did appear to be negative effects from weekly applications of acephate on this cultivar, with this treatment having the lowest yield in the test (Table 1). This negative effect did not show up in 2008 (Table 2). Yields for 2008 are reported in Table 2. There were no significant differences in yield in 2008 [Prob(F)=0.86]. This was most likely a result of the low TBP numbers throughout the 2008 growing season.

TPB movement data from TX-frego into ST4554B2RF is shown in Fig. 5. TPB numbers were extremely low in the test until 30 July. On the 30 July 30 and 4 August sample dates TPB numbers in frego were significantly higher than in the adjacent ST4554. In ST4554 TPB numbers were significantly higher in the first row adjacent to frego than numbers in the seventh and twelfth rows over on both these dates. There were no significant differences on the last sampling date (13 August).

PRACTICAL APPLICATION

TPB densities vary in certain cotton cultivars. Cultivars such as ST4554B2RF that exhibit low attraction to TPB required fewer insecticide applications than other more attractive cultivars. Utilization of these cultivars by growers in Arkansas should reduce the number of insecticide applications needed for control and delay the development of insecticide resistance in this important pest.

ACKNOWLEDGMENTS

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Table 1. Cultivar by TPB threshold cotton yields in 2007.

Threshold	TX-Frego	SG105	DP117B2RF	ST4554B2RF
Weekly	1047	1366	1246	996
3 TPB/5 ft	1032	1074	1168	1159
5 TPB/5 ft	982	1188	1130	1090
Untreated	730	953	1151	1070
LSD	----- 122 -----			

Table 2. Cultivar by TPB threshold cotton yields in 2008.

Threshold	TX-Frego	SG393	ST4554B2RF
Weekly	1118	1366	1375
3 TPB/5 ft	1118	1344	1364
5 TPB/5 ft	1001	1264	1209
Untreated	1086	1231	1318
LSD	NS	NS	NS

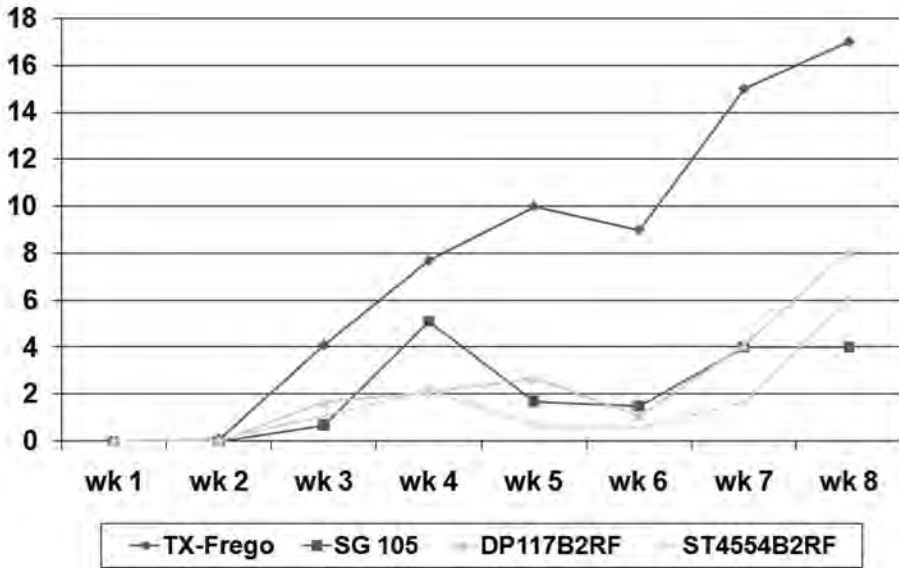


Fig. 1. TPB per 5 row-ft in untreated control plots in 2007.

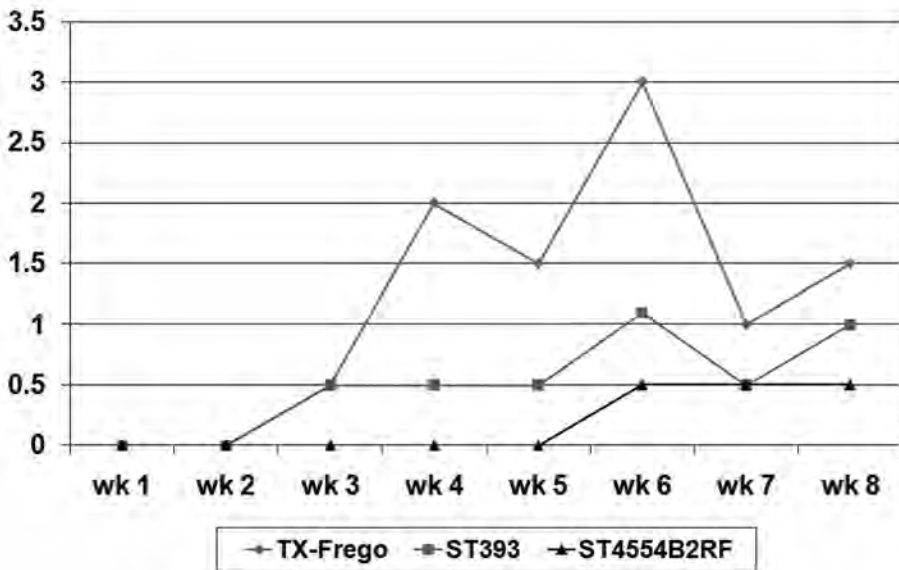


Fig. 2. TPB per 5 row-ft in untreated control plots in 2008.

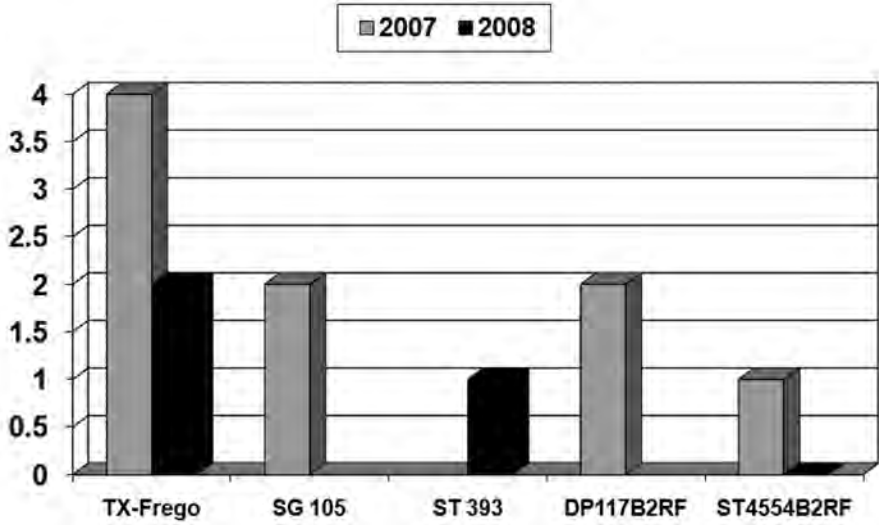


Fig. 3. Number of times the 3 TPB/5 row-ft threshold was reached in 2007 and 2008.

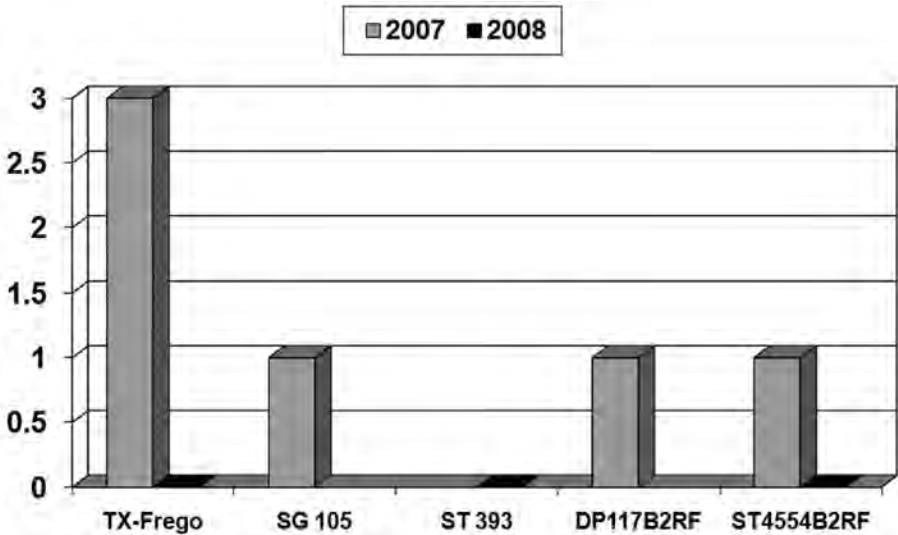


Fig. 4. Number of times the 5 TPB/5 row-ft threshold was reached in 2007 and 2008.

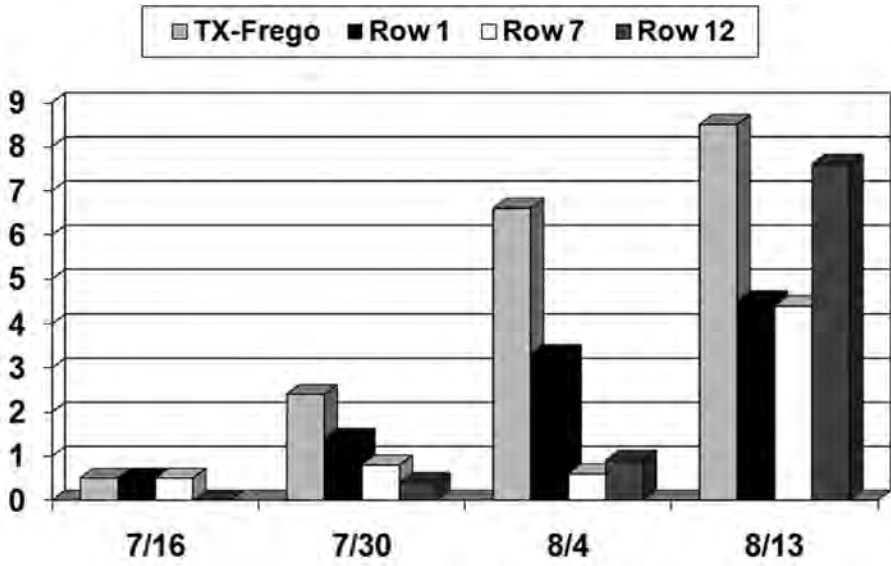


Fig. 5. TPB levels in ST4554B2RF next to TX-frego.

Tillage and Pest Control - Where Should We Focus Management in Building a Sustainable Cotton System?

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Calvin Shumway, and Larry Fowler¹*

RESEARCH PROBLEM

As cotton producers examine ways to reduce costs and increase use of their on-farm mechanization and technology investments, they may consider increasing use of preventative approaches for pest control to reduce the management-intensive practices of scouting and crop monitoring. The Arkansas Integrated Pest Management (IPM) approach endorses scouting and spraying pesticides only when needed. In this report, we summarize results from the first year of a planned 3-year study comparing crop protection practices across different tillage systems.

BACKGROUND INFORMATION

Initiation of formal sustainability research partnerships between Arkansas State University, the University of Arkansas Division of Agriculture, and the Judd Hill Foundation began in 2008 with this Core Cotton Incorporated-sponsored project. A principle project focus is directed toward building and maintaining a sustainable cotton production system that ensures profitability while protecting soil and water quality. While these priorities are shared across the U.S. cotton industry, the Judd Hill Plantation affords an ideal environment for the integrated systems approach needed to further develop, refine, and demonstrate sustainable production methods.

Conservation tillage has become a standard practice for many Arkansas cotton producers. Cover crops of wheat or rye often are used in these systems to reduce damage associated with wind and blowing sand and to enhance weed management. Interest in nitrogen-fixing legume cover crops also is increasing in response to high costs of fertilizer. One concern among producers and their crop advisors is the potential for out-

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breaks of pest insects such as thrips and plant bugs in reduced tillage systems because of increased availability of plant hosts in spring. Perhaps there also are different pest management needs among different tillage systems in the new “low spray” transgenic crop environments that exist in the post-boll weevil era.

MATERIALS AND METHODS

The experiment was carried out at the Judd Hill Plantation near Trumann, Ark. The small plot study was arranged as a split-plot design with 3 different tillage systems, 1) conventional, 2) no till, or 3) no till + legume/cereal cover crop (cover crop), considered main plots. The five crop protection programs, 1) automatic full-season insecticide (early+mid+late season), 2) automatic insecticide mid + late, 3) automatic insecticide mid + late + late miticide, 4) automatic insecticide mid + late + late fungicide, and 5) untreated check, were considered sub-plot treatments. Program details are provided in Table 1. Main plots were 16 rows wide and 450 ft long. Sub-plots were 16 rows wide, 75 ft long with 10 ft alleys.

In October 2007, fall field preparation included disking and establishing beds with disk-hippers. For the cover crop, a balansa clover (Kapraht Seeds, Inc., Manteca, Calif.) and wheat mixture was seeded in appropriate treatment plots on raised beds using a small plot grain drill. The seed blend was prepared and drill calibrated to deliver a seeding rate of 10 lb wheat and 8 lb coated clover seed/acre. In the spring, the cover crop was terminated with broadcast aerial application of glyphosate herbicide made across the entire research farm on 14 April 2008. The experiment was planted using Cruiser treated (thiamethoxam) Stoneville 4554 B2RF on 6 May 2008 in the Dundee silt loam soil at 3 to 4 seeds/ft. Production practices were similar across all tillage treatments in-season with the following exceptions used only in conventional tillage main plots: disk bedders (hippers) used to re-form beds (26 March), tops of beds flattened with a Do-All fitted with incorporater baskets prior to planting, Cotoran + MSMA herbicide applied with hooded sprayer on 16 and 24 June, row middles (water furrows) cleared with sweep plows on 5 June. No cultivations were made in the conventional treatment. Additional herbicides applied across all plots included Prowl (24 oz/acre) + Flo-met (0.6 lb/acre) applied 6 May preplant, and glyphosate applications made 21 May and 12 June. Mepiquat chloride was broadcast applied on 17 June (6 oz/acre), 9 July (6 oz/acre), and 13 Aug (16 oz/acre).

In the main plot tillage treatments, temperature data loggers were installed at the soil surface and at 4- and 12-inch depths. Plant stand density was determined on 30 May by counting plants per 3 ft in two transects across the center 8 rows of each sub-plot (=80 measures/main plot). At 35 days after planting (DAP), 50 consecutive plants were inspected in 2 rows in the center of each plot to estimate percent of plants squaring at 35 DAP.

The COTMAN crop monitoring system (Danforth and O’Leary, 1998; Oosterhuis and Bourland, 2008) was used to document differences in crop development among tillage and crop protection treatments from squaring until physiological cutout. Records of weekly damage assessments and crop response were collected for each crop protection input (pesticides). Square and boll retention was monitored weekly using Squaremap

and in the final week of sampling Scoutmap protocol was used to document incidence of boll rot and hard lock. Boll rot also was noted in end of season sampling. Other pesticide treatment effects were monitored using an array of direct and indirect sampling for pests and their effects. In early season, thrips numbers were monitored using weekly washes of whole plants. Incidence of caterpillar pests (Heliethines), aphids, and other arthropods along with natural enemies (ants and spiders) were counted weekly in drop cloth sampling, sweep net sampling, and using pitfall traps. Beginning in late July, sampling was expanded to include monitoring for two-spotted spider mite (*Tetranychus urticae*). Mite numbers were monitored by counting adults and eggs associated with the fourth fully-expanded leaf counting down from the terminal. Five leaves per sub-plot were collected 3 times immediately preceding and following application of the miticide on 29 July.

Defoliation was initiated on 15 Sept with application of Def (10 oz/acre) + Dropp (1.6 lb/acre) followed one week later with applications of Finish (1 qt/acre) + Ginstar (4 oz/acre). Final end-of-season mapping using COTMAP sampling protocols (Bourland and Watson, 1990) was performed 25 September. Prior to harvest, 50 consecutive bolls were hand-picked from whole plants in each sub-plot for fiber quality assessments. These samples were ginned on a laboratory gin and submitted to the Fiber and Biopolymer Research Institute at Texas Tech University for HVI fiber quality determinations. Additional yield component calculations were made using methods employed in the University of Arkansas variety testing program (Bourland et al., 2008). Plots were harvested with a 2 row research cotton picker on 1 October. Additional “grab” samples of seedcotton from each plot were pulled directly from the picker basket during harvest; these samples also were ginned and submitted for fiber testing. All plant monitoring and yield and fiber quality data were analyzed using ANOVA with mean separation using protected LSD.

RESULTS AND DISCUSSION

Spring 2008 conditions included cool temperatures, high winds, and frequent rain-fall; none were conducive to cotton seedling establishment. Plant stand was significantly reduced in no till and the cover crop system compared to the conventional system (Fig. 1). Heat unit (DD60) accumulations during May indicate higher soil temperatures at 4- and 12-in. depths associated with the conventional tillage treatment compared to the stale seedbeds in the no till and cover crop treatments (Fig. 2). Cool air temperatures in mid-May appeared to be buffered by the presence of the tall wheat cover. There were no measured pest problems associated with arthropods affecting reductions in stand (data not shown); seedling disease measurements were not taken in 2008. Differences in plant growth associated with tillage treatments were evident in preflower sympodial development as depicted in COTMAN growth curves (Fig. 3). At 35 DAP, significantly fewer plants were squaring in the cover crop and no till systems compared to conventional system (Fig. 4). COTMAN sampling results indicated no differences in first position square or boll retention among pesticide treatments (or tillage). Late season boll evaluations with Scoutmap showed no retention differences or differences in boll rot or hard lock associated with the fungicide treatment (data not shown).

Insect pest numbers were very low in 2008. Thrips, tarnished plant bugs, aphids, caterpillars and stink bug numbers never exceeded action thresholds for initiating protective insecticide sprays. No differences were noted across tillage treatments for pest insects. Predaceous arthropods were sampled using pitfall traps, and when total numbers were pooled, no differences were noted in catches among pesticide treatments. June counts of predaceous arthropods indicated that higher total numbers were found in cover crop compared to the no till and conventional system (data not shown). Ants were the most commonly collected group followed by spiders. Preventative insecticide spray treatments induced a spider mite outbreak in mid July, and mite numbers exceeded UA Cooperative Extension action thresholds. On the first mite sample date, significantly higher numbers of mite eggs were noted in cover crop compared to other tillage treatments (data not shown). Numbers of live mites dropped dramatically following the miticide treatment sub-plots; however, the decrease in numbers occurred across all treatments. Mean mite numbers were ca. 50/leaf prior to application and were near zero across the experiment by 8 days after application. Mite mortality across all treatments appeared to be the result of disease epizootic in the field population - a common occurrence in Mid-south cotton.

Results from end of season mapping using COTMAP showed few plant structure differences among treatments. Plants in the conventional system were taller than either no till treatment (Table 2). Plants from the cover crop treatments had fewer sympodial nodes. No differences in final plant mapping measurements were observed among the pest-control program treatments.

Significantly higher yields were associated with the conventional system compared to the no till and cover crop systems ($P=0.01$; $LSD_{05}=183$). Mean lint yields (Figs. 5 and 6) were calculated using 39% turnout. Yield component and HVI lint quality analyses showed no differences among tillage or pest control inputs for quality parameters including % lint, micronaire, length, uniformity, strength, elongation, color, lint index, seed index, fibers per seed, or fiber density (data not shown).

Pesticide applications had no significant effect on yield in 2008 (Fig. 6).

PRACTICAL APPLICATION

Many improvements in water and soil quality were associated with implementation of conservation tillage and cover crops in this first study year, but these are not included in this report. Concurrent improvements in yield were not observed. Yields were significantly reduced in no-till and cover crop systems in 2008.

Yield differences measured among the three tillage systems most likely were related to crop establishment and growth in the first 35 days after planting. Field preparation in the conventional tillage system resulted in a seedbed that was more favorable for germination and seedling establishment in the cool, wet May conditions compared to the stale seedbeds in the no-till and cover crop treatments. A conventional John Deere Max Emerge Air-Flow planter was used, and at times, closure of the seed furrow was not uniform, resulting in reduced seed-to-soil contact leading to stand reductions. Perhaps more importantly, seedbed preparations in the conventional tillage treatment resulted in higher soil temperatures which positively affected seedling growth in the critical first month of crop development.

Pest conditions at Judd Hill in 2008 were such that the insecticide, miticide, and fungicide programs offered no agronomic benefit in any of the three tillage systems. Automatic insecticide applications resulted in secondary spider mite outbreaks. A sustainable cotton system incorporates an IPM strategy which does not include automatic, preventative applications of pesticides. Such applications result in unneeded additional expense and pose risks for environmental contamination. Automatic applications increase risk of pest resurgence and secondary pest outbreaks and can lead to selection of resistant pest populations. Crop monitoring, scouting, and applying chemical control options only when needed are a distinguishing characteristic of the cotton culture of Arkansas where IPM has a long and prominent history. IPM is a key component in a sustainable cotton system.

ACKNOWLEDGMENTS

Special thanks to the Judd Hill Foundation and the staff at the University of Arkansas Division of Agriculture and Arkansas State University Cooperative Research Farm at Judd Hill including UA Program Technicians Jami Nash, Kamella Neeley, and Alan Beach and student assistants Michelle Johnson, Austin Lewis, and Lyndsey Tindell. This project was supported through Core funds from Cotton Incorporated.

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Table 1. Pesticide program descriptions including product, rate, and timings for the five pest control sub-plot treatments in 2008 JH trial.

Treatment description	Pesticide application date ----- (rate/acre)-----
Early, mid, and late season insecticides ^z	Trimax (1.8 oz) 18 June, 2 July; Centric (2 oz) + Diamond (9 oz) 8 July; Leverage (3.75 oz) 22 July; Centric (2 oz) 29 July; Bidrin (3.2 oz) 6 Aug
Mid and late season insecticides	Centric (2 oz) + Diamond (9 oz) 8 July; Leverage 2.7 SC (3.75 oz) 22 July; Bidrin 8EC (3.2 oz) 6 Aug
Mid and late season insecticides + miticide ^y	Centric (2 oz) + Diamond (9 oz) 8 July; Leverage (3.75 oz) 22 July, Zephyr (8 oz) 29 July, Bidrin (3.2 oz) 6 Aug
Mid and late season insecticides + fungicide ^x	Centric (2 oz) + Diamond (9 oz) 8 July; Leverage (3.75 oz) 22 July Bidrin (3.2 oz) 6 Aug; Headline (17, 30 July); Bidrin (3.2 oz) 6 Aug
Untreated check	

^z Automatic insecticide applications were directed at preventing tarnished plant bug and stink bug infestations. All applications were made with a tractor-mounted high clearance sprayer equipped with 8 row boom. Insecticides included were Trimax (imidacloprid), Leverage (imidacloprid/cyfluthrin), Bidrin (dicotophos), Centric (thiamethoxam), and Diamond (novaluron).

^y Zephyr (abamectin) miticide was applied to control spider mites.

^x Headline fungicide (pyraclostrobin) was applied for prevention/control of foliar diseases and boll rot.

Table 2. Results from final end-of-season plant mapping using COTMAP for tillage main plot effects- 2008 Judd Hill^z.

Category	Mean per plant for management treatment			P>F	LSD _{0.05}
	Conventional	no-till	No-till		
First sympodial node	6.9	7.3	6.5	0.11	
No. monopodia	2.7	2.7	2.2	0.08	
Highest sympodia with 2 nodes	11.0	8.4	10.2	0.17	
Plant height (inches)	45.4	36.2	40.0	0.05	6.9
No. effective sympodia	10.8	9.6	10.3	0.17	
No. sympodia	15.7	12.8	14.5	0.05	2.4
No. sympodia with first position bolls	5.3	4.5	5.3	0.36	
No. sympodia with second position bolls	1.2	1.3	1.2	0.87	
No. sympodia with first and second bolls	1.6	0.9	1.2	0.33	
Total bolls/plant	10.3	9.2	9.6	0.66	
% Total bolls in first position	67.5	59.4	67.5	0.46	
% Total bolls in second position	26.6	23.4	25.0	0.71	
% Total bolls in outer position	2.7	3.8	1.0	0.32	
% Total bolls on monopodia	2.8	12.8	6.5	0.06	
% Total bolls on extra-axillary	0.3	0.6	0.0	0.23	
% Boll retention - first position	43.4	41.9	44.6	0.59	
% Boll retention - second position	25.9	25.7	24.1	0.96	
% Early boll retention	49.0	45.7	53.7	0.59	
Total nodes/plant	21.6	19.2	20.0	0.06	
Internode length (in.)	2.1	1.9	2.0	0.14	

^z Means of 10 plants per plot.

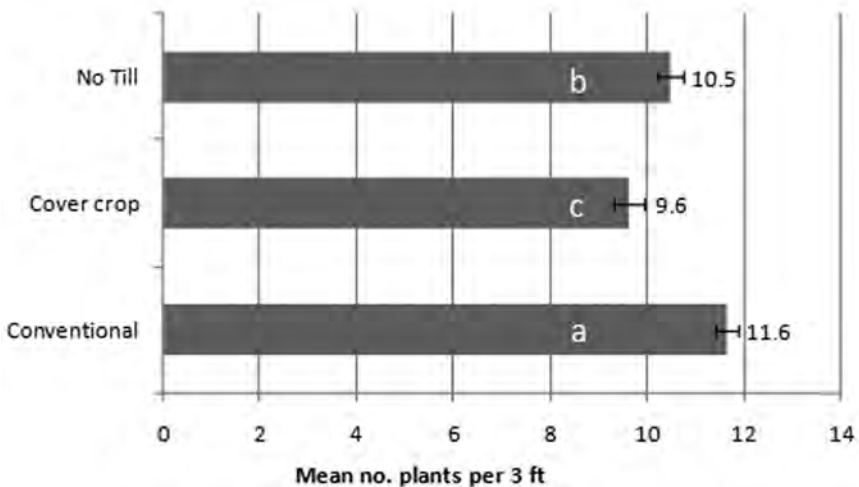


Fig. 1. Crop status and residues on soil surface for the three tillage systems are shown in photographs taken at 9 and 24 days after planting. Significant differences in plant stand density was observed among tillage treatments; mean no. plants (\pm SEM) per 3 ft at 24 days after planting was lowest in cover crop compared to no till. Highest plant stand density was observed in the conventional system ($P=0.001$; $LSD_{05}=0.59$).

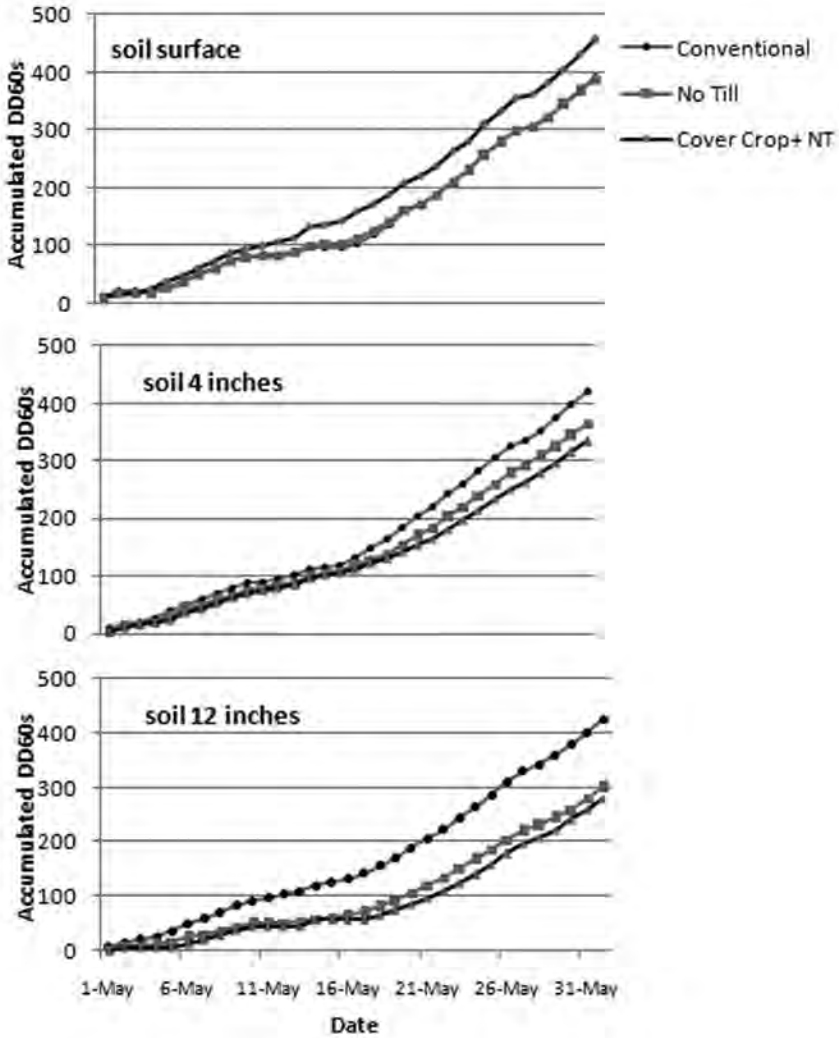


Fig. 2. Cumulative DD60s measured for the month of May for each tillage treatment monitored with Watchdog™ temperature sensors buried at 12- and 4-in. depths and at the soil surface at Judd Hill in 2008 (left). Temperature sensors were encased in weather shields on the soil surface (above) or were in direct soil contact if buried. Date of planting was 6 May.

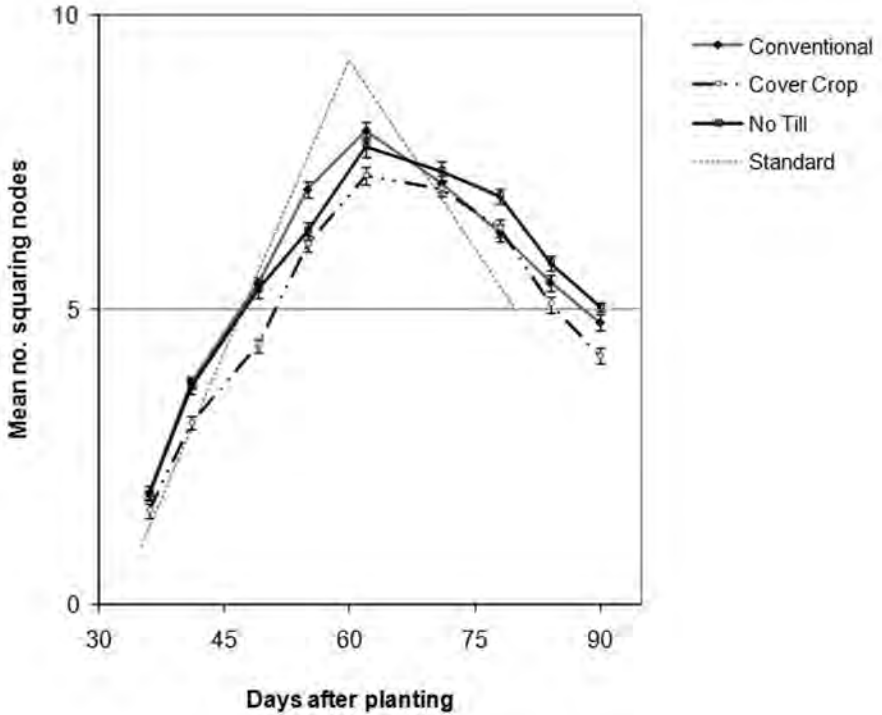


Fig. 3. COTMAN growth curves for main plot tillage treatments in 2008 JH tillage study. Mean number of squaring nodes (\pm SEM) in preflower Squaremap counts indicate delayed cotton plant development in cover crop treatments compared to no-till and conventional. Both cover crop and no-till treatments had fewer main-stem sympodia than conventional by 58 days after planting ($P=0.01$).

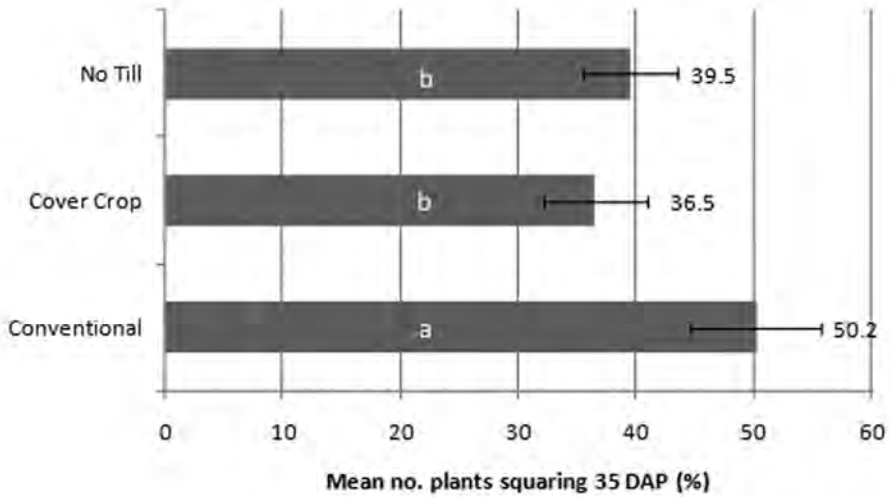


Fig. 4. Mean % of plants (\pm SEM) squaring were determined at the first COTMAN sample date, 35 days after planting. A higher proportion of plants were squaring in the conventional compared to no-till and cover crop treatments.

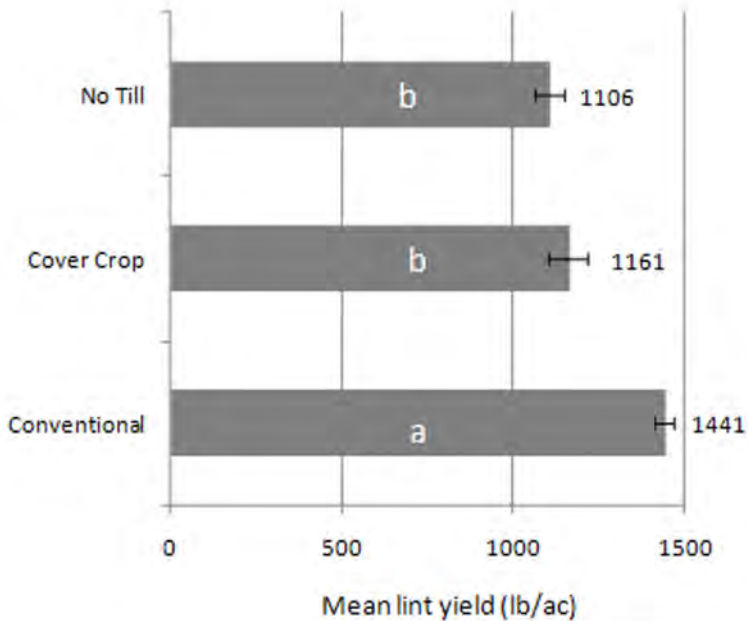


Fig. 5. Lint yield for main plot tillage treatments; conventional management resulted in significantly higher yields compared to the no-till and cover crop systems ($P=0.01$, AOV).

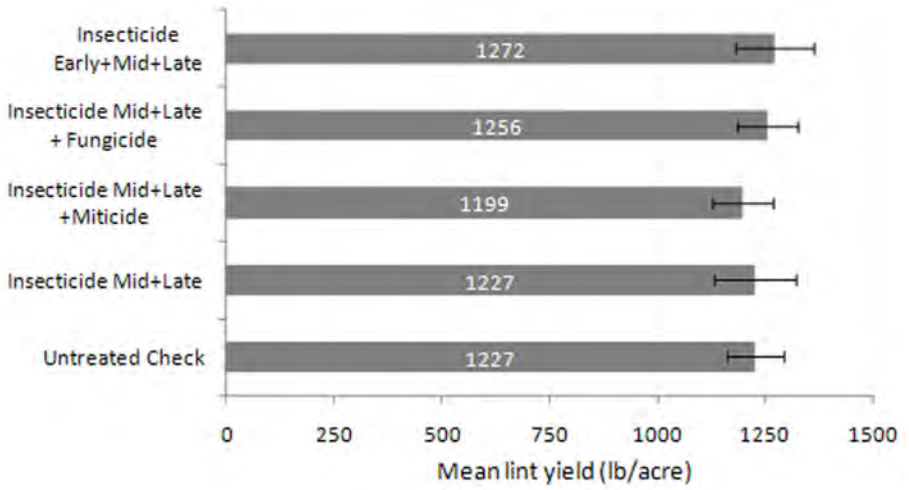


Fig. 6. Mean lint yields (\pm SEM) among pesticide treatments were not different ($P=0.68$), and there were no significant pesticide * tillage interactions ($P=0.78$).

Glyphosate-Resistant Palmer Amaranth Control in Roundup Ready® Flex Cotton

Ryan C. Doherty, Kenneth L. Smith, Jeremy A. Bullington, and Jason R. Meier¹

RESEARCH PROBLEM

Palmer amaranth (*Amaranthus palmeri*) is known to be glyphosate-resistant and one of the most common and troubling weeds in Arkansas cotton production. Roundup Ready® Flex cotton was introduced and grown on two million acres nationwide in 2006. In 2008, 99% of the 620,000 acres of cotton grown in Arkansas were Roundup Ready or Roundup Ready Flex cultivars. In 2008, 215,475 cotton acres were infested with glyphosate-resistant Palmer amaranth. The objective of this study was to evaluate glyphosate-resistant Palmer amaranth control in a Roundup Ready Flex system.

BACKGROUND INFORMATION

In the absence of glyphosate-resistant weeds, Roundup Ready Flex provides the opportunity to control weeds with convenient over-the-top applications. The lack of Palmer amaranth control provided by glyphosate has been fully recognized by most growers and consultants. Glyphosate does still control many of our common weeds found in Arkansas cotton production. More information was needed on the control of glyphosate-resistant Palmer amaranth in Roundup Ready Flex systems.

METHODS AND MATERIALS

In 2008 a trial was established in Lee County, Ark., on a farm known to have a glyphosate-resistant Palmer amaranth population. The trial was established in a Robinville sandy loam soil in a randomized complete block design with four replications.

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Palmer amaranth control was recorded on a 0 to 100 scale with 0 being no control and 100 being complete Palmer amaranth control. Herbicide rates and timings used in this experiment were Cotoran at 0.75 lb ai/acre applied preemergence, Direx at 0.5 lb ai/acre applied to 8-leaf cotton or layby, Dual Magnum at 0.95 lb ai/acre applied to 1-leaf or 4-leaf cotton, Reflex at 0.25 lb ai/acre applied preemergence or to 8-leaf cotton, Suprend at 0.8 lb ai/acre applied to 8-leaf cotton, Valor at 0.064 lb ai/acre and MSMA at 2.0 lb ai/acre applied layby, Roundup PowerMax at 0.95 lb ai/acre applied alone or in combination to 1-, 4-, or 8-leaf cotton and at layby.

RESULTS AND DISCUSSION

Seven days after the 1-leaf cotton application, Roundup PowerMax applied at 1-leaf (lf) provided less than 75%, while all other treatments provided greater than 95% Palmer amaranth control (Table 1). Seven days after the 4-leaf cotton application Cotoran applied preemergence (PRE) followed by (fb) Roundup at 4-lf fb Roundup plus Dual at 4-lf, Reflex fb Roundup plus Dual at 1-lf fb Roundup at 4-lf, and Reflex fb Roundup at 1-lf fb Roundup plus Dual at 4-lf all provided 100% control of Palmer amaranth (Table 2). Eight days after 8-leaf application Reflex fb Roundup plus Dual at 1-lf fb Roundup at 4-lf fb Roundup plus Suprend at 8-lf provided 100% control of Palmer amaranth (Table 3). Thirty-four days after layby Reflex fb Roundup plus Dual at 1-lf fb Roundup at 4-lf fb Roundup plus Suprend at 8-lf fb Roundup plus Valor at layby provided 100% control of Palmer amaranth, while Roundup at 1-lf fb Roundup at 4-lf fb Roundup at 8-lf fb Roundup at layby provided 70% (Table 4). Residual herbicides in combination with glyphosate provided greater than 90% Palmer amaranth control.

PRACTICAL APPLICATIONS

Glyphosate-resistant Palmer amaranth cannot be controlled with over-the-top application of glyphosate alone. Glyphosate tank-mixed or in combination with residual herbicides provided good control of glyphosate-resistant Palmer amaranth. Glyphosate systems are still a viable option for cotton production in Arkansas. The information from this trial is being used to make recommendations to county agents, growers, and consultants throughout the state.

Table 1. Palmer amaranth control 7 days after the 1-lf application.

Treatment	Timing		Palmer amaranth control (%)
	PRE ^z	1-lf	
1 (UTC)	--	--	0.0
2	Cotoran	Roundup + Dual	97.5 a ^y
3	Cotoran	Roundup	100.0 a
4	Reflex	Roundup + Dual	100.0 a
5	Reflex	Roundup	100.0 a
6	Cotoran	Roundup + Dual	97.5 a
7	Cotoran	Roundup + Dual	96.0 a
8		Roundup	72.0 b
9		Roundup	76.0 b

^z PRE = preemergence.

^y Numbers in a column with the same letter are not significantly different (P = 0.05).

Table 2. Palmer amaranth control 7 days after the 4-lf application.

Treatment	Timing			Palmer amaranth control (%)
	PRE ^z	1-lf	4-lf	
1 (UTC)	--	--	--	0.0
2	Cotoran	Roundup + Dual	Roundup	92.0 ab
3	Cotoran	Roundup	Roundup + Dual	100.0 a
4	Reflex	Roundup + Dual	Roundup	100.0 a
5	Reflex	Roundup	Roundup + Dual	100.0 a
6	Cotoran	Roundup + Dual	Roundup	92.0 ab
7	Cotoran	Roundup + Dual	Roundup	87.0 ab
8		Roundup	Roundup + Dual	80.0 b
9		Roundup	Roundup	77.0 b

^z PRE = preemergence.

^y Numbers in a column with the same letter are not significantly different (P = 0.05).

Table 3. Palmer amaranth control 8 days after the 8-If application.

Treatment	PRE ^z	Timing			Palmer amaranth control (%)
		1-If	4-If	8-If	
1 (UTC)	--	--	--	--	0.0
2	Cotoran	Roundup + Dual	Roundup	Roundup + Suprend	96.0 ab
3	Cotoran	Roundup	Roundup + Dual	Roundup + Suprend	95.0 ab
4	Reflex	Roundup + Dual	Roundup	Roundup + Suprend	100.0 a
5	Reflex	Roundup	Roundup + Dual	Roundup + Suprend	98.0 ab
6	Cotoran	Roundup + Dual	Roundup	Roundup + Reflex	90.0 b
7	Cotoran	Roundup + Dual	Roundup	Roundup + Direx	93.0 ab
8		Roundup	Roundup + Dual	Roundup	76.0 c
9		Roundup	Roundup	Roundup	78.0 c

^z PRE = preemergence.

^y Numbers in a column with the same letter are not significantly different (P = 0.05).

Table 4. Palmer amaranth control 34 days after the layby application.

Treatment	PRE ^z	Timing			Palmer amaranth control (%)
		1-If	4-If	Layby	
1 (UTC)	--	--	--	--	0.0
2	Cotoran	Roundup + Dual	Roundup	Roundup + Valor	94.0 abc
3	Cotoran	Roundup	Roundup + Dual	Roundup + Valor	93.0 bc
4	Reflex	Roundup + Dual	Roundup	Roundup + Valor	100.0 a
5	Reflex	Roundup	Roundup + Dual	Roundup + Valor	95.0 abc
6	Cotoran	Roundup + Dual	Roundup	MSMA + Direx	98.0 ab
7	Cotoran	Roundup + Dual	Roundup + Reflex	Roundup + Valor	94.0 abc
8		Roundup	Roundup + Dual	Roundup + Valor	88.0 c
9		Roundup	Roundup	Roundup	70.0 c

^z PRE = preemergence.

^y Numbers in a column with the same letter are not significantly different (P = 0.05).

Management of Seedling Diseases and the Root-Knot Nematode on Cotton with an Indian Mustard Winter Cover Crop

Kimberly A. Cochran and Craig S. Rothrock¹

RESEARCH PROBLEM

One of the limiting factors in cotton production is soilborne diseases. Disease management techniques for these pathogens include fungicide seed treatments and nematicides for seedling diseases and nematodes, respectively. Even with these chemical inputs, diseases continue to be important in limiting yields. Brassica green manure amendments have shown efficacy for disease management for a number of crops. Brassica winter cover crops would fit into an annual cropping sequence with cotton and could offer an alternative to traditional chemical control strategies. The objective of this study was to examine the efficacy of brassica amendments in cotton production systems using the Indian mustard cultivar Fumus.

BACKGROUND INFORMATION

One of the limiting factors in cotton production is soilborne diseases (Kirkpatrick and Rothrock, 2001). Seedling diseases, caused by *Rhizoctonia solani*, *Pythium* spp., *Fusarium* spp., and *Thielaviopsis basicola*, are important in cotton stand establishment every year. In addition to reducing stands and stand uniformity, seedling diseases may reduce plant vigor, delaying crop maturity and reducing yields. Pathogenic nematodes also reduce yields in infested fields. In Arkansas, the most important nematodes in cotton are *Meloidogyne incognita* and *Rotylenchulus reniformis*, the root knot and reniform nematodes, respectively. Disease management techniques for these pathogens include fungicide seed treatments for seedling diseases and nematicides for nematodes.

Brassica crop residues have shown efficacy for disease management for a number of crops. Brassica amendments have been effective in managing diseases on grape (Rahman and Somers, 2005), strawberries (Lazzeri et al., 2003), apple (Mazzola et al., 2007),

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wheat (Kirkegaard et al., 2000), soybean (Lodha et al., 2003), and potato (Snapp et al., 2007). Brassica tissues contain glucosinolates, which breakdown into isothiocyanates, nitriles, thiocyanates, and oxazolidinethiones which are thought to be involved in plant disease suppression (Bending and Lincoln, 1999; Morra and Kirkegaard, 2002). In the southeastern United States, brassica winter cover crops used for soil amendments would fit into an annual cropping sequence with cotton and could offer an alternative to traditional chemical control strategies.

The objective of this study was to examine the efficacy of brassica amendments in cotton production systems using the Indian mustard (*Brassica juncea*) cultivar Fumus, bred specifically for high levels of glucosinolates. Bates (2006) has shown previously that a brassica cover crop suppressed nematodes and seedling pathogens and improved cotton growth in a reniform nematode infested field.

RESEARCH DESCRIPTION

Field experiments were performed in a producer's field with existing soilborne pathogen problems in the 2007 and 2008 cotton seasons in Ashley County. Treatments were the Indian mustard winter cover crop, winter fallow, and winter fallow fumigated with *1,3-dichloropropene* (Telone II). Plots were approximately 70 meters long and 6 rows wide. The experiment had five and eight replications in 2007 and 2008, respectively, and were analyzed as randomized complete block designs.

Brassica seed was applied using hand-held spreaders into the cotton crop near the end of the growing season on 28 September 2006 and 30 September 2007 at a seeding rate of approximately 7 kg/ha. Seed was obtained from Australian Agricultural Commodities (Wee Waa, NSW, Australia). Above-ground biomass was determined by collecting and weighing biomass from an arbitrary 1-m square area in each plot at flowering, just prior to cover crop destruction. Standard herbicide practices were used to manage winter weeds, as well as the brassica crop. Residues were incorporated when beds were prepared. To avoid phytotoxicity to the cotton crop, the brassica crop was destroyed at least four weeks before planting cotton. Cotton was planted on 12 May 2007 and 10 May 2008.

Soils were sampled at the time of brassica crop termination, cotton planting, 21 days after planting (DAP), and cotton harvest. Soil samples were assayed for the populations of the seedling pathogens *R. solani*, *Pythium* spp., and *T. basicola*. For the planting and harvest sampling times, nematode populations were determined at the Arkansas Nematode Diagnostic Clinic, University of Arkansas Southwest Research and Extension Center in Hope, Ark.

At 21 DAP, stand counts were determined on 15.2-m sections of rows 3 and 4. At this time, 25 to 30 seedlings were collected from arbitrary 0.3-m sections from each plot. Seedlings were put on ice and then stored at 4°C prior to processing. Root discoloration and hypocotyl disease symptoms were recorded and the below-ground portions of the seedlings were excised and rinsed with tap water for 20 minutes, disinfested for 1.5 minutes in a 0.5% NaClO solution, and plated on water agar amended with rifampicin, ampicillin, and fenpropathrin (Danitol 2.4 EC, Valent USA Corp.) (WARad). Colonies growing from the seedlings were transferred to potato dextrose agar amended with the

same chemicals (PDArad) for identification. Seedlings were transferred to the selective medium TB-CEN (Specht and Griffin, 1985) modified with 60 mg/liter of Penicillin G and incubated for two weeks for assessment of colonization by *T. basicola*. For early-season seedlings and 6-week-old plants gall ratings were assessed for each plant. Twenty plants were collected for the 6-week sampling from each plot.

Prior to harvest, cotton plants were mapped by arbitrarily selecting a site in one of the two center rows and taking 8 or 10 consecutive plants from each plot on 1 October 2007 or 28 September 2008, respectively, using COTMAP (Bourland and Watson, 1990).

RESULTS AND DISCUSSION

At the Ashley County location in 2007, above-ground brassica biomass averaged 1.967 kg/m². In 2008, the brassica biomass was less than was recorded in 2007, 0.651 kg/m².

No differences were found among the treatments in stand or root discoloration in 2007 (Table 1). In 2008 there were no significant differences in stand (Table 1). However, root discoloration and hypocotyl lesions were reduced by both the Telone and Fumus treatments compared to the fallow treatment (Table 1). Galling ratings were significantly lower for Fumus and Telone treatments than the fallow treatment in 2007 and 2008 (Table 1). *T. basicola* colonization of roots at the Ashley County location for the Telone and Fumus treatments were statistically lower than the fallow treatment in 2007 (data not shown). However, no significant differences were observed in *T. basicola* percent root colonization in 2008. Frequency of isolation of *R. solani* or *Pythium* spp. from seedlings was not significantly different among treatments (data not shown).

The cotton mapping and yield data at the Ashley County location in 2007 showed significant differences in total bolls produced and the seed cotton yield (Table 2). The Fumus and Telone treatments had more bolls per plant than the fallow treatment. Seed cotton yield for mapped plants for the Fumus treatment was significantly greater than both the fallow and Telone treatments. In 2008, harvest data was not statistically different among the treatments (Table 2). In both years, plant height for Fumus and Telone were greater than the fallow treatment at $P = 0.10$.

Pythium and *T. basicola* populations were significantly reduced for the brassica and Telone treatments for some sampling times and years (data not shown). However, no statistical differences were found in *R. solani* or *M. incognita* populations for any sampling time.

When grown as a winter crop and incorporated, the Indian mustard cultivar Fumus effectively reduced cotton seedling disease symptoms. Early-season galling was consistently reduced by the winter cover crop and Telone treatments. Soilborne pathogen population reductions were less consistent across the pathogen groups than disease suppression.

The brassica cover crop treatment resulted in higher cotton yields comparable to or greater than those associated with the Telone treatment. This data supports the results of Bates (2006) in a similar field study in Monroe County. In that study, yield increases were associated with *R. reniformis* population reductions. Yield increases

may be dependent upon establishing significant amounts of biomass, with disease being reduced and cotton growth improved in 2007 but not in 2008 in Ashley County. Other research has shown that rate of brassica application has an impact on disease suppression (Cochran, 2009; Snapp et al., 2007).

PRACTICAL APPLICATION

The Indian mustard cultivar Fumus is a promising new disease management strategy for cotton production systems. While disease suppression was not observed in all years, this strategy reduced seedling disease symptoms and galling and improved cotton yields. Telone and the brassica winter cover crop were found to have similar efficacy. Future studies should examine the method of planting the brassica crop to increase biomass production and evaluate different brassica crops. Large scale evaluations will be needed for evaluating the economic value of this cultural practice compared to chemical control practices. Brassica amendments appear to be a sustainable option for producers.

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Table 1. Seedling stands and disease symptoms.

Year	Treatment	Stand ^z (no./m of row)	Hypocotyl	Root	Galling ^w
			lesions ^y	discoloration ^x	
			----- (%) -----		
2007	Fallow	3.8 a		28.2 a	23.1 a
	Fumus	3.9 a		31.1 a	13.6 b
	Telone II	3.9 a		30.1 a	7.3 b
	<i>P</i> -value	0.4150		0.4189	0.0082
2008	Fallow	3.9 a	97.2 a	30.1 a	33.3 a
	Fumus	4.1 a	76.4 b	25.8 b	23.2 b
	Telone II	4.0 a	81.5 b	26.8 b	21.4 b
	<i>P</i> -value	0.3551	0.0088	0.0049	0.0058

^z Means in a column and year followed by a common letter are not significantly different, protected LSD at $P \leq 0.05$.

^y Percentage of plants with lesions, a rating of 3 or greater; 1= healthy, 2= discoloration, 3= lesion, 4= large or several lesions, 5= girdling lesions.

^x Mid-percentile values of assigned discoloration ratings; 0 = 0%, 1 = 1 to 20%, 2 = 21 to 40%, 3 = 41 to 60%, 4 = 61 to 80%, 5 = 81 to 100% discoloration.

^w Mid-percentile values of assigned gall ratings; 0 = 0%, 1 = 1 to 10%, 2 = 11 to 25%, 3 = 26 to 50%, 4 = 51 to 75%, 5 = 76 to 100% galling.

Table 2. Cotton mapping data and seedcotton yield in 2007 and 2008.

Year	Treatment	First fruiting node	Plant height (cm)	Bolls (no./plant)	Seed-cotton ^z (g)
2007	Fallow	6.0 a ^y	82.5 a	6.6 b	333.60 b
	Fumus	5.0 a	92.8 a	12.3 a	683.80 a
	Telone	5.1 a	94.9 a	10.0 a	418.00 b
	<i>P</i> -value	0.2485	0.0547	0.0138	0.0002
2008	Fallow	5.6 a	101.2 a	12.3 a	1108.20 a
	Fumus	5.5 a	109.6 a	12.4 a	1211.45 a
	Telone	5.8 a	112.8 a	11.5 a	1061.45 a
	<i>P</i> -value	0.5039	0.0690	0.6173	0.4310

^z Total yield for 8 mapped plants in 2007 and 10 mapped plants in 2008.

^y Means in a column and year followed by a common letter are not significantly different, protected LSD at $P \leq 0.05$.

Efficacy of Selected Insecticides for Control of Thrips in Arkansas, 2008

Kyle Colwell, Gus M. Lorenz III, Heather Wilf, Nicole Taillon, Ben Von Kanel¹

RESEARCH PROBLEM

Foliar, in-furrow, and seed-applied treatments for thrips (*Frankliniella fusca*) are often necessary components for cotton production in Arkansas. The agriculture chemical industry continues to develop new insecticides for control of thrips in cotton. These studies were conducted to evaluate and compare the efficacy of foliar insecticides to in-furrow and seed-treatment insecticides. In these trials foliar and seed-treatment applications significantly reduced the thrips populations. With the results of this study, better recommendations can be made for foliar applications in the event that in-furrow and seed treatments lose their effectiveness.

BACKGROUND INFORMATION

Thrips are perennial pests in Arkansas. Levels of damage vary from year to year based on the severity of thrip populations in Arkansas (Hopkins, 2006). Thrips continue to be an economic pest in cotton causing delayed maturity and stunted growth. Under heavy infestations thrips can cause injury to the terminal resulting in delayed maturity and reduced yields. Thrips infested approximately 640,000 acres of Arkansas cotton in 2008. Of the total acres infested with thrips, 356,000 acres were treated with a seed treatment or a foliar application (Williams, 2008). Growers and consultants rely mainly on in-furrow insecticides or insecticidal seed treatments. However, foliar insecticide applications are often required when in-furrow and seed treatments lose control.

RESEARCH DESCRIPTION

Two trials were located in Lonoke County, Ark., in 2008. Plot size was 12.5 ft by 50 ft. The field was planted on 21 May 2008 and monitored weekly for thrips. When

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thrips levels reached the University of Arkansas Division of Agriculture established threshold (5 thrips per plant) in the untreated checks, foliar insecticide treatments were applied with a Mud Master Spray Tractor. The boom was fitted with Tee-Jet TX6 hollow cone nozzles at 19-in. nozzle spacing. Spray volume was 10 gal/acre at 40 psi. Insect density was determined by collecting 5 plants per plot and using a wash technique. Data were processed using Agriculture Research Manager Version 8. Analysis of variance was conducted and Duncan's New Multiple Range Test ($P=0.10$).

RESULTS AND DISCUSSION

During 2008, thrips pressure was heavy and the tobacco thrips were the predominant species infesting cotton at both trial locations. In Trial 1 all treatments had a significantly lower thrips count than the untreated control (Table 1). Dimethoate at 8 oz/acre and Cruiser had significantly fewer thrips than Portal three days after treatment. Ratings at seven days after foliar applications indicated Cruiser had significantly fewer thrips than Portal, Temik, Radiant at 1oz/acre and 1.5 oz/acre, and the untreated control. In Trial 2 at three days after application Avicta and Cruiser had fewer thrips than all other treatments in the trial except Bidrin and Temik (Table 2). Seven days after foliar applications were made, Avicta and Cruiser had statistically fewer thrips than all other treatments in the trial. Orthene, Exp. 4, and Exp. 5 showed better control of thrips than the untreated control and Exp. 2. Ratings after the second application on trial 2 indicated Orthene, Bidrin, Cruiser, and Avicta had fewer thrips than the UTC, Exp. 2, Exp. 3, Exp. 4, Exp. 5, and Portal. Five days after the second foliar application, Orthene, Bidrin, Cruiser, and Avicta provided more control for thrips than Exp. 5 and Temik.

PRACTICAL APPLICATION

The results of these studies will provide growers and consultants with vital information for control of thrips when seed treatments and in-furrow insecticides lose control. Additional trials will be conducted to evaluate new foliar insecticides against current seed treatments and in-furrow recommendations.

ACKNOWLEDGMENTS

The authors thank Don Johnson for his cooperation in these studies. We also acknowledge Cheminova, Bayer, Syngenta, Dow, Nichino, and AmVac for their support.

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Table 1. Efficacy of selected insecticides for control of thrips in Arkansas (Trial 1-Lonoke County).

Treatment			Total thrips per 5 Plants ^z			
			First application		Second application	
Name	Rate	Unit/acre	3DAT	7DAT	2DAT	5DAT
UTC ^y			204.5 a	189.8 a	195.5 a	157.3 a
Radiant	3.0	oz/acre	67.3 bc	90.5 bcde	36.5 b	90.3 b
Radiant	1.5	oz/acre	72.0 bc	135.8 b	50.0 b	110.8 b
Radiant	1.0	oz/acre	89.3 bc	178.3 a	46.8 b	108.0 b
Radiant + COC	1.5 0.5	oz/acre % v/v	40.5 bc	86.8 bcde	8.8 b	42.5 c
Bidrin	0.2	lb ai/acre	41.0 bc	58.8 cde	7.3 b	40.0 c
Acephate	0.2	lbai/acre	38.8 bc	38.0 de	4.3 b	40.0 c
Cruiser	0.34	mg ai/seed	22.5 c	31.3 e	49.0 b	32.5 c
Temik	5.0	lb/acre	105.0 bc	122.3 bc	241.8 a	99.8 b
Dimethoate	4.0	oz/acre	40.8 bc	80.5 bcde	10.3 b	43.3 c
Dimethoate	8.0	oz/acre	29.8 c	40.3 de	4.5 b	23.5 c
Portal	16	oz/acre	124.0 b	102.0 bcd	138.3 ab	120.0 b

^z Means within a column followed by the same letter are not significantly different ($p=0.10$).

^y UTC = untreated control.

Table 2. Efficacy of selected insecticides for control of thrips in Arkansas (Trial 2- Lonoke County).

Treatment			Thrips per 5 Plants ^z			
			First application		Second application	
Name	Rate	Unit/acre	3DAT	7 DAT	2 DAT	5 DAT
UTC ^y			145.5 a	249.8 ab	180.0 ab	89.0 a
EXP1			158.0 a	172.0 a	123.5 bc	82.3 a
EXP2			153.0 a	271.5 a	179.5 ab	96.5 a
EXP3			137.3 a	199.5 abc	252.5 a	67.0 a
EXP4			149.3 a	140.0 a	156.3 ab	77.5 a
EXP5			120.8 a	137.8 c	140.0 ab	59.8 ab
Portal	16.00	oz/acre	147.3 a	199.8 abc	179.8 ab	75.0 a
Avicta complete cotton			16.5 b	28.5 d	26.0 c	15.5 b
Cruiser	0.34	mg ai/seed	17.5 b	20.3 d	21.3 c	8.8 b
Bidrin	0.20	lb ai/acre	145.5 a	164.5 bc	14.0 c	7.0 b
Temik	5.00	lb/acre	79.5 ab	169.8 bc	106.8 bc	40.0 ab
Orthene	0.20	lb/acre	80.0 ab	123.5 c	17.8 c	13.3 b

^z Means within a column followed by the same letter are not significantly different ($p=0.10$).

^y UTC = untreated control.

Efficacy of Selected Compounds for Control of Tarnished Plant Bugs (*Lygus lineolaris*) in Arkansas Cotton

*Heather Wilf, Gus M. Lorenz III, Kyle Colwell,
Nicole Taillon, Robert Goodson, and Ben Von Kanel¹*

RESEARCH PROBLEM

The tarnished plant bug (*Lygus lineolaris*) is the predominant plant bug species in Arkansas and is considered an economical pest of cotton. Two trials were conducted in Lee County, Ark., during the 2008 growing season. The objective of these studies was to evaluate the efficacy of selected insecticides for the control of tarnished plant bugs.

BACKGROUND INFORMATION

The tarnished plant bug (TPB) has become the primary target of foliar insecticides in cotton throughout the mid-South over the last several years. This has prompted a re-evaluation of recommended sampling procedures and thresholds for this pest. Furthermore, scattered reports of TPB showing insecticide resistance and small profit margins prompt growers to become better stewards of the insecticides that are available. Therefore the need for efficacy testing of new and standard insecticides is necessary to help growers and consultants make the best decisions on insecticides for control of this pest.

RESEARCH DESCRIPTION

Test one and test two were located on the Lon Mann Cotton Research Station in Lee County, Ark., in 2008. The cotton (*Gossypium hirsutum* L.) cultivar was PHY 425. A randomized complete block design with four replications was used in both studies.

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Insecticide treatments were applied with a Mud Master spray tractor. The boom was fitted with a TX6 hollow cone nozzles at 19-in. nozzle spacing. Spray volume was 10 gal/acre at 45 psi. Insect density was determined by taking 2 drop cloth samples per plot with a standard 2.5 ft drop cloth (5 row-ft total per plot). Data from test one was collected on 2 September (4 DAT) and 11 September 11 (13 DAT). All ratings from test two were collected on 14 August (7 DAT) and 18 August (4 days after second application).

RESULTS AND DISCUSSION

In test 1 at 4 DAT all compounds reduced TPB numbers compared to the untreated control. Results were similar at 13 DAT. Overall seasonal damage indicated that the untreated control had a significantly higher amount of TPB than all other treatments throughout the season.

In test 2 at 7 DAT, all treatments significantly reduced plant bug numbers compared to the untreated control. Endigo 5 oz/acre had significantly fewer TPB than BAS 320 19.2 oz/acre + Penetrator Plus 0.5% v/v. Ratings from 4 days after the second application indicated that the untreated control had a significantly higher amount of TPB than all other treatments, while Orthene 0.75 lb/acre + X77 Spreader 0.25% v/v had significantly fewer TPB than UTC, BAS 320 16.1 oz/acre + Penetrator Plus 0.5 % v/v, BAS 320 16.1 oz/acre, BAS 320 19.2 oz/acre + Penetrator Plus 0.5 % v/v, and BAS 320 19.2 oz/acre.

PRACTICAL APPLICATION

Evaluation of new and labeled insecticides is an ongoing process which allows us to determine the correct insecticide for a changing cotton production system. With the onset of resistance in many classes of insecticides today efficacy trials take on a vital role in the control of plant bugs for Arkansas cotton producers. Foliar applications provided adequate protection against tarnished plant bugs in both trials conducted. Results from this trial will provide growers and consultants with information to make better decisions in regards to integrated pest management.

ACKNOWLEDGMENTS

We thank the Lon Mann Cotton Research Station for providing a test location. We also acknowledge AMVAC, BASF, Bayer Crop Science, Chemtura, FMC, Helena, MANA, Syngenta, and Valent for their cooperation with these studies.

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Table 1. Efficacy of selected compounds for control of tarnished plant bugs (*Lygus lineolaris*) in Arkansas cotton (Test 1 - Lee County).

Treatment	Rate (oz/acre)	Total tarnished plant bugs - nymphs and adults		
		4 DAT	13 DAT	Seasonal total
UTC ^z		74 a ^y	10 a	83 a
Alias	0.75	33 b	1 a	34 b
Alias	1.50	25 b	3 b	28 b
Tri-Max Pro	1.35	39 b	2 b	41 b
Centric	2.50	17b	3 b	20 b
Alias + Diamond	0.75 6.00	30 b	4 b	34 b
Alias + Diamond	1.50 6.00	18 b	2 b	19 b
Centric + Diamond	2.50 6.00	15 b	4 b	18 b
Diamond	6.00	13 b	1 b	15 b
Diamond	10.00	29 b	2 b	30 b
Dicrotophos	8.00	15 b	2 b	16 b
Bidrin	8.00	16 b	2 b	18 b

^z UTC = untreated control.

^y Means within a column followed by the same letter are not significantly different (p=0.10).

Table 2. Efficacy of selected compounds for control of tarnished plant bugs (*Lygus lineolaris*) in Arkansas Cotton (Test 2 - Lee County).

Treatment	Rate	Unit	Total tarnished plant bugs - nymphs and adults		
			First app. 7 DAT	Second app. 4 DAT	Seasonal total
UTC ^z			39 a	52 a ^y	94 a
BAS 320 + Penetrator Plus	16.10 0.50	oz/acre % v/v	19 bc	28 bc	47 b
BAS 320	16.10	oz/acre	16 bc	29 bc	45 bc
BAS 320 + Penetrator Plus	19.20 0.50	oz/acre % v/v	25 b	31 b	52 b
Orthene + X 77 Spreader	0.75 0.25	lb/acre % v/v	8 bc	5 d	14 bc
BAS 320 Leverage +	19.20 3.80	oz/acre oz/acre	23 bc	35 d	53 b
NIS	0.25	% v/v	9 bc	16 bcd	22 bc
Leverage	5.00	oz/acre	7 bc	10 cd	17 bc
Alias	1.50	oz/acre	13 bc	19 bcd	32 bc
Endigo	5.00	oz/acre	5 bc	4 d	8 c
Carbine	2.30	oz/acre	12 bc	22 bcd	31 bc
Carbine + Orthene	2.30 0.75	oz/acre lb/acre	17 bc	16 bcd	30 bc

^z UTC = untreated control.

^y Means within a column followed by the same letter are not significantly different (p=0.10).

Comparison of Transgenic Cotton for Control of Bollworm and Fall Armyworm in Arkansas, 2008

Gus M. Lorenz III, Kyle Colwell, Heather Wilf, Nicole Taillon, Ben Von Kanel¹

RESEARCH PROBLEM

Bollworm and tobacco budworm pest management represents a significant but necessary investment for Arkansas cotton growers. Many studies have confirmed the positive yield benefit from effective integrated pest management (IPM). The boll weevil eradication program will allow us to take full advantage of the beneficial insect population in management of cotton pests. The original Bollgard technology provided excellent control of tobacco budworm and suppression of cotton bollworm and other lepidopterous pests of cotton. Bollgard II in our studies appears to provide excellent control of Bollworm and other lepidopterous pests such as loopers and beet armyworms. Very little is known about the new transgenic cottons and their efficacy for control of lepidopterous pests in cotton. The sooner we know how well these products work, the sooner we can provide our producers with information on how they best fit on their farm and the advantages they may provide. This study will identify the potential for improved and more economical means for control of bollworm and tobacco budworm and conservation of beneficial insect populations using the new Bollgard II, Widestrike, and original Bollgard technology. Improved use of this technology and determining the fit for Arkansas cotton producers will improve the competitive position of Arkansas cotton producers in the world cotton market.

BACKGROUND INFORMATION

Arkansas has traditionally adhered to using environmentally sound IPM practices in the management of cotton. Professor Dwight Isley was the first to recognize the importance of scouting, economic thresholds, and beneficial insects in the management of bollworm and tobacco budworm. The cotton industry is currently on the brink of a

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new wave of innovation that includes several classes of revolutionary approaches in biotechnology as well as new insecticides.

As a result of the boll weevil eradication program, more than 4.5 million acres of cotton in 8 states are weevil free. Growers are receiving a rate of return of at least 12 to 1 on their eradication dollars - significantly more in some areas. Integrated pest management strategies are working very well in post eradication areas. The amount of pesticide applied in these areas has been reduced by at least 40% and in many cases by as much as 90%. Yields in these weevil-free areas have increased because, with BT cotton and good management, growers are getting a top crop that used to be consumed by late season boll weevils (Cunningham and Grefenstette, 1998). Bollgard cultivars planted in areas where the boll weevil has been eliminated as an economic pest have created a low insecticide use environment compared to historical standards.

In Arkansas we have reported on the economics of Bollgard cotton versus conventional cotton for six years (Kelly et al., 2002, 2004). In many years these economic comparisons indicated that the best use of Bollgard cotton was in the southeast part of the state and the value of the technology was less in the northeast. Widestrike is a new transgenic cotton with a different Bt gene and was observed for the first time by most research and extension personnel in 2003. It is produced by Dow AgroScience.

RESEARCH DESCRIPTION

The trial was located in Jefferson County, Ark., in 2008. Treatments included: a conventional variety DPL 434 (2X); three Bollgard cultivars: STV 5599, DPL 445, and DPL 515; three Bollgard II cultivars: DPL 4554, STV 4427, and DPL-161; and, two WideStrike cultivars: PHY 485 and PHY 375. Plot size was 4 rows by 50 ft. Insect density was determined by sampling 25 terminals, squares, blooms, and bolls per plot. Samples were taken on 22 and 31 July, 8 and 13 August 2008. Plots were machine harvested 15 October. Data were processed using Agriculture Research Manager Version 8, AOV, and Duncan's New Multiple Range Test ($P=0.10$).

RESULTS AND DISCUSSION

Seasonal totals for damage indicated that the conventional variety sustained substantially more damage than all transgenics, however no differences were detected between the different transgenic types. Total bollworm larval numbers showed some differences between the transgenics with conventional cultivars having substantially larger totals than all transgenics (Fig. 1). Also, the Bollgard II cultivars separated from two of the three Bollgard cultivars, although no significant differences were observed between the Bollgard II and WideStrike cultivars. When fall armyworm (FAW) infestations were observed all transgenic cultivars except two of the three Bollgard cultivars had fewer FAW's than the conventional variety (Fig. 2). Harvest data indicated all transgenic cultivars had a significantly higher yield compared to the conventional variety (Fig. 3).

PRACTICAL APPLICATION

The results of these studies will provide growers and consultants with information on the efficacy of the different transgenics for control of the most important lepidopterous pests in cotton. This will help the Arkansas cotton producer determine which of these technologies are the most cost efficient for their operation.

ACKNOWLEDGMENTS

We thank Don Johnson for his cooperation in these studies. We also acknowledge Cheminova, Bayer, Syngenta, Dow, Nichino, and AmVac for their support.

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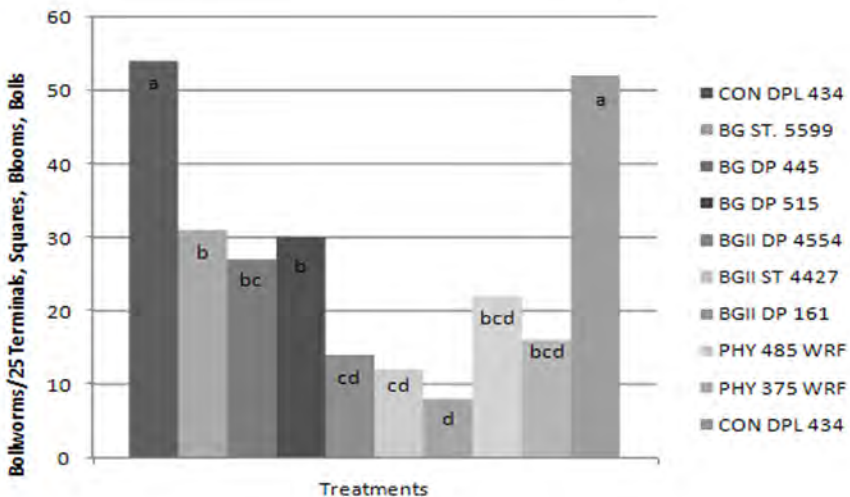


Fig. 1. Small block transgenic seasonal total bollworm larvae. Rating dates 22 and 31 July, and 8 and 13 August 2008. Means followed by the same letter do not significantly differ ($P = 0.10$).

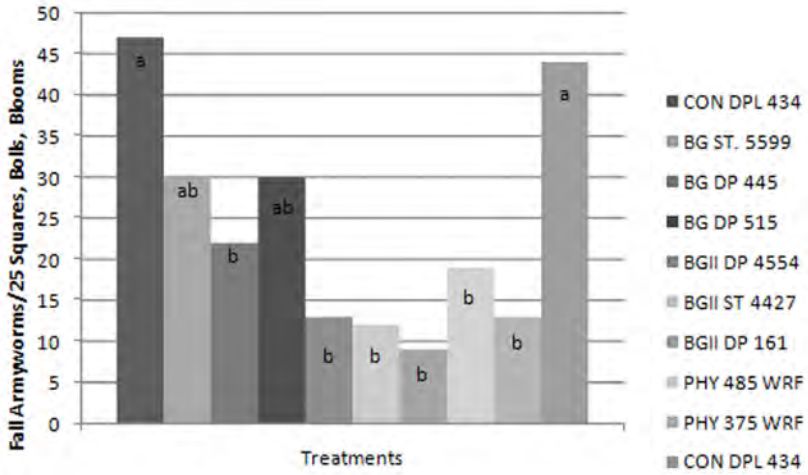


Fig. 2. Small block transgenic FAW totals. Rates dates 22 and 31 July, and 8 and 13 August 2008. Means followed by the same letter do not significantly differ ($P = 0.10$).

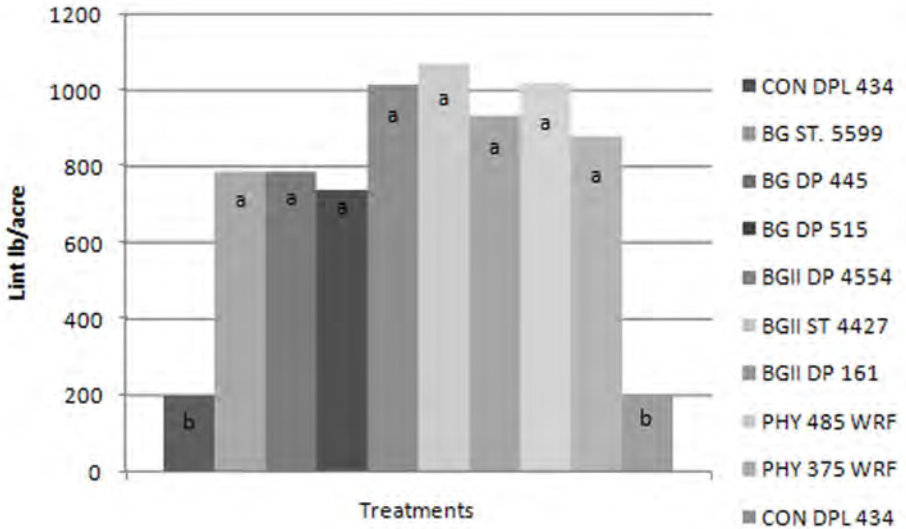


Fig. 3. Small block transgenic harvest data. Planting date 19 May 2008, harvest date 15 October 2008. Means followed by the same letter do not significantly differ ($P = 0.10$).

Selected Yield Components and Associated Properties of Upland Cotton Across Fruiting Zones

Frank E. Groves and Fred M. Bourland¹

RESEARCH PROBLEM

Cotton (*Gossypium hirsutum* L.) yields in Arkansas have fluctuated greatly over the last 10 years (U.S. Dept of Agriculture, 2009). The long-term effects of selection based upon lint percentage have decreased seed size and decreased stability (Lewis, 2001). Lewis suggested that yield and yield stability might be improved by increasing the fibers/seed and fibers/seed could be increased by selecting for higher lint index (i.e., weight of fiber/100 seed). Bednarz et al. (2006) suggested the use of an index such as lint frequency (Hodson, 1920), where seed surface area would be taken into account. The use of fiber density as a selection tool would incorporate the suggestions of Lewis (2001) and Bednarz et al. (2006), but the inheritance of such a component is unknown. In addition, inheritance may vary across the plant depending upon fruit age and exposure to various environmental occurrences.

BACKGROUND INFORMATION

Higher yielding cultivars for a given area typically display yield by location interactions and exhibit decreased stability across environments (Calhoun and Bowman, 1999). The improvement of multiple quantitative traits that contribute to lint yield has proven difficult. In addition to the basic genetic by environmental influences, fruiting zones on a plant may provide sub-environments. These sub-environments create an additional dimension that must be considered for the evaluation of traits. Many yield and fiber components have been shown to vary within the cotton crop canopy (Bennet et al., 1967). Differences in seed index have been observed within fruiting positions (Conkerton et al., 1993). An evaluation of yield component variables within zones might elucidate selection strategies and could shed light on inheritance patterns of yield component variables. Therefore, we hypothesize that differences exist between fruiting

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zones for seed index (SI), lint index (LI), fibers per seed (FPS), and fiber density (FDEN). In addition, we hypothesize these traits are heritable. The objectives of this study were to determine the variation for certain yield component variables among parents and F_1 populations across fruiting zones and over two environments.

RESEARCH DESCRIPTION

In 2007, a test was conducted to evaluate variation for selected yield component traits and to determine their inheritance patterns. The test included a full-diallel set of all F_1 combinations plus the parents and was planted into a Sharkey silty clay soil (very-fine, smectitic, thermic Chromic Epiaquerts) at Keiser on 30 April and a Hebert silt loam soil (fine-silty, mixed, thermic Aeric Ochraqualf) at Rohwer, Ark., on 15 May. Field plots consisted of two rows 6.7-m long on 0.96-m centers with two replications. Genotypes were randomized in each replication with reciprocal crosses in adjacent plots. After emergence, plants were thinned to a uniform density of about 6 plants/row-m. Plants were managed according to University of Arkansas recommended practices and soil moisture was supplemented by furrow irrigation.

Prior to harvest, 10 random plants per plot were mapped using COTMAP (Bourland and Watson, 1990). COTMAP is a modified whole plant mapping technique, which may be used to evaluate various plant structures, boll retention, and boll distribution variables. Bolls on each plant were assigned to six maturity zones based on standard vertical and horizontal flowering intervals. Bolls within zones were hand-harvested and bulked by plot. After ginning, fiber length, length uniformity, and micronaire were determined. Yield component variables included seed index (SI, weight of 100 fuzzy seed), lint index (LI) (weight of lint of 100 seed), fibers per seed (FPS, estimated using lint index fiber properties), and fiber density (FDEN, an estimate of the number of fibers per mm² of seed surface area).

SI, LI, FPS, and FDEN were each analyzed as a split-split plot with replication nested within location as the whole plot (fixed effect), genotype (fixed effect) as the subplot, and fruiting zone (fixed effect) as the sub-subplot. Means were separated using Fisher's protected LSD at the 0.05 significance level. All data were analyzed using the PROC GLM procedure in SAS Version 9.1 (SAS Institute, Cary, N.C.). In addition, weighted means for each variable within each plot were calculated by multiplying the proportion of total bolls that occurred within each fruiting zone by yield component values obtained from each fruiting zone.

RESULTS AND DISCUSSION

Significant variation in location, genotype and zone methods was found for SI, LI, FPS, and FDEN. Location by genotype and location by zone interactions affected all traits. The lack of genotype by zone interaction indicated that genetic effects were consistent over zones and, therefore genetic analyses within zones was not needed. For each variable, whole-plant means (weighted by percentage of bolls in each zone as determined by COTMAP) were then calculated and used in subsequent genetic analyses.

Location by zone interactions for each variable suggested differences in the distribution of fruit between Keiser and Rohwer. Although significant variation among zones was observed at each location, the means exhibited a much smaller range at Rohwer than at Keiser. The relatively low variation between zones at Rohwer may be contributed to increased season length at this more southern location. SI at both locations and LI at Keiser declined from zone 1 (bolls from first week of flowering) to zone 4 (fourth week of flowering) while values for zone 5 (bolls in positions 3 or greater) and zone 6 (bolls from monopodial branches) were intermediate to values for zones 3 and 4. This variation relates closely to expected maturity of bolls with later maturing bolls producing lower SI and LI. FPS and FDEN at Keiser tended to increase, rather than decrease, from zones 1 to 4. Genotype by location interactions for each trait may be partly explained by relative values across locations of specific genotypes (the parents and F_1 's). Specific parents and associated F_1 's that most greatly affected the interaction varied among the traits.

Due to the genotype by location interactions, genetic analyses were conducted by location for each trait. Both general combining ability (GCA) and specific combining ability (SCA) were significant for SI, LI, FPS, and FDEN at each location (Table 1). Significant reciprocal effects were only found for LI at Keiser. For each trait, the influence of GCA greatly exceeded the influence of SCA. For SI and FPS, the relative values of GCA and SCA were similar at both locations. GCA had relatively stronger influence on LI at Rohwer than at Keiser, but had relatively stronger influence on FDEN at Keiser than at Rohwer.

PRACTICAL APPLICATION

The lack of an interaction of genotypes by fruiting zones verifies current boll sampling procedures for yield component traits. The general combining ability indicates strong additive effects for each trait, including FDEN. FDEN may be used in a cotton breeding program and should respond favorably to direct selection.

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Table 1. General combining ability (GCA), specific combining ability (SCA), and reciprocal effects for four yield component variables determined from eight parents and their complete set of F_4 's.

Trait	Location	GCA	SCA	Reciprocal
Seed index	Keiser	5.79 ***	0.50 ***	0.27
	Rohwer	4.79 ***	0.48 ***	0.28
Lint index	Keiser	1.21 ***	0.27 ***	0.17 *
	Rohwer	6.10 ***	0.27 *	0.23
Fibers per seed	Keiser	13.90 ***	1.98	1.18
	Rohwer	16.54 ***	1.15 **	0.65
Fiber density	Keiser	6.53 ***	1.27 ***	0.66
	Rohwer	3.91 **	0.50 **	0.17

APPENDIX I
STUDENT THESES AND
DISSERTATIONS RELATED TO COTTON
RESEARCH IN PROGRESS IN 2008

- Allen, Kerry Clint. Spatial and temporal distribution of *Helicoverpa zea* (Boddie) and *Heliothis virescens* (F.) in heterogeneous cropping environments in southeastern Arkansas. (Ph.D., advisor: Luttrell)
- Avila, Carlos A. Transfer of reniform nematode resistance from diploid cotton species to tetraploid cultivated cotton. (Ph.D., advisor: Stewart)
- Bibi, Androniki. Effect of high temperatures on the biochemistry of the reproductive process in cotton genotypes. (Ph.D., advisor: Oosterhuis)
- Chappell, Adam. Evaluation of a new cotton aphid threshold and the impact of selected insecticides on the beneficial arthropod complex found in Arkansas cotton with emphasis on predacious coccinellids important for cotton aphid suppression. (M.S., advisor: Lorenz)
- Galligan, Larry. Optimizing release strategies of *Neozygites fresenii* (Entomophthorales: Neozygitaceae) for induction of epizootics in *Aphis gossypii* (Heteroptera: Aphididae). (M.S., advisor: Steinkraus)
- Griffith, Griff. Erratic cotton responses to trifloxysulfuron and applications. (M.S., advisor: Norsworthy)
- Groves, Frank. Inheritance of cotton yield components and relationships among yield, yield components, and fiber quality. (Ph.D., advisor: Bourland)
- Gonias, Evangelos. Environmental factors and plant growth regulator effects on radiation use efficiency in cotton. (Ph.D., advisor: Oosterhuis)
- Jackson, Sarah. Relationships of marginal trichomes on cotton bracts to yield and fiber quality. (M.S., advisor: Bourland)
- Kawakami, Eduardo. Agronomic, physiological, and biochemical effects of 1-MCP on the growth and yield of cotton. (M.S., advisor: Oosterhuis)
- Kulkarni, Subodh. Soil compaction modeling in cotton. (Ph.D., advisor: Bajwa)
- Loka, Dimitra. Effect of high night temperature on cotton gas exchange and carbohydrates. (M.S., advisor: Oosterhuis)
- Ma, Jianbing. Influence of soil physical parameters, *Thielaviopsis basicola*, and *Meloidogyne incognita* on cotton root architecture and plant growth. (Ph.D., advisors: Kirkpatrick and Rothrock)

- Nader, Anna Camila. Effect of transgenic antifungal peptides on mycorrhizal associations. (M.S., advisor: Stewart)
- 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)
- Osorio, Juliana. Comparison of BC1 and F2 maps of an interspecific hybrid (*G. darwinii* x *G. hirsutum*). (M.S., advisor: Stewart)
- Snider, John. Effects of high temperature stress on the anatomy and biochemistry of pollen-pistil interactions in cotton. (Ph.D., advisor: Oosterhuis)
- Still, Josh. Ecology and overwintering ability of *Rotylenchulus reniformis* in Arkansas. (M.S., advisor: Kirkpatrick)
- Storch, Diana. Physiological and biochemical response of cotton to temperature stress during reproductive development. (M.S., advisor: Oosterhuis)
- Tiwari, Rashmi. Molecular characterization of the diversity and natural hybridization of the *Gossypium* species of the arid zone of Australia. (M.S., advisor: Stewart)
- Toksoz, Harun. Efficacy of seed treatment chemicals, including fungicides and host resistance inducers, and chlamyospore germination stimulants in controlling the black root rot pathogen, *Thielaviopsis basicola*, on cotton. (M.S., advisor: Rothrock)

APPENDIX II
RESEARCH AND EXTENSION
2008 COTTON PUBLICATIONS

BOOKS

- Oosterhuis, D.M. and F.M. Bourland (eds.). 2008. COTMAN Crop Monitoring System Manual. Published Cotton Incorporated, Gary, N.C.
- Oosterhuis, D.M. (ed.). 2008. Summaries of Arkansas Cotton Research in Progress. University of Arkansas Agricultural Experiment Station. Research Series 562. 180 pp.

BOOK CHAPTERS

- Bourland, F.M., D.M. Oosterhuis, N.P. Tugwell, and M.J. Cochran. 2008. Stepwise progression through BOLLMAN with instructions for non-computer users. Chapter 7. COTMAN Crop Monitoring System Manual. Published Cotton Incorporated, Gary, N.C., and University of Arkansas, Fayetteville.
- Bourland, F.M., N.P. Tugwell, T.A. Kerby, and R. Benson. 2008. Recurring questions about COTMAN. Chapter 13. COTMAN Crop Monitoring System Manual. Published Cotton Incorporated, Gary, N.C., and University of Arkansas, Fayetteville.
- Bourland, F.M., D.M. Oosterhuis, N.P. Tugwell, and M.J. Cochran. 2008. Interpretation of crop growth patterns generated by COTMAN. Chapter 9. COTMAN Crop Monitoring System Manual. Published Cotton Incorporated, Gary, N.C., and University of Arkansas, Fayetteville.
- Bourland, F.M., D.M. Oosterhuis, N.P. Tugwell, and M.J. Cochran. 2008. Initial development of the COTMAN program. Chapter 2. COTMAN Crop Monitoring System Manual. Published Cotton Incorporated, Gary, N.C., and University of Arkansas, Fayetteville.
- Danforth, D.M. 2008. Appendices. COTMAN Crop Monitoring System Manual. Published Cotton Incorporated, Gary, N.C., and University of Arkansas, Fayetteville.
- Hogan, R., M.J. Cochran, D.M. Danforth, W.C. Robertson, and K.J. Bryant. 2008. Costs and benefits of COTMAN. Chapter 12. COTMAN Crop Monitoring System Manual. Published Cotton Incorporated, Gary, N.C., and University of Arkansas, Fayetteville.

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- Oosterhuis, D.M., F.M. Bourland, N.P. Tugwell, and M.J. Cochran. 2008. Overview of the COTMAN expert system of cotton plant management. Chapter 1. COTMAN Crop Monitoring System Manual. Published Cotton Incorporated, Gary, N.C., and University of Arkansas, Fayetteville.
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- Oosterhuis, D.M. and T.A. Kerby. 2008. Measures of cotton growth and development. Chapter 3. COTMAN Crop Monitoring System Manual. Published Cotton Incorporated, Gary, N.C., and University of Arkansas, Fayetteville.
- Oosterhuis, D.M., N.P. Tugwell, D. Fromme, and F.M. Bourland. 2008. Using COTMAN to manage defoliation and harvest efficiency. Chapter 10. COTMAN Crop Monitoring System Manual. Published Cotton Incorporated, Gary, N.C., and University of Arkansas, Fayetteville.
- Robertson, W.R., D.M. Oosterhuis, R. Benson, F. Groves, and F.M. Bourland. 2008. Utilization of COTMAN in to enhance yield and revenue in cotton. Chapter 11. COTMAN Crop Monitoring System Manual. Published Cotton Incorporated, Gary, N.C., and University of Arkansas, Fayetteville.
- Teague, T.G. and D.M. Danforth. 2008. COTMAN Sampling and Data Collection. Chapter 5. COTMAN Crop Management System Manual. Published Cotton Incorporated, Gary, N.C., and University of Arkansas, Fayetteville.

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