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Summaries of Arkansas Cotton Research 2007

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Edited by Derrick M. Oosterhuis

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Summaries of Arkansas Cotton Research 2007 Oosterhuis AAES

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SUMMARIES OF ARKANSAS COTTON RESEARCH 2007

Edited by Derrick M. Oosterhuis

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SUMMARIES OF ARKANSAS COTTON RESEARCH 2007

PREFACE

Arkansas' cotton producers reduced acreage approximately 29% to 850,000 acres of cotton in 2007. The reduction in acres was a direct result of increased commodity prices, mainly for corn. Cotton producers averaged 1,062 lb lint/acre in 2007. This was the second highest yield on record for Arkansas and 17 lb/acre on average higher than the 2006 crop. The highest yield recorded for the state was 1,114 lb lint/acre in 2004. For the last four seasons, cotton producers in Arkansas have averaged over 1,000 lb lint/acre and ranked second for the last three years behind Texas in United States cotton production. Arkansas produced 1.8 million bales of cotton in 2007.

The 2007 growing season started off rough for many producers across Arkansas. Colder temperatures causing a late April freeze resulted in many acres of replanted corn. The cooler temperatures also delayed cotton planting for the first time in many years. However, conditions improved and the bulk of the 2007 crop was planted during the first and second week of May. Cotton emerged quickly with warm temperatures and with these warmer temperatures, emergence was more even than the last few seasons. Environmental conditions were excellent for cotton early, which resulted in quick growth and high fruit retention going into bloom. Rainfall patterns were scattered throughout the state in 2007. The northeast portion experienced droughty conditions, while in some areas of southeast Arkansas, irrigation pumps were not turned on until late July or early August due to frequent rainfall.

Production problems in 2007, other than the extreme dry conditions in the northeast, were mostly pest-related. The increased acreage of corn surrounding cotton fields resulted in extremely heavy infestations of tarnished plant bugs. Many producers suffered yield losses from plant bugs where fields bordered corn. In some cases, threshold levels were reached every time the fields were scouted, resulting in numerous sprays to control re-infestations of plant bugs. Glyphosate-resistant weeds continued to be a problem that plagued cotton fields. This past season numerous fields were sampled and found to contain populations of glyphosate-resistant pigweed. Management of glyphosate-resistant weeds will continue to be a major challenge in the future of Arkansas cotton production.

Overall, 2007 was a good year for cotton production in Arkansas. However, increased costs of production, mainly fuel and fertilizer, reduced profit margins in many areas. Producers needed to average close to 1200 lb/acre to break even in 2007.

Tom Barber and Derrick Oosterhuis

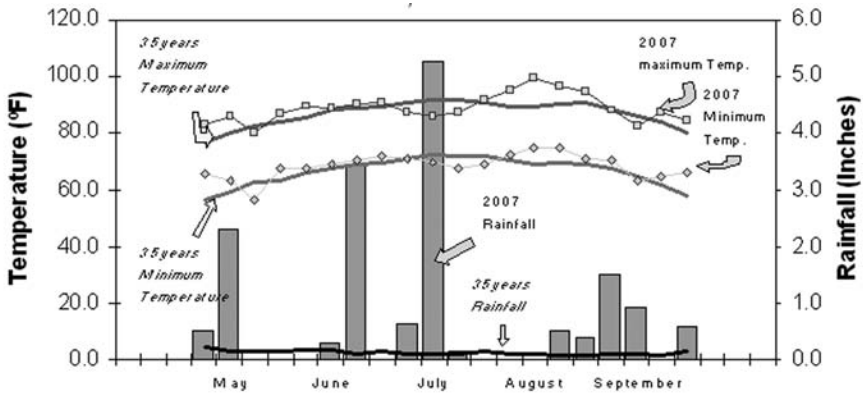

Fig. 1. Weekly maximum and minimum temperatures and rainfall for 2007 compared with the long-term 35-year averages in eastern Arkansas.

ARKANSAS COTTON RESEARCH GROUP

2007/2008

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 M. Bourland, Frank Groves, Gus Lorenz, Gene Martin, Robert McGinnis, Derrick M. Oosterhuis (Chm.), Craig Rothrock, James McD. Stewart, and David Wildy.

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

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

Genetics: Fred M. Bourland, Hal Lewis, and James McD. 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.

2007 Cotton Achievement Award

The Arkansas Boll Weevil Eradication Foundation

The Arkansas Boll Weevil Eradication Foundation (ABWEF) was established by legislation, Act 710 of the 1991 Arkansas State Legislature, for the purpose of eliminating the boll weevil from Arkansas. The eradication of the boll weevil was and still is a national program designed to eliminate the boll weevil north of Mexico. Eradication of the boll weevil from the southeastern states has allowed resurgence of cotton production from Virginia to Florida, and only Texas now produces more cotton than Georgia. Prior to implementation of the Boll Weevil Eradication Program, the states of the southeast were not considered as major players in cotton circles.

The members of the ABWEF are cotton producers from five regions of the state. The Board currently has nine members including the Director of the State Plant Board. Six of the members are new appointees, replacing members that had served from the beginning. The ABWEF is the vehicle that has given the Arkansas cotton farmer the benefit of a boll weevil-free growing season. Without the eradication of the boll weevil, and especially with the current input costs of seed, fuel, and fertilizer for the crop, cotton would not be grown in Arkansas today.

The program revenues are as follows: 71% paid by cotton producers ($131,000,000), 25% by USDA Aphis ($46,000,000), and 4% by the State of Arkansas ($7,500,000). With total income of $199,730,000 and total expenses of $218,616,000, this leaves a deficit of $18,886,000 that the producers will pay through fees. In recent years the approximate annual revenue for cotton production was $832,536,407. An average yield increase of 200 to 300 lb/acre has occurred during the eradication program.

The ABWEF has developed and implemented a program that has played a leadership role in saving an important segment of Arkansas Agriculture. For this reason the Arkansas Boll Weevil Eradication Foundation was elected to receive the 2007 Arkansas Cotton Achievement Award for their contribution to Arkansas cotton. While the individuals named below were responsible for implementation of the program, many individuals (too numerous to name here) were responsible for the day-to-day operation of the eradication program.

The current, former, and non-voting members of the ABWEF are as follows:

CURRENT

Ritter Arnold (Chairman, Dec. 03 - present)	Marked Tree
Laudies Brantley (Secretary / Treasurer)	England
Trent Felton (Vice-Chairman)	Marianna
Glenn Brackman	Bradley
Bobby Gammill	Tyronza
Darryl Little	Little Rock
Joe Mencer	Lake Village
Kenneth Qualls	Lake City
Randy Reynolds	Blytheville

FORMER

Don Alexander (replaced by Darryl Little)	Little Rock
Mark Bryles (replaced by Randy Reynolds)	Blytheville
Joe Burns (Chairman, April 1996 - December 2003)	Rector
Jack Carey (Chairman, April 1991 - April 1996) (replaced by Joe Mencer)	Dumas
Hal Hyneman (replaced by Bobby Gammill)	Jonesboro
Gerald King (replaced by Don Alexander)	Little Rock
Perry Stratton (Chairman April 2002 - December 2003) (replaced by Laudies Brantley)	Pine Bluff
Charles Tillmon (replaced by Glenn Brackman)	

NON-VOTING

Bill Yearian (first member)	Fayetteville
Don Johnson (replaced Dr. Yearian)	Cabot
Gus Lorenz (current, replaced Dr. Johnson)	Little Rock

COTTON INCORPORATED AND THE ARKANSAS STATE SUPPORT COMMITTEE

The *Summaries of Arkansas Cotton Research 2007* has been 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 certain staff members of the University of Arkansas, 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, Tennessee, administers the act, and contracts implementation of the program with Cotton Incorporated, a private company with its world headquarters in Cary, North Carolina. 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 2007.

Projects	Researcher	Short title	$ Funding
02-291AR	Oosterhuis	Annual Research Summaries	$6,500
04-439AR	Kirkpatrick	Reniform nematode biology-Ark.	$18,488
05-630AR	Cochran	Economics of N & K Fertilization	$34,114
05-631AR	Baker	Remote sensing for scouting	$8,549
05-632AR	Savage	Liberty-Link vs. RoundupReady	$16,000
05-634AR	Robertson	Optimal defoliation timing	$19,140
06-797AR	Lorenz	Plant bug thesholds	$21,520
07-973AR	Bourland	Cotton breeding	$26,804
07-974AR	Hogan	Irrigation start and stop	$23,780
07-975AR	Espinoza	Gypsum	$23,715
07-976AR	Lorenz	Bt technology	$25,565
07-977AR	Oosterhuis	High temperature effects	$15,975
07-978AR	Groves	Verification program - SE	$31,073
07-979AR	Rothrock	Black root rot	$19,916
07-980AR	K. Smith	Palmer amaranth	$19,661
07-981AR	Stephenson	15-inch rows	$24,035
07-986AR	Oosterhuis	Cuticle penetration	$4,165
TOTAL			**$339,000**

SUMMARIES OF
ARKANSAS COTTON RESEARCH
— 2007 —

University of Arkansas Cotton Breeding Program - 2007 Progress Report

Fred M. Bourland[1]

RESEARCH PROBLEM

The University of Arkansas Cotton Breeding Program attempts to develop cotton genotypes that are improved with respect to yield, host-plant resistance, fiber quality, and adaptation to Arkansas environments. Such genotypes would be expected to provide higher, more consistent yields with fewer inputs. To maintain a strong breeding program, continued research is needed to develop techniques that will identify genotypes with favorable genes, combine those genes into adapted lines, and 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 (2007) provided the most recent update of the current program.

RESEARCH DESCRIPTION

Each year, breeding lines and strains are tested 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 evaluated

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

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 2007 was to combine lines having specific morphological traits, enhanced yield components, and improved fiber characteristics. In the conventional breeding effort, 12 new crosses, 18 F_2 populations, 18 F_3 populations, 16 F_4 populations, 704 first year progeny, and 228 advanced progeny were evaluated. Bolls were harvested from superior plants in F_2 and F_3 populations and bulked by population. Individual plants (651) were selected from the F_4 populations. After discarding individual plants for fiber traits, 442 progeny from the individual plant selections will be evaluated in 2008. Also, 216 superior F_5 progeny were advanced, and 72 F_6 advanced progeny were promoted to strain status.

Additionally, transgenic forms of Arkot lines were crossed with lines possessing nectariless, frego-bract, high-glanding, or red-leaf traits. The transgenic effort included 10 new crosses, 10 F_2 populations, and 51 first-year progeny. A total of 300 plants was selected from F_2 transgenic populations, and 203 of these will be evaluated as progeny in 2008. After discarding for fiber traits, 34 of the 51 first-year progeny will be evaluated as advanced progeny in 2008.

Strain Evaluation

In 2008, 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 2008 New and Advanced Strain Tests. Superior strains exhibited a wide range of lint percentages, leaf pubescence, maturity, and fiber quality. The 2007 New and Advanced Strains were tested for host-plant resistance (tarnished plant bug, bacterial blight, fusarium wilt, root knot nematode, 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 2007, the Arkansas Agricultural Experiment Station released six cotton germplasm lines that were developed by this breeding program. These included Arkot 9608ne, Arkot JJ46, Arkot 9610, Arkot 9620, Arkot 9623, and Arkot 9625. Arkot 9608ne possesses the nectariless trait, which provides some resistance to tarnished plant bugs. All of the 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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Relationships of Yield Component Variables to Yield and Fiber Quality Parameters

Frank E. Groves and Fred M. Bourland[1]

RESEARCH PROBLEM

Increased yield and improved yield stability have been difficult traits to attain in a cultivar (Geng et al., 1987). Arkansas cotton production state averages have trended upward from 714 in 1999 to 1062 lb/acre in 2007 (Anonymous, 2008). During the same nine-year period, yields from the Arkansas Cotton Variety Testing Program fluctuated greatly among locations within and over years. Therefore, the upward trend in the state average yields may have masked a continued problem of yield stability among cultivars. These wide fluctuations suggest that strong genetic-by-environmental interactions are present that influence yield stability.

BACKGROUND INFORMATION

Lint percentage has long been used as selection criterion for improved lint yield. Lint percentage measures the relative proportions of lint and seed in seedcotton and is strongly influenced by seed size. Continued selection for increased lint percentage may have contributed to yield instability through the selection of smaller seeded lines. As early as 1908, Cook suggested lint index as a preferred selection tool over lint percentage (Cook, 1908). Lint index represents the grams of fiber per 100 seed. Selection for lint index will likely increase seed size since larger seed have greater surface area to produce fibers. Hodson (1920) recognized the importance of seed surface area and introduced lint frequency as a method of improving yield potential while reducing the influence of seed size. Lint frequency measures the grams of fiber of uniform length produced per square centimeter of seed surface area. Thurman (1953) expanded on previous findings with the introduction of lint density index. Lint density index measures the weight of fibers produced per 100 square centimeters of seed surface area. The search for appropriate selection criteria has continued to evolve, but has fallen short of the simultaneous improvement of lint yield and yield stability. A better understanding

[1] Cotton research verification program coordinator, Southeast Research and Extension Center, Monticello; and director, Northeast Resarch and Extension Center, Keiser, respectively.

of the influence of fiber and yield components on lint yield could provide insight into yield stability.

RESEARCH DESCRIPTION

In an effort to improve selection methods, data from strain tests and irrigated and non-irrigated variety tests conducted in the University of Arkansas Cotton Breeding and Variety Testing programs were evaluated. Data were collected from 1999 through 2006 at four locations encompassing a range of 200 miles. Path coefficients from PathSAS were used to identify the direct effects and correlations of a model involving: lint yield; seed per acre; fiber density; seed yield; seed surface area; fibers per seed; seedcotton yield; seed percentage or lint index; lint weight per fiber; upper half mean length; and micronaire or uniformity index.

RESULTS AND DISCUSSION

Preliminary analysis indicated that seed per acre had the greatest influence on lint yield (0.86, 0.85, and 0.91) for the strain (Fig. 1), irrigated (Fig. 2) and non-irrigated (Fig. 3) variety tests, respectively. However, this trait exhibits low heritability and is highly dependent on environmental factors. Strain tests and non-irrigated variety trials proved to be poor representatives of true genetic relationships due to limited genetic diversity and moisture variability, respectively. The irrigated variety tests data indicated fiber density (0.17) had greater influence on lint yield than seed surface area (-0.02). Fibers per seed (0.68) had the greatest influence on fiber density, and lint index (0.69) had the greatest effect on fibers per seed. These preliminary data suggest that fiber density could serve as selection criteria for increased yield and stability.

PRACTICAL APPLICATION

The historical focus on lint yield improvement in breeding programs has encouraged decreased seed size and increased seed per acre. Although these traits have been shown to improve yield, they have been strongly influenced by environmental conditions and contributed to instability. The use of fiber density as a selection criterion could improve yield stability by improving the heritable traits that contribute to lint yield and minimizing the environmental influences. Ultimately, improved yield stability could lead to improved farm management by minimizing extreme fluctuations in net returns.

ACKNOWLEDGMENTS

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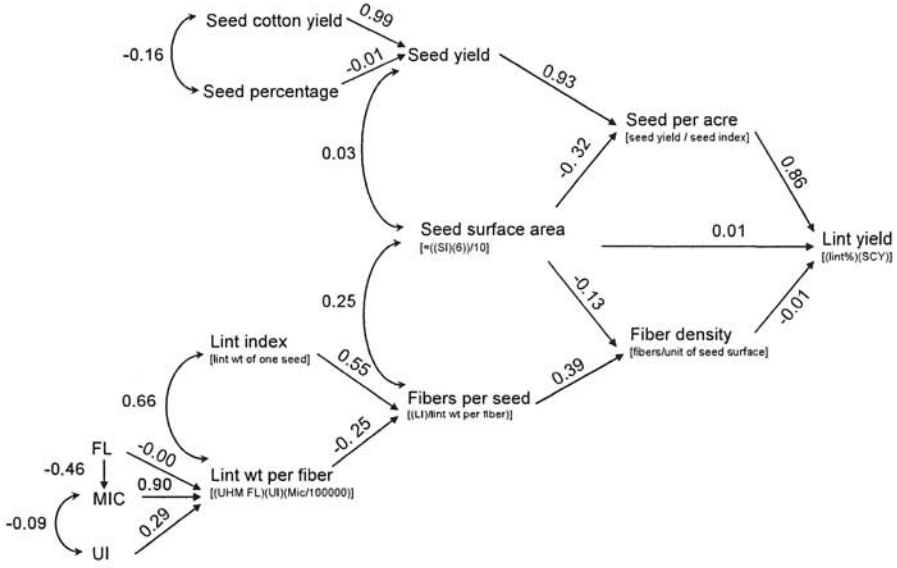

Fig. 1. Direct effects and correlations on S5 and S6 strains from the University of Arkansas Cotton Breeding Program (1999-2006).

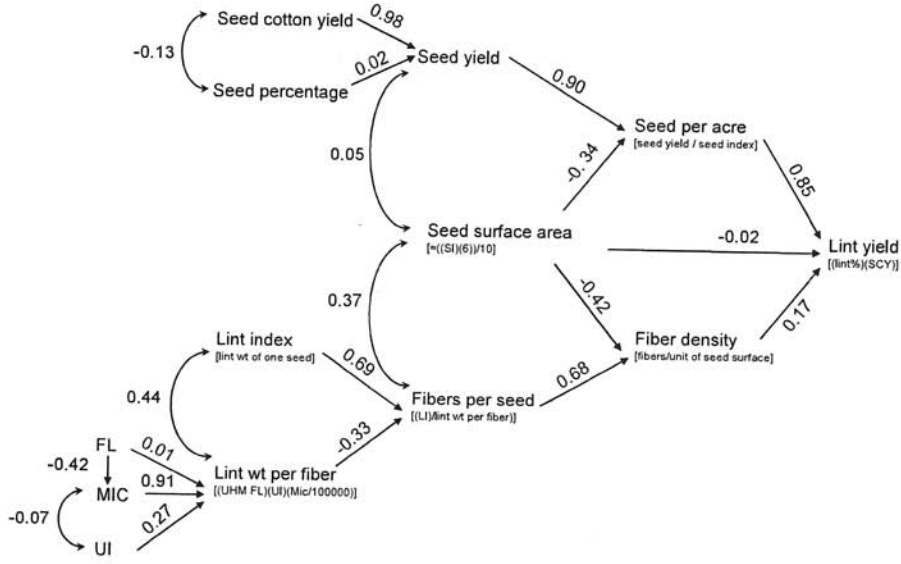

Fig. 2. Direct effects and correlations on V1 and V2 varieties from the University of Arkansas Cotton Breeding Program (1999-2006).

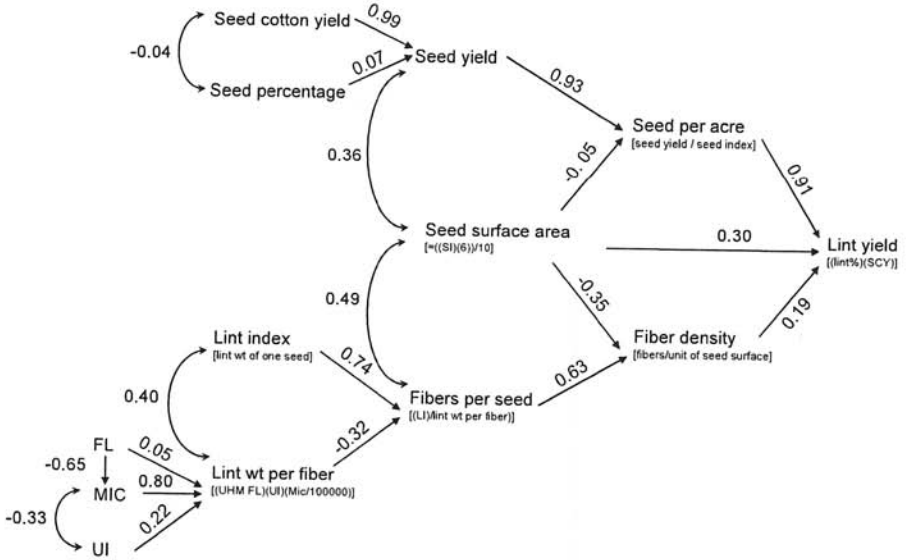

Fig. 3. Direct effects and correlations on V1 and V2 varieties under non-irrigated conditions from the University of Arkansas Cotton Breeding Program (1999-2006).

Performance of VipCot in Arkansas, 2007

Gus M. Lorenz, D. Scott Akin, Kyle Colwell, Glenn Studebaker, Heather Wilf, Craig Shelton, Ben Von Kanel, and Keith Driggs

RESEARCH PROBLEM

In 2007, VipCot was evaluated in two trials in Jefferson and Desha counties to determine the efficacy of this new transgenic for control of the heliothine complex and other lepidopterous pests. Significant differences were observed among treatments for seasonal total damage and seasonal total for heliothine larvae at both locations and VipCot was shown to be efficacious for looper control at the Desha Co. location.

BACKGROUND INFORMATION

VipCot is a new transgenic cotton from Syngenta. It utilizes a recently discovered protein, vip3a (Vegetative insecticidal protein), for control of lepidopterous pests in cotton. Similar to Bollgard, the target insects ingest the protein toxin by eating the plant. The toxin attacks midgut cells causing an immediate cessation of feeding and mortality within 24 to 72 hr after consumption. The toxin in VipCot, unlike currently used transgenics, is expressed during the vegetative stage of bacterial growth.

RESEARCH DESCRIPTION

Field trials were conducted under experimental use permits (EUP) in 2007 in Jefferson and Desha counties in Arkansas. Plots were 8 rows (38-inch spacing) and 100 feet in length in a paired comparison with four replications with a 50-ft minimum buffer surrounding the study. The treatments were the transgenic, VipCot, and a conventional, Coker 312. The Jefferson County study was planted 30 May and the Desha County location 15 June. Fields were scouted by sampling 50 terminals, squares, blooms, and

[1] Extension entomologist, Cooperative Extension Service, Little Rock; extension entomologist, Southeast Research and Extension Center, Monticello; seasonal agricultural technician, Cooperative Extension Service, Little Rock; extension entomologist, Northeast Research and Extension Center, Keiser; program associate-entomology, Cooperative Extension Service, Lonoke; graduate assistant, Cooperative Extension Service, Little Rock; graduate assistant, Crop, Soil, and Environmental Sciences Department, Fayetteville; and technical service representative, Syngenta Crop Protection, North Little Rock, respectively.

bolls in each plot starting late July and sampled weekly through August. At the Jefferson location, data were taken 26 July, and 2, 9, 14, 24, and 30 August. Sampling dates at Desha Co. were 1, 8, 15, 22, and 29 August and 11 and 18 September. Additional drop cloth samples, 2 per plot, were taken at the Desha Co. location to assess looper numbers. Data were analyzed using Agricultural Research Manager using Analysis of Variance and LSD (P=0.10, Duncan's New MRT).

PRACTICAL APPLICATION

VipCot will provide growers an alternative to existing transgenic cotton for control of lepidopterous pests in cotton and will reduce the potential for resistance problems.

RESULTS AND DISCUSSION

VipCot was shown to have excellent activity for Heliothine control. In the Jefferson Co. trial, significant differences were observed for seasonal total damage (Fig 1.) and seasonal total larvae (Fig. 2.). VipCot had significantly less damage and larvae than the conventional cotton. Similar control of heliothines was observed in the Desha Co. trial (Fig. 3.). A mixed population of soybean and cabbage looper-infested plots at the Desha Co. location on 29 August and VipCot had significantly less larvae than the conventional cotton (Fig. 4.)

These trials indicate VipCot has very good efficacy for control of Heliothines in low to moderate population levels and good control of loopers. Further studies are warranted to assess the control with higher population levels and other species such as fall armyworm. With VipCot having a novel mode of action, this new transgenic will help with resistance management issues and provide growers with a new tool for control.

ACKNOWLEDGMENTS

The authors thank Chuck Hooker and Frank Appleberry for providing test locations and Syngenta Crop Protection for their support of these studies.

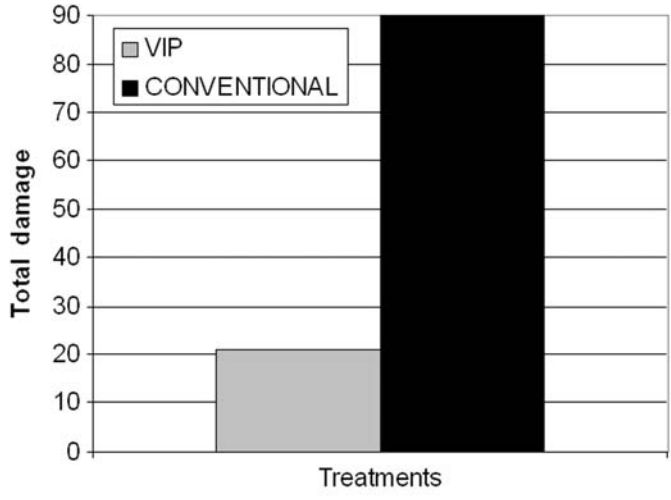

Fig. 1. Seasonal damage on VipCot and conventional cotton, Jefferson Co., 2007.

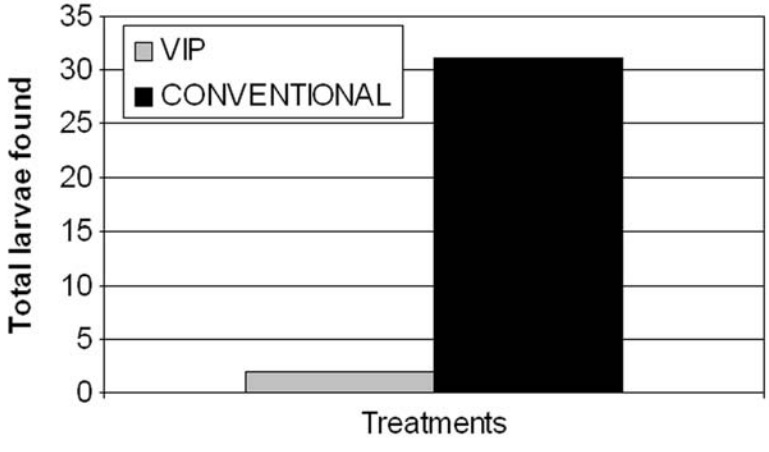

Fig. 2. Seasonal total larvae on VipCot and conventional cotton, Jefferson Co., 2007.

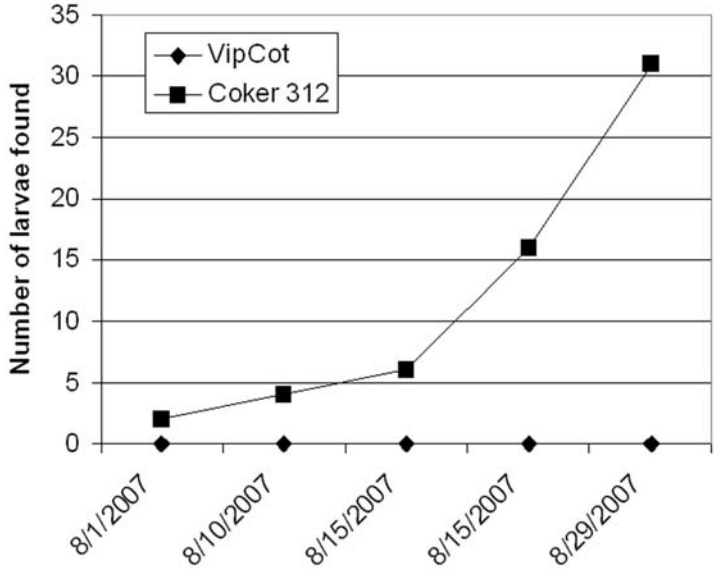

Fig. 3. Seasonal larvae on VipCot and conventional cotton, Desha Co., 2007.

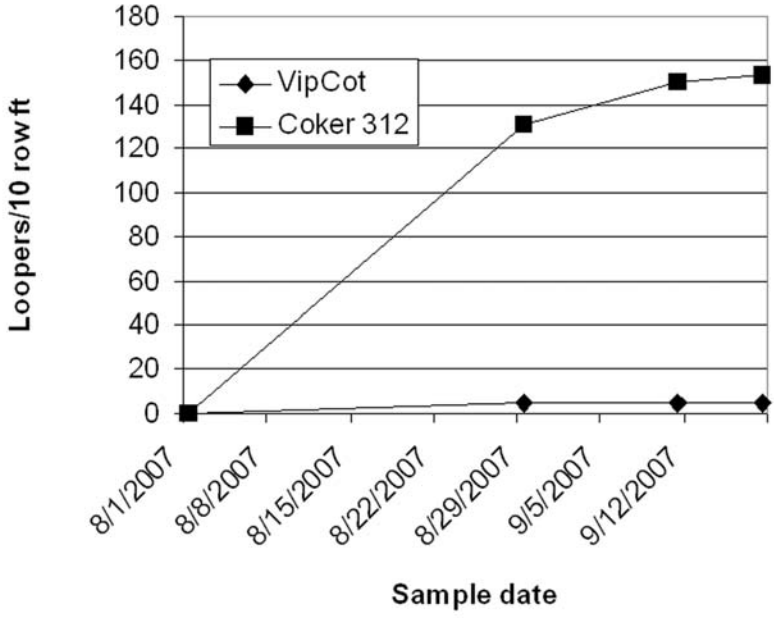

Fig. 4. Looper control with VipCot versus conventional cotton, Desha Co., 2007.

Effect of Phosphorus Deficiency on Cotton Growth

Derrick M. Oosterhuis, Androniki C. Bibi, Evangelos D. Gonias, and Morteza Mozaffari[1]

RESEARCH PROBLEM

Prior to 2006, no P fertilizer was recommended for cotton when modified Mehlich-3- (1:7 extraction ratio) extractable P was >100 lb P/acre. In 2002, approximately 95% of the soil samples submitted from cotton fields had soil-test P >100 lb/acre. This suggests that past P fertilization practices have resulted in buildup of P in Arkansas soils and recommendations need to be updated. Information on the range of tissue-P concentrations that are sufficient for currently grown commercial cotton cultivars is an important component of developing improved P management recommendations. Improved P fertilizer recommendations and increasing P use efficiency will help increase the profitability of agricultural production and reduce the potential for offsite loss of P in drainage waters. The rapid introduction of modern cotton (*Gossypium hirsutum* L.) cultivars and changes in production practices during the past several decades have created a need to update the science base of cotton P-fertilization recommendations. Information on critical levels of nutrients such as P is an important component of this knowledge base. The objectives of this study were to quantify the effects of P deficiency on cotton growth and determine the critical tissue-P concentrations for growth.

BACKROUND INFORMATION

Phosphorus (P) is an essential element required for structural and metabolic functions. Phosphorus is mobile in the plant such that young leaves or developing bolls can be nourished from the labile P of older tissues; i.e., P is redistributed from older to younger parts. The critical P concentrations for cotton range from 0.20 to 0.31% (Crozier et al., 2004; Cox and Barnes, 2002). For cotton grown in the southern regions of the USA, the critical P-concentration range for the upper mature leaf at first flower or first square is

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0.30 to 0.50% (Plank, 1988). In Arkansas, a critical P-concentration for petioles is not used because P is not recommended by the petiole monitoring program.

PROCEDURES

The experiment was conducted in a growth chamber at the University of Arkansas Altheimer Laboratory in Fayetteville, Ark. The growth chamber was programmed for a 12-hour photoperiod, with day/night temperatures of 30/20°C, and relative humidity of 60 to 80%. The cotton cultivar DPL 444BR was planted in 2-L pots filled with washed sand. Each pot had a 2-cm diameter hole in the base for drainage. After emergence, seedlings were thinned to one plant per pot. All pots were watered with one-half strength Hoagland's nutrient solution during the first four weeks after planting to maintain a sufficient nutrient and water supply. Four weeks after planting, all pots where flushed with deionized water and the pots were separated into two treatment groups: P deficient and P sufficient. Plants in the P-sufficient treatment continued to receive the half-strength nutrient solution with P. Plants in the P-deficient treatment received half-strength Hoagland's nutrient solution without P. Four plants in each treatment were harvested weekly for four weeks after the initiation of the P treatments. The effects of P deficiency on plant growth, dry matter accumulation, and partitioning were determined as described by (Zhao and Oosterhuis, 2002). The plants were separated by plant part (leaves, main stem and branches, petioles, fruits, and roots) and each group of tissues was oven-dried, weighed, and digested with concentrated HNO_3 and 30% H_2O_2 for determination of tissue-P concentrations. The experiment was a randomized complete block design with five replications. A *t*-test was performed to determine whether significant ($P \leq 0.05$) differences existed between treatment means.

RESULTS AND DISCUSSION

Plant height was reduced significantly at three weeks after withholding P (Fig. 1A). Similarly, leaf area was reduced significantly at two weeks after treatment in P-deficient plants compared to P-sufficient plants (Fig.1B). However, the effect of P on total plant dry matter was not observed until three weeks after withholding P (Fig. 1C). Phosphorous-deficient plants showed significantly less root dry weight four weeks after the assignment of the treatments compared to the P-sufficient plants (Fig. 1D).

PRACTICAL APPLICATIONS

The study documented the effect of P deficiency on cotton plant growth. Plant height, leaf area, total dry weight, and root dry matter were sensitive indicators of P deficiency.

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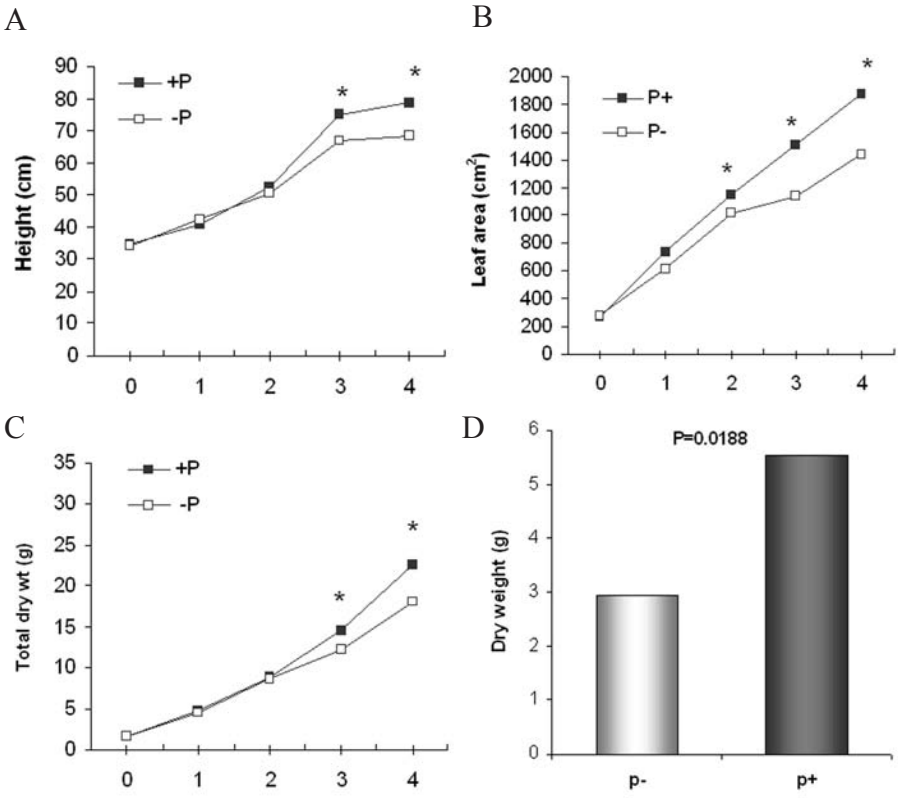

Fig. 1. The effect of phosphorus deficiency on (A) height, (B) leaf area (LA), (C) total dry weight measured weekly starting 28 days after planting when P was withheld from the P treatment, and (D) root dry weight measured four weeks after treatment. The asterisk (*) indicates significant differences at $p \leq 0.05$ for measurements comparing P treatments within each week.

Effect of Phosphorus Deficiency on Cotton Physiology

Derrick M. Oosterhuis, Androniki C. Bibi, Evangelos D. Gonias, and Morteza Mozaffari

RESEARCH PROBLEM

Phosphorus (P) is an essential element in plants, required for vital structural and metabolic functions. A shortage of P will lead to a breakdown of plant membranes and reduce energy transfer within the plant. Crop fertilization programs must insure adequate P to support the critical role of this element in plant metabolism. Improving P fertilizer recommendations and increasing P use efficiency will increase grower profit margin and reduce the potential for offsite loss of P in drainage waters. Rapid introduction of modern cotton (*Gossypium hirsutum* L.) cultivars and changes in production practices, in the past several decades, have created a need to update the science base of cotton P fertilization recommendations. The objectives of this study were to quantify the effects of P deficiency on the physiological growth of cotton.

BACKGROUND INFORMATION

Phosphorus (P) is an essential macronutrient required for energy transfer (i.e., ATP and NADPH); genetic information (i.e., DNA and RNA); and formation of phospholipids; and it plays an important role in membrane integrity. Phosphorus is mobile in the plant such that young leaves or developing bolls can be nourished from the labile P of older tissues; i.e., P is redistributed from older to younger parts. In cotton, the critical-P concentrations range from 0.20 to 0.31% (Crozier et al., 2004; Cox and Barnes, 2002). For cotton grown in the southern regions of the USA, the critical-P concentration range in the upper mature leaf at first flower or first square is 0.30 to 0.50% (Plank, 1988). In Arkansas, a critical-P concentration range for petioles is not used because P is not recommended by the petiole monitoring program. Prior to 2006, no P fertilizer was recommended for cotton when modified Mehlich-3 (1:7 extraction ratio)-extractable

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P was >100 lb P/acre. In 2002, approximately 95% of the soil samples submitted from cotton fields had soil-test P >100 lb/acre. This suggests that past P-fertilization practices have resulted in buildup of P in Arkansas soils and recommendations need to be updated. Information on the range of tissue-P concentrations that are sufficient for currently grown commercial cotton cultivars is an important component of developing improved P-management recommendations.

MATERIALS AND METHODS

The experiment was conducted in a growth chamber at the University of Arkansas Altheimer Laboratory in Fayetteville, Ark. The growth chamber was programmed for a 12-hour photoperiod, with day/night temperatures of 30/20°C and relative humidity of 60 to 80%. The cotton cultivar DDL 444 was planted in 2-L pots filled with washed sand. Each pot had a 2-cm diameter hole in the base for drainage. After emergence, seedlings were thinned to one plant per pot. All pots were watered with one-half strength Hoagland's nutrient solution during the first four weeks after planting to maintain a sufficient nutrient and water supply. Four weeks after planting, all pots where flushed with deionized water and separated into two groups: P-sufficient and P-deficient. The P-sufficient treatment continued to receive the half-strength nutrient solution with P, while the P-deficient treatment received half-strength Hoagland's nutrient solution without P. Four plants in each treatment were harvested weekly for four weeks after the initiation of the P treatments. The effects of P deficiency on leaf photosynthesis, quantum yield of PSII, membrane leakage, and chlorophyll SPAD were determined. The experimental design was a completely randomized design with five replications. A *t*-test was performed to determine whether significant ($P \leq 0.05$) differences existed between treatment means.

RESULTS AND DISCUSSION

Withholding P caused photosynthesis to significantly decline below that of cotton plants in the P-sufficient treatment two, three, and four weeks after treatments began (Fig. 1A). Quantum yield of PSII, as a measure of plant stress, reflected significant stress in the P-deficient plants the first week after treatment was imposed and three weeks later (Fig. 1B). Membrane leakage also increased significantly the third and fourth week of the treatment for the P-deficient treatment compared to the P-sufficient plants (Fig. 1C). The rapid effect of P deficiency on membrane leakage was expected in view of the critical role of P in the formation of phospholipids in plant membranes. Membrane leakage is a measure of cell integrity and provides a sensitive indicator of the plant stress suffered due to P deficiency. Finally, phosphorous deficiency caused significantly higher chlorophyll content two, three, and four weeks after the beginning of the treatment in the P-deficient treatment compared to the P-sufficient plants (Fig. 1D).

PRACTICAL APPLICATION

This growth room study quantified the effect of P deficiency on the physiological growth of cotton plants. Phosphorus deficiency caused a reduction on leaf photosynthesis and quantum yield of PSII, while resulting in increased membrane leakage and chlorophyll SPAD compared to phosphorous-sufficient plants.

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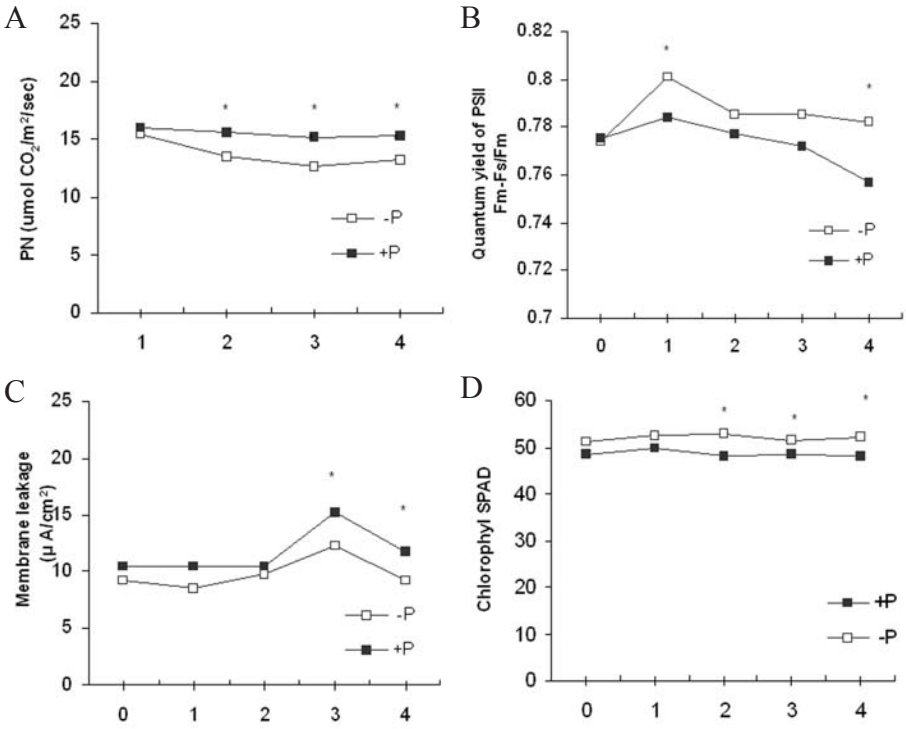

Fig. 1. The effect of P-deficiency on (A) leaf photosynthesis, (B) Quantum yield PSII, (C) membrane leakage, and (D) Chlorophyll SPAD measured weekly starting 28 days after planting when P was withheld from the P-deficient treatment. The asterisk (*) indicates significant differences at $p \leq 0.05$ between P treatments within a sample week.

Cotton Response to Phosphorus Application in a Commerce Silt Loam

Morteza Mozaffari, Nathan A. Slaton, Josh Long, Jason Osborn, Mike Hamilton, and B.T. Schmid[1]

RESEARCH PROBLEM

Phosphorus (P) is an important plant essential nutrient that is needed for energy transfer reactions in plants. Phosphorus deficiency will limit cotton (*Gossypium hirsutum* L.) yield and excessive buildup of P in soil will increase the potential for transport of P from agricultural fields and may enhance the risk of eutrophication of surfacewaters. Therefore, accurate P fertility recommendations will benefit the cotton growers and aid in protecting the environment.

BACKGROUND INFORMATION

Cotton production practices in Arkansas have dramatically changed during the last three decades, consequently yields have improved and nutrient requirements have changed. Therefore there is a need for updated information on cotton response to P fertilization with the current soil and cropping conditions in Arkansas. The objective of this study was to evaluate the effect of P fertilizer rate on seedcotton yield and soil-test P levels on a soil commonly used for cotton production in Arkansas.

RESEARCH DESCRIPTION

A replicated field experiment was conducted on a commercial farm in Crittenden County, Ark., in 2007. Soil at the experimental site is mapped as a Commerce silt loam and the previous crop was cotton. Prior to application of any soil amendments, 10 to 12 soil cores were collected and composited from the 0- to 6-inch soil depth of each replication. Soil samples were oven-dried at 65°C, crushed, extracted with Mehlich-3 solution, and the elemental concentrations were measured by inductively coupled

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plasma atomic emission spectroscopy (Table 1). Soil pH was measured in a 1:2 (weight: volume) soil-water mixture (Donahue, 1983). Soil particle size was determined on each composite sample using the hydrometer method (Arshad et al., 1996).

Cotton cultivar Stoneville5590 was planted by the cooperating grower on 5 May 2007 into a conventionally tilled seedbed. Phosphorus fertilizer (triple superphosphate, 0-46-0) was applied to the soil surface at rates of 0, 30, 60, 90 and 120 lb P_2O_5 /acre on 14 May. Potassium was blanket applied to the experimental plots at the rate of 60 lb K_2O/acre as potassium chloride (0-0-60) on the same date. Urea was applied by the grower to supply 100 lb N/acre in mid-May. Individual experimental plots were 40-ft long and 12.5-ft wide allowing for four rows of cotton with 38-inch-wide row spacings. All other cultural practices, including fertilization, closely followed the University of Arkansas recommendations for irrigated-cotton production. Irrigation timing was managed by the cooperating grower. Plants in one 10-ft-long section of one center row were hand picked on 3 October.

The experiment was a randomized complete block design with four replications. Analysis of variance (ANOVA) was performed using the GLM procedure of SAS to determine the effect of P fertilizer application rate on seedcotton yield. Mean separations were performed by the Waller Duncan minimum significant difference (MSD) test at significance levels of 0.05 and 0.10.

RESULTS AND DISCUSSION

Soil pH was 7.4 and soil contained 30, 46, and 24% sand, silt, and clay, respectively (Table 1). Pre-fertilizer application Mehlich-3-extractable P was 17 ppm, thus the soil-test P was classified as Low and would have received a recommendation for 70 lb P_2O_5/acre to aid in building soil-test P and maximize cotton yields.

During the season plants in the control plots were stunted and by harvest time were much shorter than P_2O_5 treated plots. Seedcotton yield ranged from 1881 to 2674 lb/acre and was significantly (P=0.0217) affected by P fertilizer application rate. Plants in the control plots were stunted. Seedcotton yield was maximized from application of 30 lb P_2O_5/acre, which increased yields by 42% compared with the no-P control. Application of P rates >30 lb P_2O_5/acre had no positive or negative influence on yield.

PRACTICAL APPLICATION

Seedcotton yield was significantly increased by P fertilization of a Commerce silt loam having a soil-test (0- to 6-inch depth) P of 17 ppm. University of Arkansas soil-test-based fertilizer recommendations correctly identified this soil as P deficient. The P-fertilizer rate needed to maximize seedcotton yield was only 30 lb P_2O_5/acre compared with the recommended rate of 70 lb P_2O_5/acre. Additional research is needed to properly calibrate the P-fertilizer rate needed to maximize cotton yield on P-deficient soils. Results from this experiment will be added to a database on cotton response to P fertilization so that recommendations can be verified or revised in the future if needed.

ACKNOWLEDGMENTS

We thank Mr. Lee Winner from Turrell, Ark., for allowing access to his farm. Without his contribution, this study would not have been possible.

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Table 1. Selected soil chemical and physical property means (0- to 6-inch depth) for soil samples taken before adding any fertilizer for a cotton P fertilization trial conducted on a commercial farm in Crittenden County, Ark., in 2007.

	Soil		Mehlich-3 extractable nutrients						Particle size analysis & texture			
Location	Soil pH[z]	NO_3-N[y]	P	K	Ca	Mg	Mn	Cu	Zn	Sand	Silt	Clay	Texture
		(ppm)								(%)			
CRIG71	7.4	69	17	125	2230	460	112	2.2	3.4	30	46	24	loam

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

[y] NO_3-N measured by ion-specific electrode.

Table 2. Effect of soil-applied P fertilizer rate on seedcotton yield in a commercial farm in Crittenden County Ark., in 2007.

P rate	Seedcotton yield
(lb P_2O_5 /acre)	(lb/acre)
0	1881
30	2674
60	2660
90	2468
120	2570
P value	0.0217
MSD at 0.05[z]	555
MSD at 0.10[y]	461

[z, y] Minimum significant difference at *P*=0.05 and *P*=0.1 as determined by Waller-Duncan Test.

Effect of Baled Poultry Litter and Urea on Cotton at Multiple Locations

Morteza Mozaffari, Nathan A. Slaton, H.L. Goodwin, Josh Long, Nathan Kemper, and Cindy Herron

BACKGROUND INFORMATION

Field studies to evaluate cotton response to baled poultry litter (BPL) are needed to provide information to growers who might be interested in utilizing BPL as a source of nitrogen (N) and other nutrients. The specific objective of this project was to evaluate the effect of inorganic-N fertilizer and BPL application rate on seedcotton yield on soils commonly used for cotton production in the Mississippi River Delta of Arkansas (MRDA).

RESEARCH PROBLEM

Increasing price of inorganic N fertilizers has renewed interest in alternative sources of N fertilizer for cotton production in the MRDA. Continuous application of manure has resulted in accumulation of soil phosphorus (P) in many agricultural soils in northwestern Arkansas, where poultry industry is primarily concentrated, and these high-P soils have been implicated as a potential water quality problem. Transport of poultry litter from nutrient-rich poultry-production areas of northwest Arkansas to areas of high demand for nutrients, such as the row crop-producing areas in MRDA will provide an alternative source of nutrients for Arkansas cotton producers and reduce the rate of P buildup in northwest Arkansas soils.

PROCEDURES

Replicated field experiments were conducted at three locations in MRDA on soils representing those commonly used for cotton production. The experimental sites were on University of Arkansas Agricultural Experiment Station facilities in Desha

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(DEG71), Lee (LEG71), and Mississippi (MSG71) counties. These sites represent a range of latitude from southeast to northeast Arkansas. Each study was arranged as a randomized complete block design with a factorial arrangement of N-fertilizer sources and rates. There were two sources of N (urea and BPL) and six rates of N within each source, corresponding to 0, 30, 60, 90, 120, and 150 lb N/acre from urea or BPL.

Baled poultry litter (BPL) and urea treatments were hand applied to the soil surface and incorporated with a rotary hoe or Do-All before planting. Cotton (*Gossypium hirsutum* L.) cv. DPL117 was planted between 4 and 17 May at various sites and emerged within 7 days after planting. Detailed information on important agronomic dates is listed in Table 1. Conventional tillage and pest management practices were followed and irrigation was managed according to the University of Arkansas Cooperative Extension Service Irrigation Scheduler Program. Analysis of variance (ANOVA) was performed using the GLM procedure of SAS. Sites were analyzed separately. When appropriate, mean separations were performed by the Waller-Duncan minimum significant difference (MSD) or least significant difference test (LSD) test at a significance level of 0.05 and 0.10, respectively.

RESULTS AND DISCUSSION

Properties of BPL and Soil

Baled poultry litter contained on the average (n=6) 3.06% N, 1.27% P, and 2.31% K. Organic N was the predominant form of N and NH_4-N was the predominant form of inorganic N. The manure data suggest that in addition to N, the BPL can potentially be used as a low-grade potassium (K) or P fertilizer. Analysis of soil samples, collected from the 0- to 6-inch depth before application of treatments, indicated that the average soil pH ranged from 6.4 to 7.1, and P and K were in the Optimum range. Soil NO_3-N was 3 to 5 ppm, thus a yield response to N application was expected. Surface-horizon soil texture ranged from silt loam to clay loam.

Seedcotton Yield

The N source x N rate interaction did not have any significant effect ($P \geq 0.1446$) on seedcotton yield. Nitrogen source, averaged across N rates, significantly ($P \leq 0.0748$) affected seedcotton yield (Table 2) with seedcotton yields ranging from 1699 to 2685 lb/acre for cotton receiving urea and 1519 to 2273 lb/acre for cotton receiving BPL. On average, cotton fertilized with urea produced greater overall yields.

Averaged across both N sources, seedcotton yields receiving no N or BPL ranged from 1096 to 1687 lb/acre and 2009 to 2745 lb/acre for cotton fertilized with 150 lb N/acre (Table 3). Application of >30 lb N/acre produced significantly (P=0.1) higher yields than the no-N control. Application of 120 lb N/acre increased yields 841 to 1219 lb/acre as compared to 0-N plots and in general, maximum seedcotton yields were produced with application of 120 lb N/acre. However, the yields at 150 lb N/acre were not significantly (P=0.1) different than the yields at 120 lb N/acre.

PRACTICAL APPLICATION

Application of N increased seedcotton yield, regardless of the N source. Seedcotton yield was increased 50 to 90% by application of 120 lb N/acre. This single year of data from three sites suggests that BPL is a good N source for cotton production in silt loam and clay loam soils of MRDA. Use of BPL to supply the recommended or maintenance rates of P and K and a portion of the recommended N rate appears to be a feasible nutrient management strategy for cotton. Additional field studies are needed to generate a more robust database for developing reliable N availability recommendations for utilization of BPL in cotton production in Arkansas.

ACKNOWLEDGMENTS

We thank USDA NRCS for providing financial support for this research. We also express our gratitude to the staff of the University of Arkansas Northeast Research and Extension Center, Lonn Mann Cotton Research Station, Southeast Research Station, and the University of Arkansas Soil Testing and Research Laboratory for their assistance.

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Table 1. Selected agronomic information for the experiments on evaluating nitrogen (N) availability from urea and baled poultry litter (BPL) for cotton at three locations in Arkansas in 2007.

Site ID	Previous crop	Urea and BPL application date	Planting	Predicted first square[z]	Predicted bloom[y]	Predicted first open boll[x]	Harvest date
DEG71	Cotton	17 May	17 May	15 June	2 July	12 Aug	11 Oct
LEG71	Corn	30 April	4 May	6 June	23 June	5 Aug	5 Oct
MSG71	Cotton	8 May	9 May	9 June	26 June	6 Aug	2 Oct

[z, y, x] Assuming that 475, 825, and 1675 Degree Days > 60°F is required from planting to first square, first flower,and first open boll, respectively, as suggested by Oosterhuis, 1992.

Table 2. Effect of N source, averaged across N rates, on seedcotton yields at three locations in Arkansas during 2007.

N source	Seedcotton yield		
	DEG71	LEG71	MSG71
	---------- (lb/acre)----------		
BPL	2071	1519	2273
Urea	2346	1699	2685
LSD at 0.05[z]	235	250	232
LSD at 0.10[y]	195	208	192
p value	0.0273	0.0748	0.0008

[z, y] LSD, least significant difference at *P*=0.05 and 0.10, respectively.

Table 3. Effect of urea and baled poultry litter (BPL) and the mean of N sources applied at six N rates on seedcotton yield at three locations in Arkansas in 2007.

	Seedcotton yield								
	DEG71			LEG71			MSG71		
	N source		Mean of	N source		Mean of	N source		Mean of
Total-N rate	BPL	Urea	N sources	BPL	Urea	N sources	BPL	Urea	N sources
(lb N/acre)	(lb/acre)								
0	1717	1601	1659	947	1096	1021	1687	1857	1760
30	1755	2055	1927	1299	1465	1393	1840	2053	1946
60	1787	2428	2108	1558	1467	1512	2524	2863	2693
90	2292	2569	2430	1443	2381	1845	2465	2785	2648
120	2474	2520	2500	1810	2118	1964	2740	3217	2979
150	2537	2902	2745	2009	1844	1926	2434	3133	2784
MSD 0.05[z]	interaction was NS		392	interaction was NS		426	interaction was NS		377
MSD 0.10[y]	interaction was NS		334	interaction was NS		363	interaction was NS		322
p value	interaction = 0.4856		0.0001	interaction = 0.1446		0.0003	interaction = 0.8464		<0.0001

[z, y] Minimum Significant Difference (MSD) as determined by Waller-Duncan Test at $P = 0.05$ or $P = 0.10$, respectively.

Seedcotton Yield from Applications of Nitrogen-Fortified Poultry Litter Granular Fertilizers

Mark S. Reiter, Tommy C. Daniel, and Morteza Mozaffari[1]

RESEARCH PROBLEM

Moving surplus poultry litter (PL) nutrients from northwest Arkansas to the row crop-production areas in eastern Arkansas is an ideal scenario. However, based on fertilizer value, transport of fresh PL over 40 km without subsidies is not economically feasible (Govindasamy and Cochran, 1995). The primary objective of this research was to demonstrate the efficiency of granular fertilizers composed of PL and urea for cotton production. A secondary objective was to demonstrate the effectiveness of a nitrification inhibitor, dicyandiamide (DCD), for increasing nitrogen (N) recovery efficiency when incorporated with PL.

BACKGROUND INFORMATION

Extensive Arkansas row crop agriculture uses more than 975,000 Mg of inorganic fertilizer per year (Arkansas State Plant Board, 2005); with much of the fertilizer used on 348,000 ha of cotton (*Gossypium hirsutum*) (National Agricultural Statistics Service, 2008). Approximately 1.2 billion broilers (*Gallus gallus domesticus*) are produced in Arkansas annually resulting in over 1.7 million Mg of poultry litter (PL) waste (excreta plus bedding material) containing appreciable inorganic and organic nutrients (National Agricultural Statistics Service, 2008). If PL is hauled to row crop-producing areas, fresh PL efficiency is often low due to applications that must be made prior to planting before the crop actively assimilates nutrients. Physical alteration of PL allows for production of a uniform product with additions of value-added nutrients and nitrification inhibitors that may increase utility and efficiency.

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RESEARCH DESCRIPTION

Research plots were established in 2004 and 2005 at the Lonn Mann Cotton Research Station in Marianna, Ark. (34°46'N; 90°45'W), to test upland seedcotton yield with N fertilizers developed from PL (Table 1). Plots were located on a Loring silt loam (Fine-silty, mixed, active, thermic Oxyaquic Fragiudalfs) cropped in sod prior to 2004 and cotton prior to 2005. Fertilizer treatments were fresh PL, PL + urea (PLU), PLU + DCD (PLUDCD), urea applied at-planting, and urea 50-50 split-applied between at-planting and first match-head square formation (Table 2). Fresh poultry litter, PLU, and PLUDCD treatments were applied to dry soil and incorporated. 'Stoneville 4892BR' cotton was immediately planted after fertilizer incorporation at 89,000 plants/ha. All N sources were applied on a total N basis at 34, 67, 101, 134, and 168 kg N/ha. A 0-N control was also included. Seedcotton yield was determined by harvesting the middle 2 rows from each 4-row plot.

The experiment was arranged in a factorial arrangement of 5 N sources × 5 N rates using a randomized complete block design with 4 replications. Seedcotton yield was analyzed using simple linear and non-linear regression procedures using SAS v. 9.1. Regression equations for the highest order (quadratic or linear) significant model were used. For seedcotton yields, confidence intervals were used to compare relationships at 90% peak yield for the 50-50 split urea treatment. Nitrogen agronomic efficiency (kg seedcotton produced/kg N applied) was found by subtracting the y-intercept (0-N application) from the 90% highest predicted yield value and dividing by the N rate that provided 90% maximum yield for the 50-50 split urea treatment.

RESULTS AND DISCUSSION

Seedcotton yield data were significant by year. Generally, N efficiency was 2 to 4 times higher in 2005 than 2004 (Table 3); therefore, years will be presented separately.

In 2004, seed cotton yield varied in a year × N source × N rate interaction (Table 3). A N rate of 91 kg N/ha provided 90% maximum yield for split urea treatments and is the point where N sources were compared. Fresh PL and PLU N sources had no significant relationship; therefore, means of 3372 and 3249 kg seedcotton/ha were presented and were similar according to their confidence intervals (Table 3). Urea applied at-planting, urea applied in a split application, and PLUDCD all had similar seed cotton yields and agronomic efficiencies (4.9 to 7.6 kg seedcotton /kg N applied). No yield advantage was seen by splitting urea applications compared to one at-planting application.

Quadratic regression responses were observed for all N fertilizer sources in 2005 and were compared at the 90% peak yield N rate for split urea treatments of 70 kg N/ha (Table 3). Split urea, urea applied at-planting, PLU, and PLUDCD all had similar predicted seedcotton yields and N agronomic efficiencies that ranged from 16.8 to 19.5 kg seedcotton produced/kg N applied. Applying all N at-planting may be suitable in Arkansas cotton production systems since these treatments gave similar yields and agronomic efficiencies as split N treatments. Even with all N applied at-planting, DCD did not statistically improve N agronomic efficiency over sources without DCD (Table 3).

PRACTICAL APPLICATIONS

Seedcotton yield data indicated that N efficiency generally increased in the following manner: fresh PL ≤ PLU ≤ PLUDCD = urea applied at-planting = urea applied in a 50-50 split application between at-planting and first match-head square formation. Using N-fortified PL fertilizers is a viable option since all fertilizer material can be applied at-planting and incorporated without any decrease in agronomic efficiency and yield. However, N fortification was necessary to provide sufficient N to the cotton plant during the growing season. Dicyandiamide additions were not necessary and did not increase efficiency.

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Table 1. Selected chemical properties for poultry litter and N-fortified poultry litter with and without dicyandiamide used for cotton fertilization on a dry weight basis.

N source	H_2O[z]	N	C	P	K	NO_3-N	NH_4-N
	---------- (g/kg) ----------					------(mg/kg) -----	
2004							
Poultry litter	234	47.6	362.9	20.8	34.3	203	3775
PLU[y]	155	159.9	404.3	16.9	27.6	2165	6184
PLUDCD[y]	155	146.2	405.8	16.1	29.7	1912	6146
2005							
Poultry litter	222	41.1	322.9	21.3	39.1	400	4846
PLU[w]	113	171.6	356.6	18.2	31.0	177	2980
PLUDCD[w]	117	179.2	347.4	16.9	31.0	137	2863

[z] Moisture content "as-is."

[y] Poultry litter + urea (PLU) and PLU + dicyandiamide (PLUDCD). Manufactured by Lee Harris Farms, Inc., Bentonville, Ark., 72712.

[w] Manufactured by Mars Mineral, Inc., Mars, Pa., 16046.

Table 2. Selected dates for cotton management at the Lonn Mann Cotton Research Station in Marianna, Ark.

	Year	
Management event	2004	2005
Applied PL fertilizers	20 May	11 May
Incorporated fertilizers	22 May	11 May
Planted cotton	22 May	4 May
Applied second urea split	27 June	6 June
Defoliant applied	4 October	23 September
Harvested cotton	22 October	5 October

Table 3. Seedcotton yield and N agronomic efficiency from applications of poultry litter, N-fortified poultry litter fertilizers with and without dicyandiamide (DCD), and urea applied at-planting or split 50-50 between at-planting and first match-head square formation on a silt loam soil.

N source	Yield response[z]	R^2	Split urea N rate[y]	Predicted yield	Predicted yield confidence interval	Agronomic efficiency[x]	Split urea basis[w]
			(kg N/ha)	(kg/ha)	(kg/kg N)	(%)	
2004							
Poultry litter	NS[v]; mean = 3372	NS	91	3372	3288-3473	0.0	0
PLU[u]	NS; mean = 3249	NS	91	3249	3157-3342	0.0	0
PLUDCD[u]	3109 + 7.6N	0.97	91	3801	3709-3894	7.6	138
At-planting urea	3257 + 4.9N	0.84	91	3703	3609-3795	4.9	89
Split urea[t]	3288 + 5.5N	0.68	91	3789	3700-3886	5.5	100
2005							
Poultry litter	$2816 + 15.9N - 0.058N^2$	0.45	70	3645	3473-3819	11.8	61
PLU	$2738 + 22.0N - 0.071N^2$	0.84	70	3930	3760-4108	17.0	87
PLUDCD	$2806 + 22.0N - 0.074N^2$	0.72	70	3983	3820-4158	16.8	86
At-planting urea	$2736 + 24.6N - 0.090N^2$	0.87	70	4017	3840-4188	19.3	94
Split urea	$2638 + 26.1N - 0.094N^2$	0.76	70	4004	3831-4178	19.5	100

[z] Highest order model (quadratic or linear) that was significant is presented.
[y] Nitrogen rate required for 90% yield in split urea treatments.
[x] Nitrogen agronomic efficiency = (predicted yield – y-intercept)/split urea N rate.
[w] Split urea basis = Source N agronomic efficiency/split urea N agronomic efficiency*100.
[v] No significant relationship found. Treatment means are presented in kg seedcotton/ha.
[u] Poultry litter + urea (PLU) and PLU + DCD (PLUDCD).
[t] Urea applications split between 50% at-planting and 50% first match head square formation.

Effect of Various Seeding Patterns and Rates on Cotton Growth and Yield

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RESEARCH PROBLEM

Cotton (*Gossypium hirsutum* L.) is typically seeded in single-rows separated by 30 to 40 inches using a seeding rate of three or four seeds per linear foot of row. However, producers and scientists continue to discuss the feasibility of seeding cotton in alternative patterns and the validity of current cotton seeding-rate recommendations. The objective of this study was to determine the effect of alternative cotton seeding patterns and rates on cotton growth and yield compared to traditional 38-inch single-row cotton.

BACKGROUND INFORMATION

Cotton seeding patterns and rates have been investigated by scientist and producers in the past. Recently, an alternative seeding pattern has gained the attention of Arkansas cotton producers. This pattern is known as twin-row cotton, which is the seeding of two rows separated by 7 to 15 inches that can be seeded atop a 36- to 40-inch raised bed. Past research has shown the feasibility of seeding cotton in single-rows planted in rows of 10 or less inches, but this production system typically requires stripper harvesting. To alleviate this issue, technology is currently available to spindle-harvest cotton seeded in 15-inch twin-rows. Also, a seeding rate of three to four seeds per linear foot of row (41,267 to 55,023 seeds per acre for 38-inch single-rows) is recommended. Research has shown the feasibility of lowering seeding rates while maintaining yield, but adequate plant populations and earliness may be sacrificed when utilizing lower cotton seeding rates.

RESEARCH DESCRIPTION

Three cotton seeding patterns and five seeding rates were evaluated in 2007 at the Northeast Research and Extension Center in Keiser, Ark., and the Lon Mann Cotton Research Station in Marianna, Ark. A split-plot arrangement of treatments in

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a randomized complete block experimental design with four replications was utilized. Seeding patterns included: 1) 38-inch single-row; 2) 7.5-inch twin-row with each set separated by 38-inches; and 3)15-inch twin-row with each set separated by 38 inches. All seeding patterns were seeded atop a 38-inch raised bed. Seeding rates included: 1) 35,000; 2) 45,000; 3) 55,000; 4) 65,000; and 5) 75,000 seeds per acre. At both locations 'Stoneville 4554 B2RF' was seeded and University of Arkansas Cooperative Extension Service recommendations were followed for pest control, growth management, and furrow-irrigation scheduling.

RESULTS AND DISCUSSION

How did seeding patterns and rates influence cotton growth?

Seeding pattern had little to no influence on cotton growth parameters such as location of first fruiting node, number of vegetative and fruiting branches, total number of main stem nodes, and plant height (Table 1). In general, 38-inch single-row cotton was observed with greater fruiting branches, total nodes, and plant height. These data indicate that seeding pattern may not affect cotton growth. Seeding rate did not affect location of first fruiting node and plant height; however, number of vegetative and fruiting branches and total main-stem nodes increased when seeding rate was escalated from 35,000 to 45,000 or 55,000 (Table 2). These data highlight the propensity of cotton to produce more branches and nodes when seeded at lower seeding rates, which produces a more "bushy" plant and may reduce earliness.

How did seeding patterns and rates influence cotton yield parameters and lint yield?

At Keiser and Marianna, 38-inch single-row cotton produced more total bolls and was observed with greater second-position boll retention then either the 7.5- or 15-inch twin-row seeding patterns (Table 3). At Keiser, first-position boll retention was similar for 38-inch single-row and 7.5-inch twin-row, but 38-inch single-row was greater than the 15-inch twin-row. Seeding pattern did not influence lint yield at either location (Table 3). No differences in first-position boll retention were observed among seeding patterns at Marianna (Table 3). At both locations, 35,000 and/or 45,000 seeds/acre produced more total bolls compared to 55,000 or greater, which was expected due to the lack of competition among plants (Table 4). First-position boll retention was slightly affected by seeding rate at Keiser, but rate did not influence it at Marianna (Table 4). At Keiser, second-position boll retention was greater with 35,000 and 45,000 seeds/acre compared to 55,000 or more seed, but little to no differences were observed at Marianna. As with seeding patterns, seeding rate did not affect lint yield at either location.

PRATICAL APPLICATION

These data indicate little to no differences among the seeding patterns tested (single 38-inch row, 7.5-inch twin-row, and 15-inch twin-row) for cotton growth and yield. Although this experiment indicated that cotton can be successfully produced with alternative seeding patterns, it should be noted that yields were not increased compared to traditional, single 38-inch rows. Also, the data showed little to no differences in cotton growth and yield across a wide range of seeding rates. However, when deciding on a seeding rate, plant a seed population that will ensure an adequate plant stand so that replanting will not be required.

Table 1. Effect of seeding pattern on cotton growth parameters at Keiser and Marianna, Ark., in 2007.

	First fruiting node		Vegetative branch		Fruiting branch		Total nodes		Plant height	
Seeding pattern	Keiser	Marianna	Keiser	Marianna	Keiser	Marianna	Keiser	Marianna	Keiser	Marianna
	(no.)								(inches)	
38-inch single-row	6 a[z]	7 a	2 a	4 a	16 a	15 a	22 a	21 a	37 a	41 a
7.5-inch twin-row	7 a	7 a	2 a	4 a	15 b	15 a	21 b	20 b	35 b	41 a
15-inch twin-row	7 a	7 a	2 a	3 b	15 b	14 b	21 b	20 b	35 b	36 a

[z] Means followed by the same letter for each parameter and location are not significantly different at P≤0.05.

Table 2. Effect of seeding rate on cotton growth parameters at Keiser and Marianna, Ark., in 2007.

	First fruiting node		Vegetative branch		Fruiting branch		Total nodes		Plant height	
Seeding pattern	Keiser	Marianna	Keiser	Marianna	Keiser	Marianna	Keiser	Marianna	Keiser	Marianna
	(no.)								(inches)	
35,000	7 a[z]	7 a	3 a	4 a	16 a	15 b	22 a	21 a	38 a	38 a
45,000	7 a	7 a	3 a	4 a	15 b	16 a	21 b	21 a	37 a	39 a
55,000	7 a	6 a	2 b	4 a	15 b	15 b	21 b	20 b	35 a	39 a
65,000	7 a	7 a	2 b	4 a	15 b	15 b	21 b	20 b	35 a	38 a
75,000	6 a	7 a	2 b	3 b	15 b	15 b	20 c	20 b	36 a	38 a
7.5-inch twin-row	7 a	7 a	2 a	4 a	15 b	15 a	21 b	20 b	35 b	41 a
15-inch twin-row	7 a	7 a	2 a	3 b	15 b	14 b	21 b	20 b	35 b	36 a

[z] Means followed by the same letter for each parameter and location are not significantly different at P≤0.05.

Table 3. Effect of seeding pattern on cotton yield parameters and lint yield at Keiser and Marianna, Ark., in 2007.

	Total bolls		First position		Second position		Lint yield	
Seeding pattern	Keiser	Marianna	Keiser	Marianna	Keiser	Marianna	Keiser	Marianna
	----------(no.) ----------		----------(%)----------				--------- (lb/acre)---------	
38-inch single-row	16 a[z]	19 a	41 a	42 a	29 a	25 a	940 a	1600 a
7.5-inch twin-row	12 b	13 b	39 ab	37 a	23 b	16 b	880 a	1490 a
15-inch twin-row	12 b	11 b	36 b	38 a	23 b	16 b	890 a	1500 a

[z] Means followed by the same letter for each parameter and location are not significantly different at P≤0.05.

Table 4. Effect of seeding rate on cotton yield parameters and lint yield at Keiser and Marianna, Ark., in 2007.

	Total bolls		First position		Second position		Lint yield	
Seeding pattern	Keiser	Marianna	Keiser	Marianna	Keiser	Marianna	Keiser	Marianna
	----------(no.) ----------		----------(%)----------				--------- (lb/acre)---------	
35,000	16 a[z]	18 a	39 ab	40 a	39 a	21 ab	860 a	1560 a
45,000	16 a	14 b	42 a	37 a	31 a	22 a	990 a	1500 a
55,000	12 b	12 b	40 ab	41 a	22 b	17 ab	900 a	1510 a
65,000	11 b	11 b	40 ab	40 a	20 b	18 ab	980 a	1670 a
75,000	10 b	11 b	37 b	38 a	18 b	15 b	950 a	1540 a

[z] Means followed by the same letter for each parameter and location are not significantly different at P≤0.05.

Effect of High Night Temperatures on Cotton Respiration, ATP Content, and Carbohydrates

Dimitra A. Loka and Derrick M. Oosterhuis[1]

RESEARCH PROBLEM

The unpredictability of cotton yields is a great concern to the cotton industry. High temperatures are considered to be one of the main environmental factors contributing to variable yields in cotton (*Gossypium hirsutum* L.). This has been attributed to a negative effect on respiration and carbohydrate accumulation, but the evidence for this is lacking. In this study it was hypothesized that high night temperatures have a negative effect on cotton respiration and energy (adenosine 5-triphosphate, ATP) levels that results in a significant loss of carbohydrates.

BACKGROUND INFORMATION

United States cotton production suffers from extreme year-to-year yield variability that has been attributed to genetics, management practices, and unfavorable weather (Robertson, 2001). High temperatures are considered to be one of the main environmental factors contributing to variable yields (Oosterhuis, 1994), but limited information exists on the effects of high temperature on cotton growth and yield.

Although cotton originates from hot climates, the ideal temperature range for its growth is between 20° and 30°C (Reddy et al., 1991) with the optimum for photosynthesis being 28°C (Burke et al., 1988). However, at higher temperatures, as are often experienced in the U.S. Cotton Belt, plant metabolism decreases dramatically, compromising the reproductive efficiency of the crop. Additionally, reports in the literature suggest that high night temperatures cause respiration rates to increase, resulting in further depletion of carbohydrates and yield reduction (Arevalo, 2008). This suggestion is supported from comparisons of yield and temperature regimes between Arkansas and Greece (Oosterhuis, 2002). Most reported studies of the effects of night temperature on growth do not involve solely the night temperatures as a contributing factor to lower yield. When night temperature was raised, the day temperature was

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also raised, making it impossible to determine the specific effect of increased night temperature alone. Therefore, the objective of this study was to determine the effect of long-term and short-term high night temperatures and similar day temperatures on respiration, ATP content, and carbohydrate accumulation.

RESEARCH DESCRIPTION

Two sets of experiments were conducted at the Altheimer Laboratory, University of Arkansas. Cotton (*Gossypium hirsutum* L.) cultivar 'DP444BR' was planted in 1-L pots containing Sunshine potting media mix. The growth chambers were set for a 12-h photoperiod with day/night temperatures of 30/20°C. All pots received half-strength Peter's nutrient solution daily to maintain adequate nutrients and water.

For the first set of experiments, cotton was grown until the pinhead square stage under normal day/night temperatures of 30/20°C. Plants were then divided in two groups and one group was transferred into a second identical growth chamber, with similar conditions of photon flux density, humidity, and photoperiod as the first chamber, but with the night temperature raised to 28°C for 4 h at the start of the dark period (20h00-24h00) for an overall duration of 4 weeks, while the control plants remained under normal temperatures (30/20°C). Measurements of respiration, ATP content, and carbohydrate status were conducted at the end of the first, second, and fourth week using the attached fourth main-stem leaf from the terminal of the plant. The experimental design was a two-factor factorial (time and temperature) with eight replications.

For the second set of experiments, cotton was grown until pinhead square under normal day/night temperatures of 30/20ºC. At the pinhead square stage, temperatures of 24, 27, and 30°C were imposed on the plants for one night starting at 19h00 (at the initiation of the dark period) with 2-h intervals between each incremental temperature regime. Measurements of respiration rates, leaf ATP content, and leaf carbohydrate status were taken at the end of each night temperature treatment, 2 h, 4 h, and 6 h into the dark period, from fresh leaves from the fourth main-stem node from the terminal. The experimental design was a completely randomized design with eight replications.

Respiration measurements were taken with a LI-COR 6200 infra-red gas analyzer (LI-COR Inc., Neb.). Leaf ATP content was determined according to a bioluminescent technique using substrate-enzyme complex of firefly luciferin-luciferase (ATP bioluminescent assay kit, Sigma Chemical Company, St Louis, Mo.) that converts the chemical energy associated with ATP into light. The light produced (proportional to ATP content) was measured with a 20/20n Luminometer (Turner Biosystems Inc., Sunnyvale, Calif.). Soluble carbohydrate content was measured according to a modification of the Hendrix (1993) protocol and readings were taken with a MultiScan Ascent Microplate Reader (Thermo Fisher Scientific Inc., Waltham, Mass.).

RESULTS AND DISCUSSION

Long-term high night temperatures had no effect on respiration rates during the first week of the temperature regime (Fig. 1). However, during the second and fourth

week, plants grown under high night temperatures (28°C) had significantly higher rates of respiration, compared to plants grown under normal night temperatures (20ºC). Leaf ATP energy levels proved to be more sensitive to the elevated night temperatures, showing a decline at the end of the first week after the night temperatures had been raised (Fig. 2). The pattern was similar for the second and fourth weeks, with leaf ATP levels of the plants exposed to elevated night temperature regimes having significantly lower ATP levels compared to those of the control. The effect of high night temperatures on carbohydrate content was similar to that of leaf ATP levels. Both hexose and sucrose content were significantly decreased, due to the elevated night temperature regime across all weeks of the study, but leaf starch content remained unaffected by the high night temperatures (data not shown). This led us to speculate that the duration of the high temperature regime (4 h during the night) was sufficient to cause a depletion of soluble carbohydrates but not enough to cause mobilization of starch.

Short-term incremental increases to the night temperatures had as an immediate effect an increase in the respiration rate. Both high temperature regimes, 27 and 30°C, caused an increase in respiration rates of the plants, compared to those kept at 24°C (Fig. 3). There was also an immediate response in ATP content to the elevated night temperatures, with ATP content of the plants at 27 and 30°C being significantly lower than that of plants at 24°C (Fig. 4). A similar decline was not observed in the carbohydrate content (data not shown). In contradiction to our expectations, leaf hexose and sucrose levels remained unaffected by either of the high night temperature regimes (27 or 30°C), leading us to assume that a longer imposition of high temperatures might be needed to significantly deplete leaf carbohydrates.

PRACTICAL APPLICATION

High night temperatures caused a significant increase in respiration rates, which resulted in a reduction of leaf energy levels and carbohydrate content. This was due to the immediate short-term (i.e., two hour) effect of increasing night temperatures on respiration and ATP content, while the effects on carbohydrates were more cumulative over a longer period of time.

Since carbohydrates are considered to be the basic building components for the majority of crops and especially for cotton, where 94% of the fiber consists of cellulose, we understand that the detrimental effect of high night temperatures on the energetics and consumption of carbohydrates will have a significantly detrimental effect on yield.

It is apparent that more research is needed in order to quantify the effect of high night temperatures on cotton's dry matter production, partitioning into fruit and yield.

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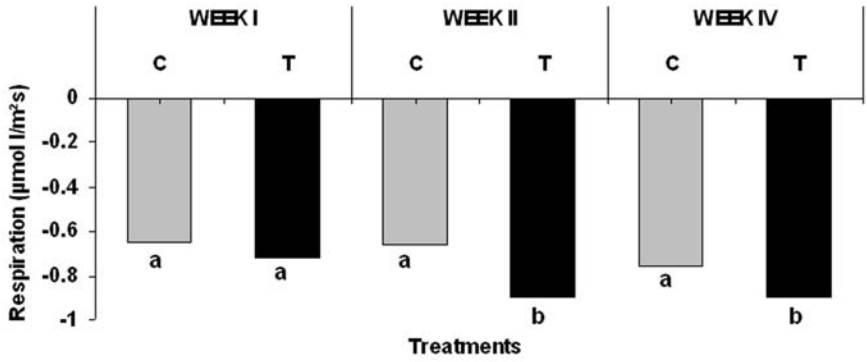

Fig. 1. Effect of high night temperature on respiration one, two, and four weeks after the night temperature was raised. Pairs of columns within each time interval with the same letter are not significantly different (P=0.05).C=control with normal night temperature (20°C), T=high night temperature (28°C).

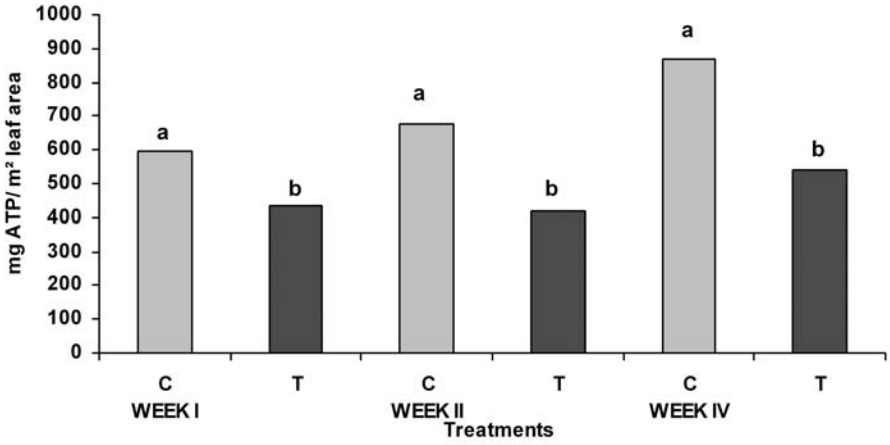

Fig. 2. Effect of high night temperature on leaf ATP content, presented as a percentage of the control, one, two, and four weeks after the night temperatures were raised. Pairs of columns within each time interval with the same letter are not significantly different (P=0.05). C= control with normal night temperature (20°C), T= high night temperature (28°C).

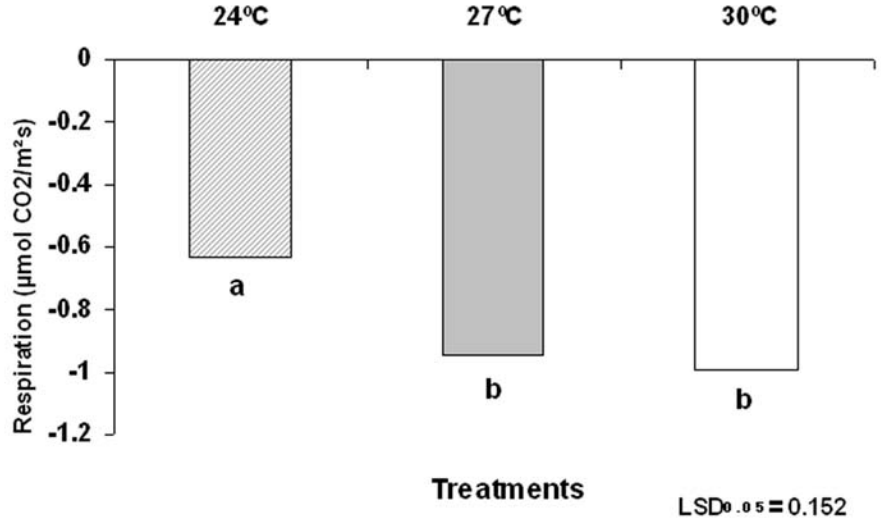

Fig. 3. Effect of short-term high night temperatures on respiration at 2 h intervals at the start of the dark period. Columns with the same letter are not significantly different (P≤0.05). Bars of ± 1 SE are shown.

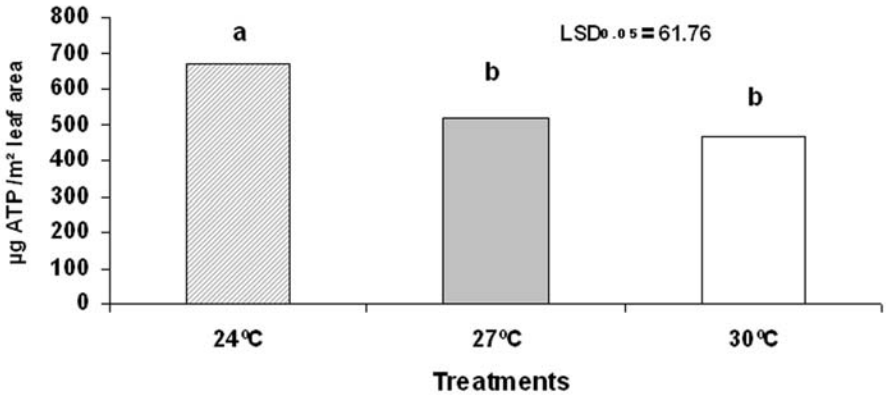

Fig. 4. Effect of short-term high night temperatures on ATP content at 2 h intervals at the start of the dark period. Columns with the same letter are not significantly different (P≤0.05). Bars of ± 1 SE are shown.

Radiation Use Efficiency of Okra- and Normal-Leaf Cotton Isolines

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RESEARCH PROBLEM

Leaf shapes of cotton (*Gossypium hirsutum*) range from highly divided leaves (okra leaf) to normal leaf shape (Meredith, 1984). The variation in leaf shape results in differences in canopy architecture and light interception characteristics (Wells and Meredith, 1986). Heitholt et al. (1992) described higher yields of okra leaf isolines for a given amount of intercepted radiation, indicating that the okra leaf types utilized intercepted radiation more efficiently than the normal-leaf types. However, no values of radiation use efficiency have been reported comparing cotton isolines.

BACKGROUND INFORMATION

Crop growth (accumulation of dry matter) depends mainly on the amount of intercepted radiation and the time allowed for growth (Sinclair and Muchow, 1999). The effectiveness of a crop to convert intercepted radiation to dry matter is called radiation use efficiency (RUE), and is defined as the amount of dry matter produced (g) per unit of radiation intercepted (MJ) by the crop canopy. Monteith (1977) described this correlation as linear.

RESEARCH DESCRIPTION

Cotton okra- and normal-leaf isolines of cultivar FM832 (provided by Dr. W.R. Meredith) were planted in Marianna, Ark., in a randomized complete block design with 10 blocks. Plot size was 15 m by 4 rows. Measurements were recorded between pinhead square stage and three weeks after flowering and included the fraction of radiation intercepted by the crop canopy (weekly) and dry matter and partitioning (every 10 to 15 days). Yield components and lint yield were determined from 1-m^2 hand-picked

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samples and mechanical harvest. For the regression analysis and analysis of variance JMP 6 software was used. Means were separated with Student's t-test at α=0.005.

RESULTS AND DISCUSSION

A significantly higher amount of radiation was intercepted by the normal-leaf isoline (Table 1). This was attributed to significantly larger fraction of light interception at all three growth stages measured compared to the okra-leaf isoline (Fig. 1). While the daily dry matter productivity did not statistically differ between the two isolines, the okra-leaf isoline had significantly higher radiation use efficiency (Table 1). In addition, at three weeks after flowering, the okra-leaf isoline partitioned a smaller percentage of dry matter to leaves and stems and a larger percentage to fruit (Fig. 2). No statistically significant differences were observed between the two isolines for lint yield, gin turnout, and number of bolls (Table 2). However, a larger boll size was observed for the okra-leaf isoline.

PRACTICAL APPLICATION

This study showed that the two leaf-shape cotton isolines produced similar amounts of dry matter while the okra-leaf type intercepted less radiation. Improved light interception by the okra-leaf isoline in addition to the more efficient utilization of intercepted radiation could increase dry matter production and yield of cotton.

ACKNOWLEDGMENTS

The authors thank Dr. W.R. Meredith for supplying the cotton isolines.

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Table 1. Radiation use efficiency, daily productivity, and intercepted radiation of the two cotton isolines.

Isolines	Intercepted radiation	Productivity	RUE
	($MJ \cdot m^{-2}$)	($gm^{-2} \cdot day^{-1}$)	($g \cdot MJ^{-1}$)
Normal-leaf	273.95	14.21	1.672
Okra-leaf	246.45	15.79	2.488
P value	0.001	0.333	0.020

Table 2. Lint yield and yield components of the two cotton isolines.

Isolines	Lint yield	Gin turnout	Bolls	Boll weight
	(kg/ha)	(%)	(#/m^2)	(g/boll)
Normal-leaf	1738.6	39.17	85.9	5.385
Okra-leaf	1662.3	39.72	76.8	5.446
P value	0.520	0.399	0.084	0.572

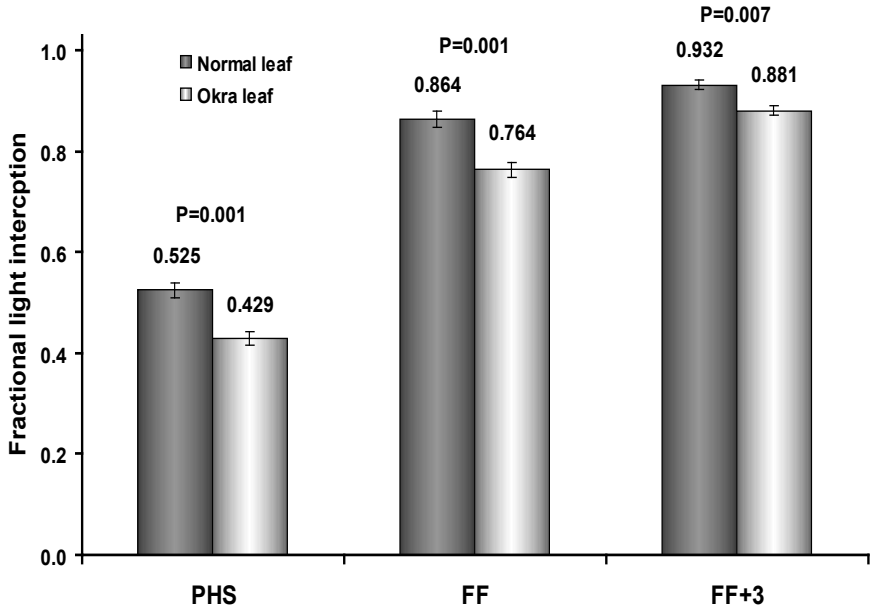

Fig. 1. Fractional light interception by the crop canopy at pinhead square (PHS), first flower (FF), and three weeks after first flower (FF+3). P values and ± 1 std. error bars are shown.

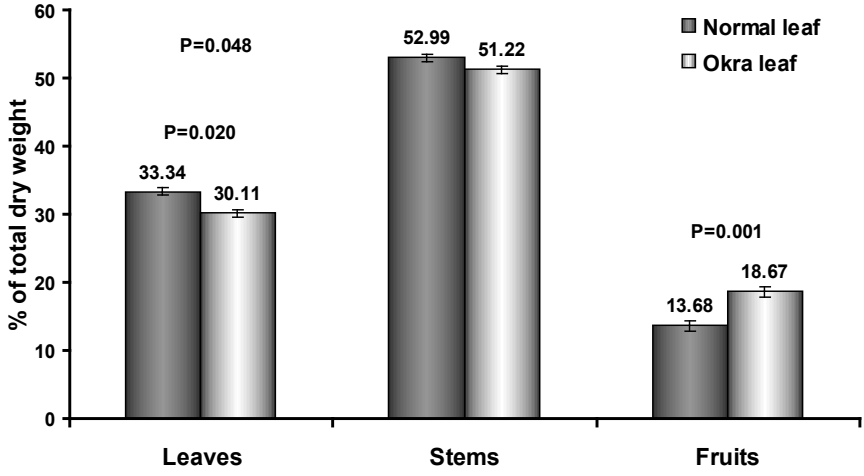

Fig. 2. Dry matter partitioning at three weeks after first flower. P values and ± 1 std. error bars are shown.

Radiation Use Efficiency of Cotton in Contrasting Environments

Evangelos D. Gonias, Derrick M. Oosterhuis, Androniki.C. Bibi, and Bruce A. Roberts[1]

RESEARCH PROBLEM

Yield variability in cotton (*Gossypium hirsutum* L.) from year to year (geographical locations) is a major production problem for farmers (Oosterhuis, 2002). Higher yields have been recorded in the drier environment of California, compared to the more humid environment of Arkansas. However, the effect of environmental factors, such as temperature, relative humidity, and vapour pressure deficit, on the radiation use efficiency of cotton has not been described for contrasting environments.

BACKGROUND INFORMATION

Crop growth (accumulation of dry matter) depends mainly in the amount of intercepted radiation and the time allowed for growth (Sinclair and Muchow, 1999). The effectiveness of a crop to convert intercepted radiation to dry matter is called radiation use efficiency (RUE), and is defined as the amount of dry matter produced (g) per unit of radiation intercepted (MJ) by the crop canopy. Monteith (1977) described this correlation as linear and the slope in the RUE. Reported values of RUE for different cotton cultivars range from 1.31 to 1.92 $g \bullet MJ^{-1}$ of intercepted photosynthetically active radiation (Pinter et al., 1994; Rosenthal and Gerik, 1991; Sadras and Wilson, 1997). Reduced values of RUE at higher vapour pressure deficits (VPD) have been documented for crops other than cotton. For sorghum and corn, RUE values based on PAR decreased with increasing VPD with a slope of 0.65 and 0.85 $g \bullet MJ^{-1} \bullet kPa^{-1}$, respectively (Stöckle and Kiniry, 1990).

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RESEARCH DESCRIPTION

To determine the effect of environmental factors on RUE, field studies were established in Marianna, Ark. (Cotton Branch Station, University of Arkansas) and Fresno, Calif. (Campus Farm, California State University, Fresno). In both locations, the cotton cultivar 'DP444' was used. The studies included two plant populations (5 and 10 plants/m^2) established two weeks after planting with five replications. Management practices were used as recommended in each location.

Radiation use efficiency was estimated by the slope of the increase in dry matter over the accumulated intercepted radiation. Dry matter was determined at the pinhead square growth stage (PHS), first flower (FF) and three weeks later (FF+3), by collecting plant samples from 1-m^2 ground area. Intercepted radiation was calculated by multiplying the incident radiation (measured by a weather station located at the edge of the field) with the fraction of intercepted radiation. The light interception by the crop canopy was measured weekly, starting at PHS, by measuring photosynthetically active radiation (PAR) above and below the canopy in unobstructed sunlight, close to solar noon, using a LI-191S line quantum-source quantum sensor (Li-Cor, Lincoln, Neb.).

RESULTS AND DISCUSSION

Although the study in Fresno, Calif., showed higher daily productivity of dry matter than in Marianna, Ark., the RUE in Fresno was lower (Table 1). The RUE was calculated as 2.2 g•MJ^{-1} of intercepted PAR at Marianna and 1.80 g•MJ^{-1} in Fresno. The higher values of productivity in Fresno can be attributed to higher amounts of incident and intercepted PAR between PHS and FF+3 compared to Marianna.

The environmental conditions between PHS and FF+3 for both locations are summarized in Table 2. It is apparent that Fresno had higher day temperatures and lower night temperatures, and lower relative humidity than Marianna. In addition, vapour pressure deficit values were lower for Marianna than for Fresno (Fig. 1). The lower values of RUE in Fresno can be explained by the higher values of VPD compared to Marianna. Data collected in 2006 and 2007 indicated that increasing vapour pressure deficit decreased radiation use efficiency by a slope of 0.47 g•M•$^{-1}$•kPa^{-1}.

PRACTICAL APPLICATION

Although higher yields have been reported in drier environments, such as California, than in the more humid environment of Arkansas, this study described higher RUE in Arkansas. However, dry matter production, as measured by daily crop productivity, was higher for California, possibly due to the larger amount of incident and intercepted radiation. As in the case of crops other than cotton, high values of vapour pressure deficit appear to decrease the efficiency of the crop to convert radiation energy to dry matter.

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Table 1. Radiation use efficiency, productivity, heat units, and intercepted radiation at the two locations of the study recorded between PHS and FF+3.

Location	RUE	Productivity	Heat units	Intercepted radiation
	(gMJ^{-1})	($g \cdot m^{-2} \cdot d^{-1}$)		($MJ \cdot m^{-2}$)
Marianna, Ark.	2.27	16.43	754	249.2
Fresno, Calif.	1.800	20.38	718	433.4
P-value	0.045	0.007	--	<.001

Table 2. Lint yield and yield components of the two cotton isolines.

Isolines	Lint yield	Gin turnout	Bolls	Boll weight
	(kg/ha)	(%)	(#/m^2)	(g/boll)
Normal-leaf	1738.6	39.17	85.9	5.385
Okra-leaf	1662.3	39.72	76.8	5.446
P value	0.520	0.399	0.084	0.572

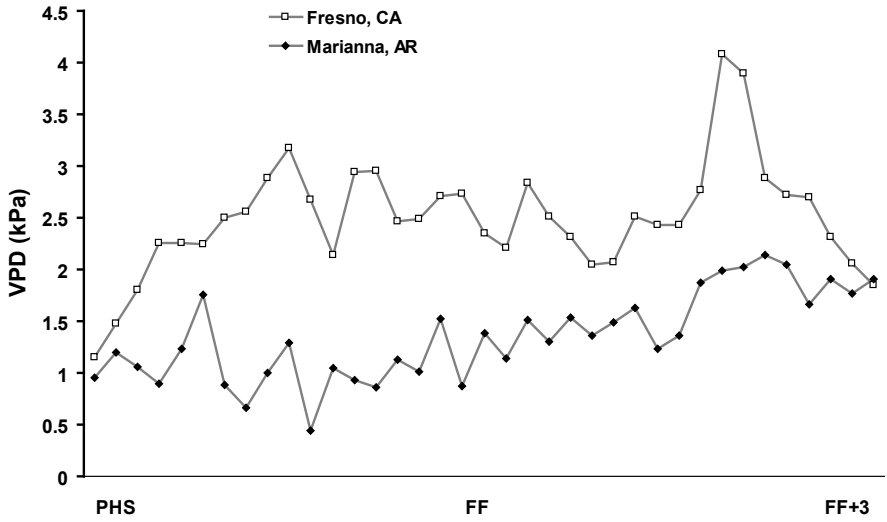

Fig. 1. Daily values of vapor pressure deficit between PHS and FF+3 for Marianna, Ark., and Fresno, Calif.

Cotton Radiation Use Efficiency Response to Plant Growth Regulators

Evangelos D. Gonias, Derrick M. Oosterhuis, and Androniki C. Bibi[1]

RESEARCH PROBLEM

Plant growth regulators (PGRs) are a common and widely used practice in cotton production for controlling plant growth, increasing yield, and improving management efficiency. Most of the PGRs used have an effect on plant growth, both vegetative and reproductive, and dry matter partitioning. However, there have been no reports of effects of PGRs on radiation use efficiency (RUE). It is logical to assume that any chemical that affects canopy dynamics will change the RUE of the crop. The objective of this study was to quantify the effect of PGRs on the RUE of cotton.

BACKGROUND INFORMATION

The amount of intercepted radiation and the time allowed for growth determines the accumulation of dry matter (Sinclair and Muchow, 1999). Dry matter production (g) per unit of intercepted radiation (MJ) can be defined as the effectiveness of the crop to convert intercepted radiation to dry matter. This correlation has been described as linear (Monteith, 1977) and the slope is the RUE of the crop. Reported values of RUE for different cotton cultivars range from 1.31 to 1.92 $g \bullet MJ^{-1}$ of intercepted photosynthetically active radiation (PAR) (Pinter at al., 1994; Rosenthal and Gerik, 1991; Sadras and Wilson, 1997).

RESEARCH DESCRIPTION

The study was conducted at the University of Arkansas Agricultural Research and Extension Center, in Fayetteville, Ark. For the calculation of RUE, the dry weight of the crop and the amount of intercepted radiation are required. Dry matter was determined at the pinhead square growth stage (PHS), first flower (FF), and three weeks later (FF+3), by collecting plant samples from 1-m^2 ground area. The light interception

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by the crop canopy was measured weekly, starting at PHS, by measuring PAR above and below the canopy in unobstructed sunlight, close to solar noon, using a LI-191S line quantum-source quantum sensor (Li-Cor, Lincoln, Neb.). Intercepted radiation was calculated by multiplying the incident radiation, measured by a weather station located next to the field, with the fraction of intercepted radiation. The PGR treatments were applied with a backpack CO_2 sprayer calibrated to deliver 10 gal/acre at PHS, FF+10 days, and FF and consisted of (1) untreated control, (2) Chaperone at 8 oz/acre, and (3) Pix Plus at 5 oz/acre.

RESULTS AND DISCUSSION

While the crop productivity was not significantly different between the PGR treatments and the untreated control, RUE values appeared to be numerically higher for the Pix Plus treatment than the untreated control and the Chaperone treatment (Table 1). At the end of the study (FF+3) the Pix Plus treatment had a significantly lower fraction of light intercepted (Fig. 1), reflected in lower amount of intercepted PAR between PHS and FF+3 (Table 1). Mepiquat Chloride applications had a significant effect on plant height and leaf area at FF+3 and canopy extinction coefficient at FF (Table 2).

PRACTICAL APPLICATION

This research suggests that radiation use efficiency of cotton can be potentially changed after application of PGRs. The production of dry matter is determined by the amount of intercepted radiation by the crop canopy and the efficiency that the light energy is converted to organic compounds. Increase in the amount of intercepted radiation or in the efficiency of energy conversion may increase dry matter production and yield of cotton.

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Table 1. Effect of the plant growth regulator treatments on dry matter productivity, intercepted photosynthetically active radiation (PAR), and radiation use efficiency of the cotton crop for the period between the pinhead square stage and three weeks after first flower.

Treatment	Dry matter productivity		Intercepted PAR		Radiation use efficiency	
	($g \cdot m^{-2} \cdot day^{-1}$)		($MJ \cdot m^{-2}$)		($g \cdot MJ^{-1}$ PAR)	
Untreated	14.70		233.0		2.43	
Chaperone	13.48	(0.4363)[z]	226.6	(0.2822)	2.60	(0.6752)
Pix Plus	13.70	(0.5250)	218.4	(0.0052)	3.16	(0.1090)

[z] P-value presented in parentheses for comparison of plant growth regulator treatment to the untreated control.

Table 2. Plant height and leaf area index measured at three weeks after first flower and canopy extinction coefficient measured at first flower.

Treatment	Plant height		Leaf area index		Canopy extinction coefficient	
	(cm)		($m^2 \cdot m^{-2}$)			
Untreated	132.3		3.86		0.418	
Chaperone	130.1	(0.2774)[z]	3.94	(0.7510)	0.435	(0.4756)
Pix Plus	104.6	(0.0027)	3.19	(0.0344)	0.492	(0.0344)

[z] P-value presented in parentheses for comparison of plant growth regulator treatment to the untreated control.

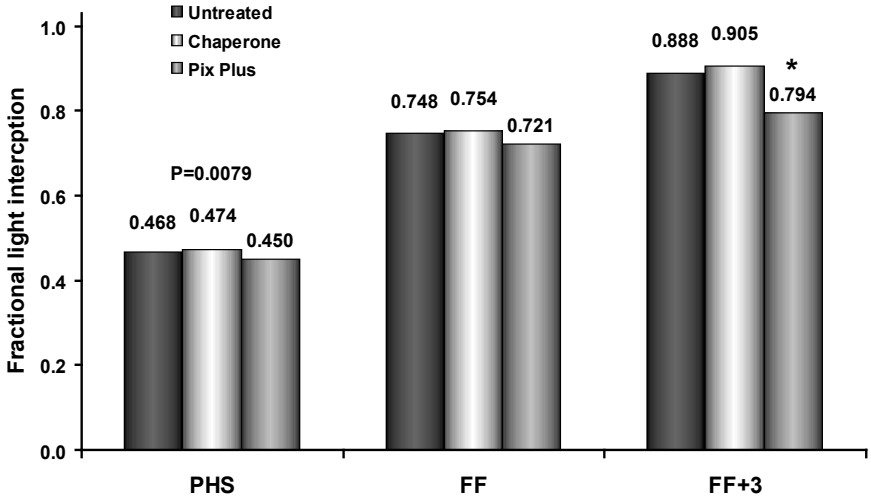

Fig. 1. Fractional light interception measured at pinhead square stage (PHS), first flower (FF), and three weeks after first flower (FF+3). An asterisk indicates a significant difference compared to the untreated control (P≤0.005).

Estimating Light Interception by the Cotton Crop Using a Digital Imaging Technique

Evangelos D. Gonias, Derrick M. Oosterhuis, Androniki C. Bibi, and Larry C. Purcell[1]

RESEARCH PROBLEM

Calculation of fractional light interception by the crop is commonly performed by measuring photosynthetically active radiation above and below the canopy using a line-source quantum sensor. However, this method is limited by the time of measurement and the presence of clouds. For soybeans grown in 19-cm rows, ground coverage values estimated from digital images taken above the canopy have been correlated to light interception measurements, but there have been no reports of using this method in cotton or in other crops on wide rows.

BACKGROUND INFORMATION

The most common method of measuring the fraction of radiation intercepted by the crop canopy is using a line-source quantum sensor by measuring photosynthetically active radiation above and below the canopy. In cotton, with a row spacing of approximately one meter, a 1-m line quantum sensor is placed perpendicularly across the two rows. The limitation of this method is that measurements should be taken in unobstructed sunlight and close to solar noon (Board et al., 1992; Egli, 1994). Purcell (2000) described a method for estimating light interception in soybean that was not affected by the above limitations. In this technique, ground area coverage was determined by digital images taken above the canopy. The canopy coverage values were similar throughout the day, and were correlated in a one-to-one relationship with light interception measurements made with a line quantum sensor at solar noon. In this study the digital imaging technique was tested for use in cotton.

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RESEARCH DESCRIPTION

The fraction of intercepted radiation was calculated by measuring photosynthetically active radiation (PAR) above and below the canopy in unobstructed sunlight, close to solar noon, using a LI-191S line-source quantum sensor (Li-Cor, Lincoln, Neb.). Three measurements were recorded for each plot. Following the light interception measurements, digital images were taken above the crop canopy from the center of each plot. The pole on which the camera was mounted was inclined by 30° to prevent the pole from being included in the image. By adjusting the height of the camera above the ground, the width of the image was set at 1 m. The SigmaScan Pro software (v. 4.0, SPSS, Inc., Chicago, Ill.) was used to determine the number of canopy pixels (green) of each image. Data were collected from four studies, across two years (2006 and 2007) and two locations (Fayetteville, Ark., and Marianna, Ark.). For the analysis of variance, JMP 6 software was used. Means were separated using Student's t-test at α=0.005.

RESULTS AND DISCUSSION

Correlation

Fractional light interception (LI) values by the crop canopy were plotted against fractional ground coverage (GC) values estimated by the digital imaging software (Fig. 1). The two measurements were found to be highly correlated (R^2=0.93) following a quadratic relationship, described by the equation: $LI = -0.5399 \times GC^2 + 1.6366 \times GC - 0.1202$.

Limitations

On 17 July 2007 images were taken every two hours between 9:00 am and 5:00 pm from 20 plots. The estimated values of ground coverage did not significantly differ between sampling time (Fig. 2). In contrast to the light interception measurements that are limited to measurements made only close to solar noon, the digital imaging technique can be used at any time of the day. Digital images were taken from eight plots in unobstructed sunlight and in the presence of passing clouds. The ground coverage values estimated by these images were not significantly different (Fig. 3). Therefore, the digital imaging technique is not limited by days with unobstructed sunlight.

PRACTICAL APPLICATION

The ability of a crop to intercept solar radiation is rarely presented in scientific manuscripts due to the effort and time necessary to record this measurement when a line-source quantum sensor is used. The imaging technique was confirmed for use in cotton with canopy coverage values, estimated by digital images recorded above the canopy, being highly correlated to light interception measurements. Limitations of recording light interception with a line-source quantum sensor were shown not to be a factor with the use of the digital imaging technique in cotton.

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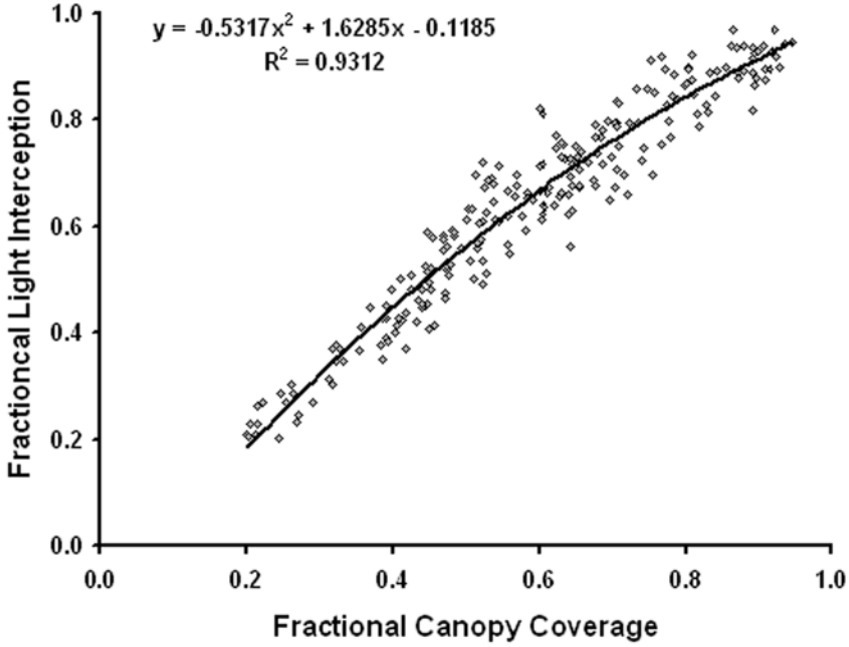

Fig. 1. Relationship between light interception and ground coverage.

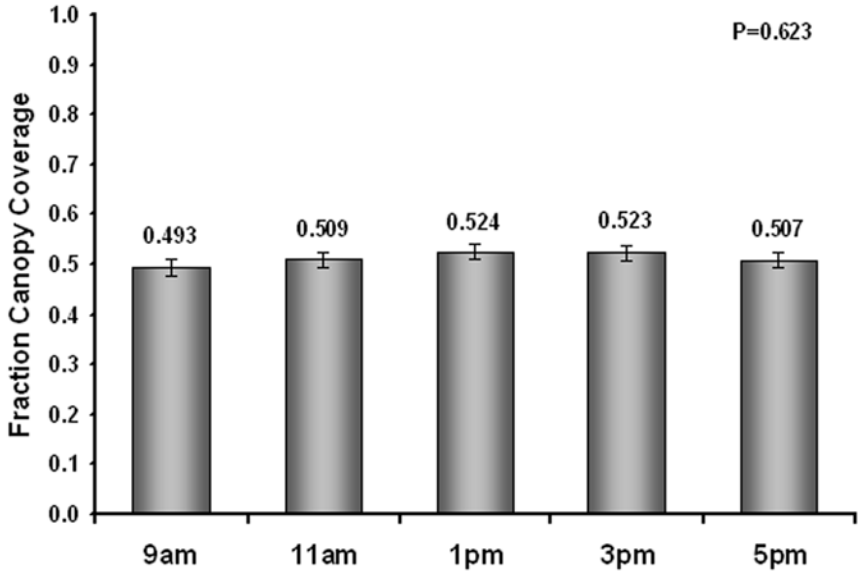

Fig. 2. Ground coverage estimates from digital images taken every two hours in unobstructed sunlight. P values and ± 1 std. error bars are shown.

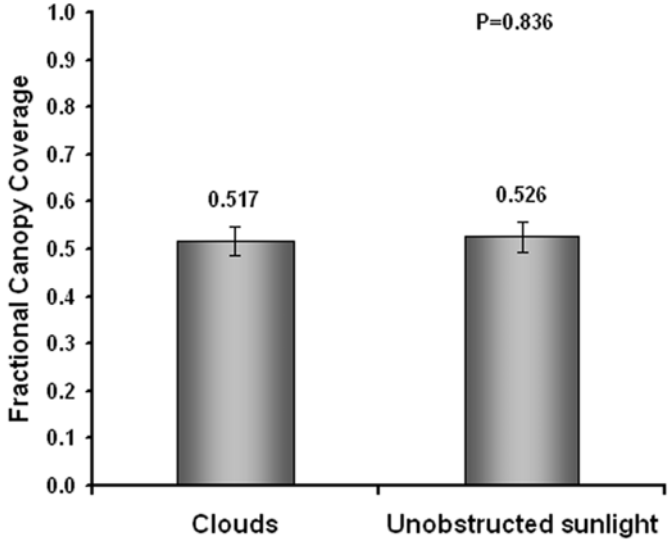

Fig. 3. Ground coverage estimates from digital images taken in the presence of passing clouds and in unobstructed sunlight. P values and ± 1 std. error bars are shown.

Exogenous Application Of Putrescine On Cotton Ovaries Under Two Temperature Regimes

Androniki C. Bibi, Derrick M. Oosterhuis, Evangelos D. Gonias and John D. Mattice[1]

RESEARCH PROBLEM

Polyamines are organic polycations that have been associated with a large number of plant growth and developmental processes, such as pollination and fruit set. Most of the research has been done in horticultural plants, with only limited information existing for cotton. Numerous studies have correlated increased fruit set with increased polyamines concentration during flowering. Therefore in this study, it was hypothesized that exogenous putrescine application in cotton ovaries might have a positive effect on cotton seed set, particularly under high-temperature stress.

INTRODUCTION

Past experience and recent research has indicated that high temperature is the major factor adversely affecting cotton yields (Oosterhuis, 2002). The ideal temperature range in cotton has been reported to be 30/20°C (Reddy et al., 1991), although cotton physiological growth is not significantly affected up to 35°C (Bibi et al., 2004). The influence of temperature on the number of ovules per flower has not been determined directly, although there is an indication that extreme high temperatures can result in a lower number of ovules per locule (Hughes, 1966).

Plant growth substances play a controlling role in the process of reproduction. Polyamines (PAs) are substances that are naturally present in plants and act as promoters of growth. They play an important role at the time of flowering, pollination, and early fruit development (Costa et al., 1984). In addition, polyamines have been associated with plant response to abiotic stress (Kumar et al.,1997).To our knowledge no evidence exists on the effect of exogenous PAs on polyamines content of cotton ovaries. Also no information exists on how PAs affect seed set of cotton in high and normal temperatures. Therefore the objective of this study was to investigate the effect of exogenous putrescine application on seed set of cotton under two temperature regimes.

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RESEARCH DESCRIPTION

A growth chamber study was conducted in the Altheimer Laboratory, Fayetteville, Ark., in December 2008. Cotton (*Gossypium hirsutum* L.) cultivar DP444BR was planted in 80 2-L pots filled with Sunshine growing media. Two growth chambers were used, one was used as a control with a day/night temperature regime of 30/20°C, while the second chamber was the high-temperature treatment with day/night temperatures of 38/20°C. The plants were maintained at the control temperatures until they reached the flowering stage (5 weeks after planting), after which 40 pots were placed in each growth chamber. The 40 pots in each chamber were split in two sets, half were used as control and half were used for the exogenous application of putrescine. Putrescine at 10 mM plus 0.5% Tween 20 was applied 2 days after the plants were in the temperature treatment. Putrescine was applied to 20 tagged "candles" of the same main stem node. In addition, 20 more candles were tagged from the control plants of each growth chamber. At anthesis (24 hours later), 4 "treated" white flowers and 4 "control" white flowers were collected for polyamine analysis. This procedure was repeated for 3 days. After 3 weeks, the remaining bolls were collected in order to determine the number of seeds per ovary. The treatment design was a split-plot with the main-factor temperature and the sub-factor Putrescine application. For the statistical analysis, JMP 6 software was used (SAS Institute Inc., Cary, N.C.).

RESULTS AND DISCUSSION

The statistical analysis of the data revealed that there was no significant temperature x exogenous putrescine application interaction. Because of the lack of interaction, we focused on the main effects of the exogenous putrescine application and the main effect of temperature. The results showed that the exogenous putrescine application significantly increased the putrescine content of cotton ovaries (Fig. 1). However spermidine and spermine concentrations in cotton ovaries were not significantly affected.

Subjecting the plants to temperatures above the 35-36°C physiological optimum (Bibi et.al., 2008) significantly decreased the spermidine concetration, but not the putrescine and spermine content (Fig. 2).

The results of seed set showed again that there was no significant temperature x exogenous putrescine application interaction. The main effects of seed set were significantly decreased by the high temperature compared to the control (Fig. 3).

In addition seed set was significantly increased by exogenous putrescine application (Fig. 4).

PRACTICAL APPLICATIONS

Polyamines play an important role in flowers and seed induction and have been shown to decrease under high-temperature stress. Exogenous application of putrescine increased the level of Put in flowers and this was associated with increased seed set. Therefore the possibility exists of ameliorating high-temperature stress in cotton flowers through exogenous application of Putrescine.

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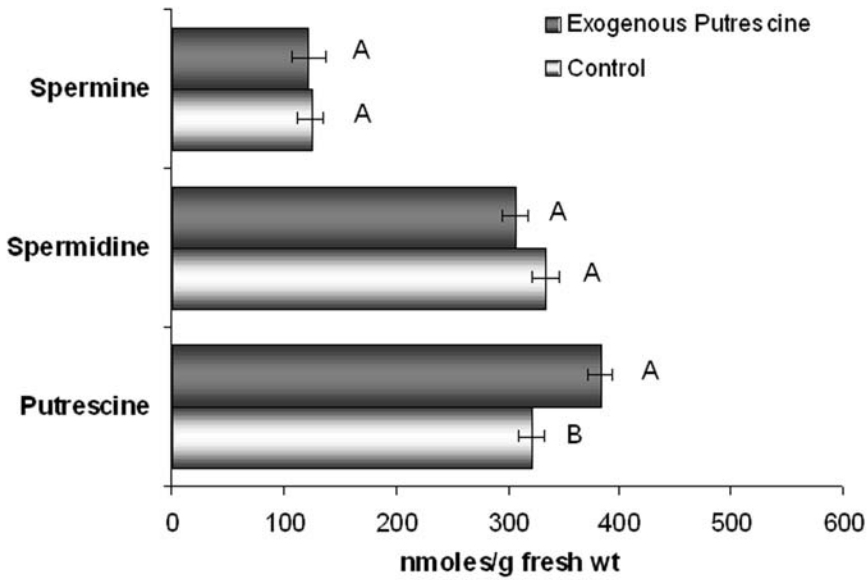

Fig. 1. Effect of exogenous Putrescine application on putrescine, spermidine, and spermine content of cotton ovaries. Pairs of columns with the same letter are not significantly different (P=0.05).

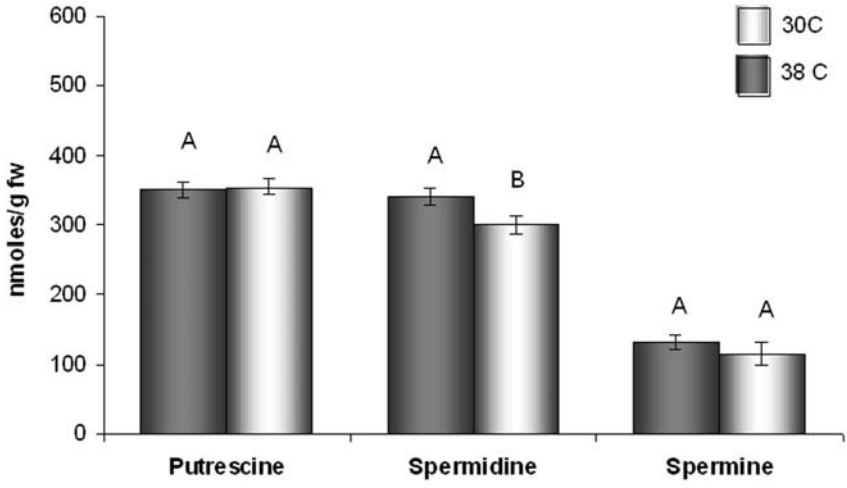

Fig. 2. Effect of high temperature on putrescine, spermidine, and spermine content of cotton ovaries. Pairs of columns with the same letter are not significantly different (P=0.05).

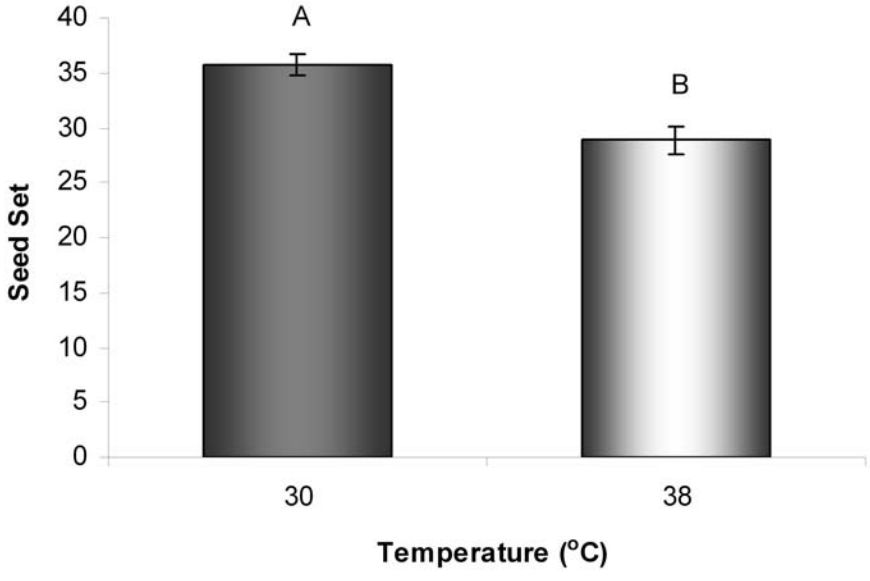

Fig. 3. Effect of temperature on seed set of cotton. Columns with the same letter are not significantly different (P=0.05).

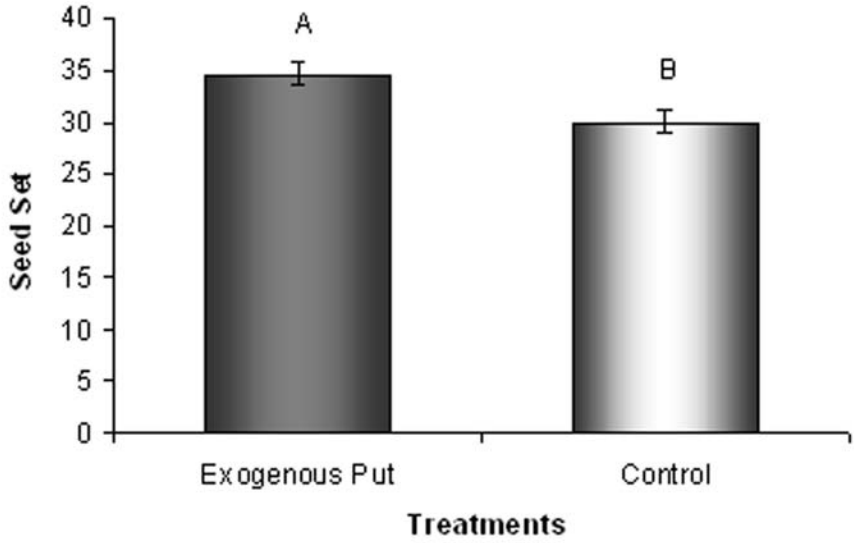

Fig. 4. Effect of exogenous putrescine application on seed set of cotton. Columns with the same letter are not significantly different (P=0.05).

Effect of the Plant Growth Regulator BM86 on Seed-Set Efficiency and Yield of Cotton

Androniki C. Bibi, Derrick M. Oosterhuis, and Evangelos D. Gonias[1]

RESEARCH PROBLEM

The plant growth regulator BM86 was formulated to stimulate seed production and fruit growth. In this study, it was hypothesized that the addition of BM86 would increase levels of polyamines for seed induction and have a direct benefit of improving fertilization and seed set in cotton. This benefit may enhance yield under extreme environmental conditions when endogenous polyamines content is reduced.

BACKGROUND INFORMATION

Year-to-year variability in cotton yield is a major concern for farmers and the cotton industry in general. The cause of this variability has been associated with environmental stress, high temperature in particular, during flowering and boll development. A correlation between high temperatures and lower cotton yields during July and August in the Mississippi River valley has been reported (Oosterhuis, 2002). An earlier report by Hughes (1966) indicated that high temperatures can result in a lower number of ovules per locule. Polyamines are substances that occur naturally in plants and play an important role during flowering, pollination, and early fruit development (Costa et al., 1984). Our earlier studies showed that polyamines are decreased by high temperature stress (Bibi et al., 2007). The plant growth regulator BM86 was formulated to increase polyamine levels but the effect on yield in cotton has not been reported. Therefore, a field study was conducted in 2005 and 2006 to investigate the effect of the plant growth regulator BM86 on seed set and yield of cotton.

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RESEARCH DESCRIPTION

A field study was conducted in 2006 at the Cotton Branch Station in Marianna, eastern Arkansas. The cotton (*Gossypium hirsutum* L.) cultivars used in this study were DP444BR, ST5599BR, and FM960BR. The soil was a Captina silt loam. A randomized complete block design with five replications and a split-split block arrangement of treatments were used. The main factor was cultivars, sub-factor BM86 application, and sub-sub factor nodal position. The plot size was 4 rows by 15 m. The study was irrigated based on an irrigation scheduler program. The fertilization program was determined by preseason soil tests and recommended values for cotton. Weed and insect control were conducted according to Arkansas recommendations.

At first flower on 8 July 2006, the PGR BM86 (Goëmar Laboratories, Saint Malo, France) was applied to the right 2 rows of each plot at 2 pt/acre with a backpack CO_2 sprayer calibrated to deliver 10 gal/acre (94 L/ha). The left two rows were used as the control. The day before the application, the flowering node was determined and 10 first-position white flowers were collected from each plot. Sampling was performed weekly using first-position flowers two nodes higher than the previous position, for a total of three weeks. The PGR BM86 was reapplied two weeks after the first application. At harvest, five bolls were picked from each plot from a similar node from which flowers had been previously collected, for both control and BM86-treated plants. The flowers were used to determine the number of ovules per ovary. The procedure involved separating the ovary from the petals and sepals, and dissecting the ovaries to determine the number of locules and the number of ovules. The final number of seed was determined from the hand-picked bolls, and seed-set efficiency was calculated using the equation: [seed-set efficiency = (# of seeds/ # of ovules) x 100]. For our experiments seed-set efficiency was calculated using both the total seed number (undeveloped ovules + harvestable seeds) and the number of the harvestable seeds. Seedcotton yields were determined by mechanically harvesting each individual sub-plot.

RESULTS AND DISCUSSION

The analysis of the data showed that there was no significant "cultivar x BM86 application" interaction in both years (Table 1). The lack of interaction allowed us to analyze the main effects of "cultivar" and "BM86 application" on seed-set efficiency (calculated with the harvestable seed number and the total number of seeds) and seedcotton yield.

Effect of BM86 application on seed-set efficiency and seedcotton yield

In 2005, BM86 application significantly increased the seed-set efficiency of cotton when calculated using the total number of seeds (P=0.0423; Fig. 1A); however, application of BM86 did not significantly affect seed-set efficiency when it was calculated with only the number of harvestable seeds (P=0.3287). Similar data were observed in 2006, when the seed-set efficiency calculated by the total seed number was significantly

increased after BM86 application (P=0.0046; Fig.1B), while when calculated with just the number of harvestable seeds, the effect was not significant (P=0.7434). The non-significant effect of BM86 application on seed-set efficiency (i.e., of harvestable seeds) was reflected in the non-significant effect on seedcotton yield in both years of the study (Fig. 2).

Effect of cultivars on seed-set efficiency and seedcotton yield

There were no cultivar differences in 2005 and 2006 for seed-set efficiency calculated by the total seed number and for seed-set efficiency calculated by the harvestable seed number (Table 1). In addition, the cultivar effect was not significant for seedcotton yield in both years of the study with P=0.2209 (2005) and P=0.6572 (2006) (Table 2).

PRACTICAL APPLICATIONS

It is obvious that the application of BM86 had a significant, positive effect on the number of total seeds (mature and undeveloped), but the number of harvestable seeds was not affected. Research needs to be conducted to find ways to capitalize on this higher number of seeds and to increase the final number of harvestable seeds for yield improvement.

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Table 1. The effect of cultivars on seed-set efficiency of cotton calculated by the total seed number and by the number of the harvestable seeds for 2005 and 2006.

		Seed-set efficiency	
Seed record	Cultivars	2005	2006
		----------(%)----------	
Total seed number	DP444BR	70.3 a[z]	80.9 a
	FM960BR	66.4 a	77.7 a
	ST5599BR	76.3 a	80.7 a
	P-Value	0.0584	0.4405
Harvestable seeds	DP444BR	88.0 a	97.5 a
	FM960BR	87.4 a	98.8 a
	ST5599BR	91.3 a	96.3 a
	P-Value	0.3008	0.4386

[z] Cultivars in a column for each parameter with the same letter are not significantly different for α=0.05.

Table 2. The effect of cultivars on seedcotton yield of cotton for 2005 and 2006.

	Seedcotton	
Cultivars	2005	2006
	----------(kg/ha)----------	
DP444BR	3839.8 a[z]	3158.3 a
FM960BR	3692.6 a	3155.6 a
ST5599BR	4056.2 a	2989.9 a
P-Value	0.2209	0.6572

[z] Cultivars in a column with the same letter are not significantly different at α=0.05.

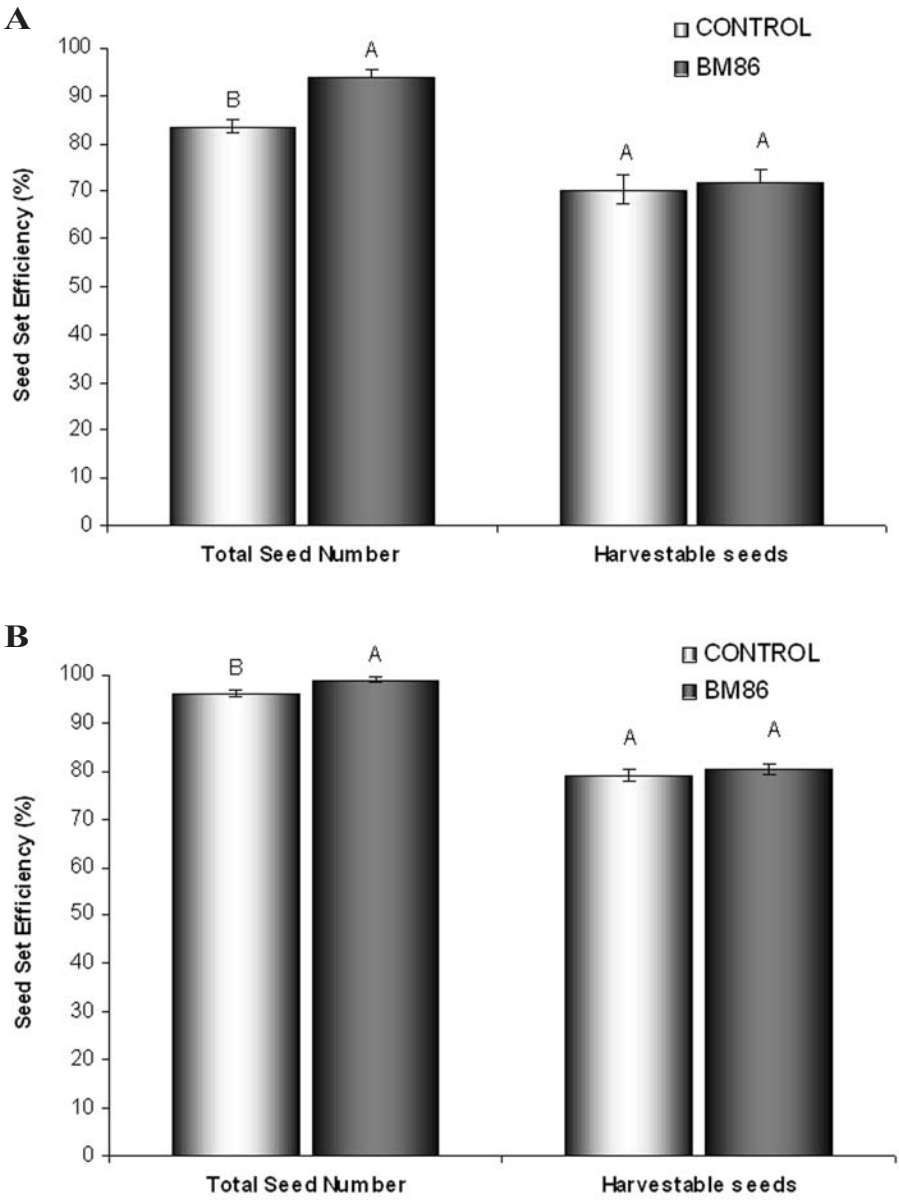

Fig. 1. The effect of BM86 on seed set efficiency of cotton in 2005 (A) and 2006 (B). Pairs of columns with the same letter are not significantly different for α=0.05 (± 1 std error bars are shown).

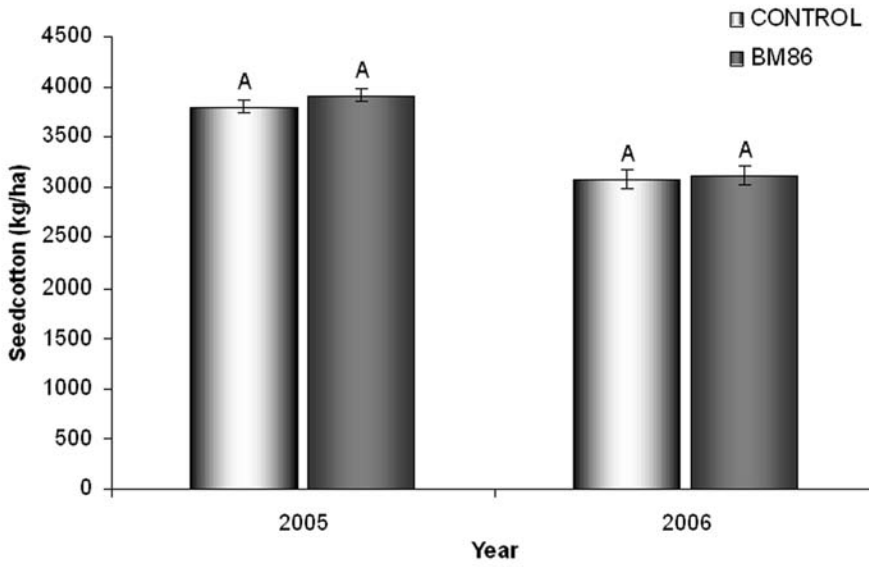

Fig. 2. The effect of BM86 on seedcotton yield in 2005 and 2006. Pairs of columns within a year with the same letter are not significantly different for α=0.05 (± 1 std error bars are shown).

Effect of 1-MCP on the Physiology and Yield of Cotton

Eduardo M. Kawakami, Derrick M. Oosterhuis, and John L. Snider[1]

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, in 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. Also ethylene is 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-MCP to alleviate the adverse effect of environmental stresses on square and boll set, and thereby reduce year-to-year yield variability and allow the cotton crop to yield closer to its potential.

BACK GROUND INFORMATION

Among all stress factors, temperature and drought appear to play the most significant roles in decreasing crop yields in the world. In August 2000 a combination of high temperature and dry weather was estimated to have caused damage to U.S. agriculture that extrapolated to a loss of U.S. $4.2 billion (Mittler, 2006).

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 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, 1982a, 1982b; Lipe and Morgan, 1972), which is initiated by the formation of the abscission layer that results in fruit shed (Lipe and Morgan, 1973).

1-Methylcyclpropene (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

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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-Methylcyclpropene has been known to occupy ethylene receptors such that ethylene cannot bind and initiate action (Sisler and Serek, 1999, Blankenship, 2001). The affinity of 1-MCP for the receptors is approximately 10 times greater than that of ethylene. In addition, compared with ethylene, 1-MPC 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.

RESEARCH DESCRIPTION

The field study was conducted at the University of Arkansas Cotton Branch Station in Marianna, Ark., and also at the Arkansas Agricultural Research and Extension Center in Fayetteville, Ark. Both experiments were planted in mid-May using the DP444BG/RR cultivar. Fertilization was according to preseason soil tests and recommended rates. Weed and insect control were performed according to state recommendations. The plot size was 4 rows by 15 m, 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 five replications. Treatments consisted of: (T1) an untreated control, (T6) 1-MCP at 10 g ai/ha applied at pinhead-square (PHS), (T2) 1-MCP at 10 g ai/ha applied at first FF, and (T3) 1-MCP at 10 g ai/ha applied at FF and FF+2. All 1-MCP treatments were sprayed with a backpack CO_2 sprayer calibrated to deliver 20 gal/acre. The adjuvant AF-400 was added to the spraying solution at a rate of 0.375% v/v.

The yield parameters, number of bolls, seedcotton yield, and lint yield were calculated from a one-meter length row of hand-picked cotton for each plot. In addition, in the experiment conducted in Fayetteville in 2007, 10 white flowers from the first sympodial fruiting position of main-stem nodes 5 (T2) and 11 (T3) were tagged on the day of 1-MCP application, and bolls were collected at the end of the experiment. Measurements consisted of percentage boll abscission, boll weight, and number of seeds per boll.

The upper fully-expanded main-stem leaf, four nodes below the terminal of the plant, was collected at FF + 1 week and FF + 3 weeks. Leaf samples were stored at -80°C for determination of the activity of the antioxidant glutathione reductase.

RESULTS AND DISCUSSION

In order to compare yield differences among treatments, the data of both locations, Marianna and Fayetteville, were combined into a single analysis, with locations added to a model as fixed effect (Table 1). The results showed no significant effect of 1-MCP on any yield parameters. In addition, no significant interaction effect was observed between treatments and locations. Numerically higher values were observed

in all 1-MCP treatments in comparison to the untreated control. Despite the absence of statistically significant differences, the treatment where 1-MCP was applied at FF and FF+2, in contrast to the untreated control, exhibited a numerical increment of 118 kg/ha of lint and 295 kg/ha of seeds.

Boll weight and number of seeds per boll (Figs. 1 and 2) were significantly influenced by applications of 1-MCP at the white-flower stage. Bolls from main-stem node 5 that received 1-MCP (treatments T2 and T3) exhibited a significant increase (P=0.05) in boll weight compared to the untreated control (Fig. 1). This effect was mainly due to the significantly higher (P=0.024) amount of seeds produced by these treatments (Fig. 3).

Similar results were observed in bolls collected from node 11, (treatments T2 and T3), which also exhibited significantly (P=0.032) bigger bolls (Fig. 1) and higher number of seeds (P=0.037; Fig. 2) in comparison to untreated cotton bolls. As expected, smaller bolls with fewer seeds were observed in node 11 in contrast to bolls from node 5. On the other hand 1-MCP did not have any significant influence on the process of cotton fruit abscission (Fig. 3).

Significantly lower (P=0.044) levels of GR activity in leaves were recorded from plants treated with 1-MCP collected one week after the FF+2 application (Fig. 4). Measurements of GR in the leaves collected one week after FF application showed only numerically lower activity in the 1-MCP treatments in comparison to the untreated control.

PRACTICAL APPLICATION

In conclusion, 1-MCP did not have a significant effect on the yield of field-grown cotton. However, 1-MCP proved to have a positive effect on the stress level of cotton plants, indicated by lower levels of glutathione reductase activity. In addition, 1-MCP treatments had an effect on cotton boll weight by increasing the number of seeds per boll, but did not influence cotton abscission rate. Future research will further elucidate the mechanism and best method of use for 1-MCP to positively impact yields.

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Table 1. Effect of 1-MCP on seedcotton yield, lint yield, and seed production. Experiment conducted in Marianna and Fayetteville, Ark., in summer 2007. Data averaged across locations.

Treatment	Seedcotton yield	Lint yield	Seed production
	---------- (kg/ha) ----------		
T1 - Untreated control	4371	1935	2457
T6 - 1-MCP at PHS	4536	2003	2572
T2 - 1-MCP at FF	4652	2020	2655
T3 - 1MCP at FF and FF + 2	4861	2119	2752
P-value (0.05)	NS	NS	NS

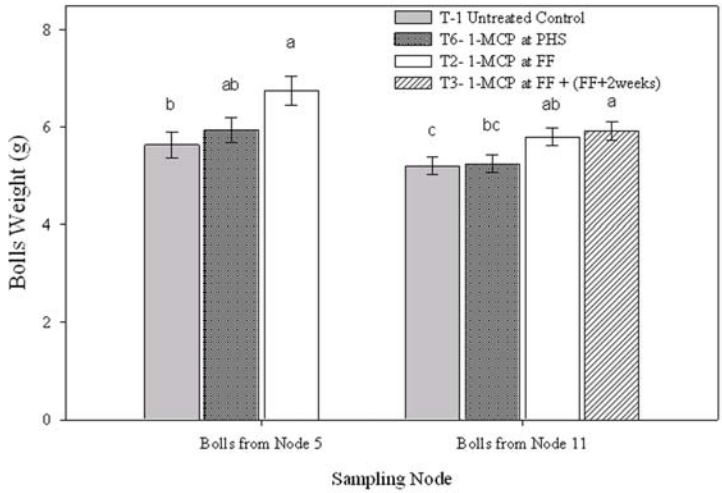

Fig. 1. Effect of 1-MCP on cotton boll weight from the experiment conducted in Fayetteville, Ark., 2007. Groups of columns within each sampling node with the same letter are not significantly different (P=0.05). Error bars represent ± one standard error.

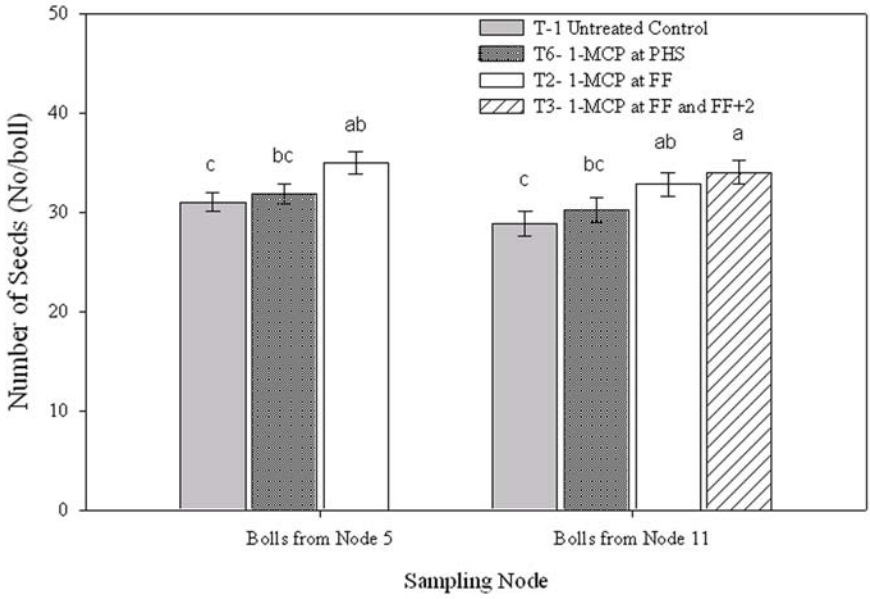

Fig. 2. Effect of 1-MCP on number of seeds per boll from the experiment conducted in Fayetteville, Ark., 2007. Groups of columns within each sampling node with the same letter are not significantly different (P=0.05). Error bars represent ± one standard error.

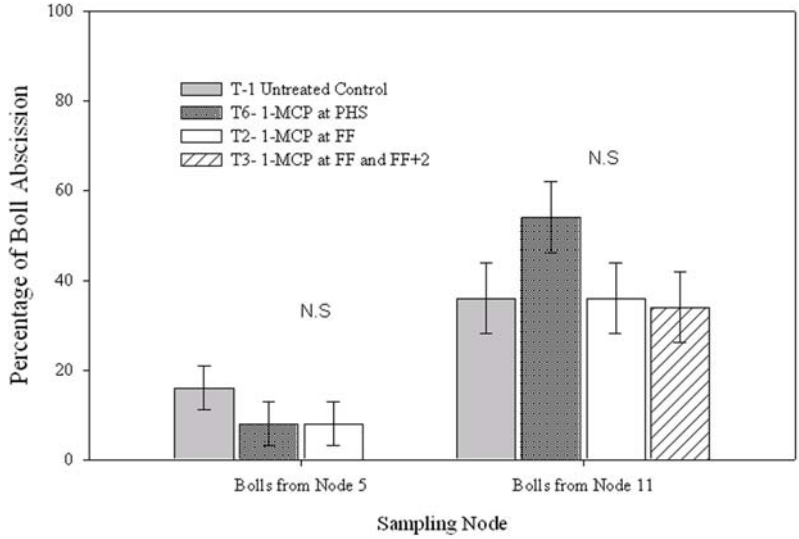

Fig. 3. Effect of 1-MCP on boll abscission, results from combined data of the experiments conducted in Marianna and Fayetteville, Ark., in 2007. NS= non-significant (P=0.05). Error bars represent ± one standard error.

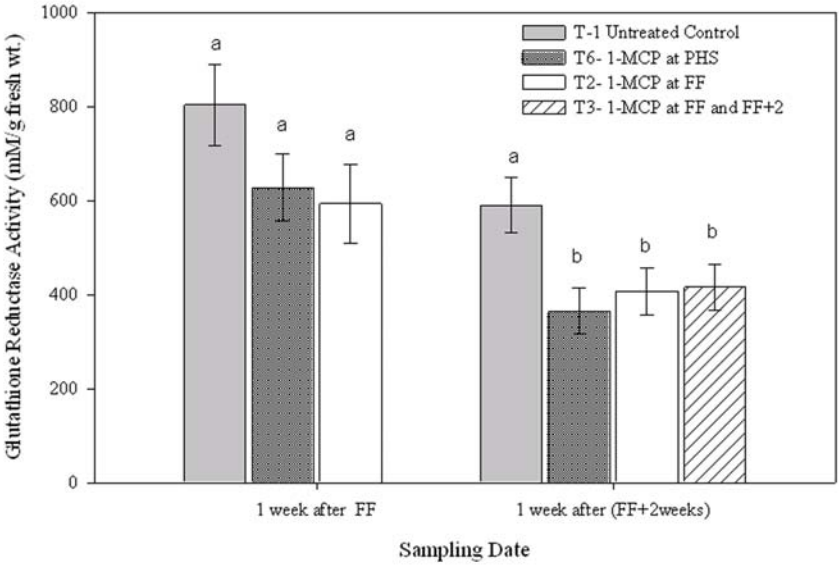

Fig. 4. Effect of 1-MCP on glutathione reductase activity, results from combined data of the experiments conducted in Marianna and Fayetteville, Ark., 2007. Groups of columns within each sampling day with the same letter are not significantly different (P=0.05). Error bars represent ± one standard error.

Effect of 1-MCP on Water Relations Parameters of Well-Watered and Water-Stressed Cotton Plants

Eduardo M. Kawakami, Derrick M. Oosterhuis, and John L. Snider[1]

RESEARCH PROBLEM

The cotton crop in the U.S. is mainly cultivated in irrigated or high-rainfall areas; however, even short periods of interruption of the water supply can cause a reduction in yield. Alleviation of plant stress during dry periods could prevent yield loss and increase profits. Ethylene is known to be the signal of the stress response in plants, and therefore, inhibiting the action of ethylene could have a positive impact on the growth and yield of cotton plants under stress situations.

BACKGROUND INFORMATION

In many regions of the U.S. Cotton Belt, cotton yields are limited by inadequate amounts, or inadequate distribution, of rainfall (Basal et al., 2005). The main physiological effect of water deficit in cotton and other plants is the reduction in photosynthetic carbon assimilation, which results in low dry matter accumulation (Geiger and Servaites, 1991). Many processes are associated with this effect, such as increased ethylene synthesis, stomatal closure, low radiation-use efficiency, and decreased plant biochemical reactions. The scarcity of water resources and the high costs of irrigation management have significantly increased the need for solutions for cotton farmers to overcome problems of water deficit. An inhibitor of the hormone ethylene could provide a possible short-term solution to situations of water deficit.

The plant growth regulator 1-Methylcyclopropene (1-MCP) is approved for use in fruit and vegetables by the EPA. The product works by decreasing or delaying the effect of ethylene, which normally acts as an endogenous stress and senescence phytohormone action (Blankenship and Dole, 2003). The mode of action of 1-MCP is to block ethylene receptor sites (Binder and Bleecker, 2003), such that ethylene cannot bind and elicit action (Blankenship and Dole, 2003). The objective of our study was to

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investigate the effect of 1-MCP on the physiology and growth of cotton plants under water-stressed and well-watered conditions. The study was designed with the objectives of analyzing the 1-MCP effect on stomatal resistance, water potential, transpiration, water-use-efficiency, and dry matter production of cotton under well-watered and water-stressed conditions.

RESEARCH DESCRIPTION

A growth chamber study was conducted in the Altheimer Laboratory, Arkansas Agricultural Research and Extension Center, Fayetteville, to determine the effect of 1-MCP on drought-stressed cotton plants. In July 2007, the cotton (*Gossypium hirsutum* L.) cultivar DP444BG/RR was planted in one-liter pots filled with Sunshine potting mix (Sun Gro Horticultural Distribution Inc., Bellevue, Wash.). Pots were arranged in a large growth chamber with a day/night temperature regime of 30/20°C, 12-hour photoperiods, and relative humidity of 60%. After four weeks, 1-MCP was sprayed according to the treatments. The pots were wrapped with plastic bags to avoid water evaporation from the soil and to confine water loss to transpiration only. Half of the pots (10 pots) were carried through a water-stress regime. The stress regime was established for five days, after which the stressed plants were re-watered. This process was repeated three times, giving a total of three water-stress cycles at the end of the experiment. The experiment was arranged in a randomized complete block design with five replications. The treatments consisted of: (T1) and untreated control well-watered, (T2) 1-MCP at 10 g ai/ha well-watered, (T3) untreated control water-stressed, and (T4) 1-MCP at 10 g ai/ha water-stressed. The 1-MCP was applied with a CO_2 backpack sprayer calibrated to deliver 20 gal/acre. All 1-MCP treatments were applied with the adjuvant AF-400 at 0.375% v/v.

Daily measurements were made of stomatal resistance, using a LICOR 1600 porometer and daily measurements of plant transpiration were recorded by weighing the pots. In addition, at the end of each stress cycle, measurements of leaf water potential were recorded using leaf discs placed in thermocouple psychrometers. All the measurements were recorded between 12:00 pm and 2:00 pm on the upper fully-expanded main-stem leaf at four nodes below the terminal of the plant. At the end of the experiment, values of total dry matter (g) were divided by the total amount of water used (ml) to calculate water use efficiency (g/ml).

RESULTS AND DISCUSSION

Stomatal resistance measurements (Fig. 1) indicated a significant interaction effect between 1-MCP treatment and water regime at d 5 and d 9. A significant water regime effect was detected at d 3, 4, 6, 7, 8, 10, 13, and 14, where as expected, water-stressed plants exhibited higher stomatal resistance than well-watered plants.

The highest stomatal resistance value was recorded at d 5, when 1-MCP treated plants under water stress reached 38.08 s cm^{-1} (Fig. 1). Under water-deficit stress, 1-MCP treated plants exhibited higher stomatal resistance than the untreated water-stressed

control. Significant differences were observed at d 5 and 9, although the magnitude of the dissimilarity between 1-MCP treatments was much greater at d 5 than at d 9. At d 5 the difference was about 20 s cm^{-1}, while at d 9 the difference was close to 5 s cm^{-1} (Fig. 1). On the other hand, under well-watered conditions there were no differences between 1-MCP treated and untreated plants, with stomatal resistance in this water regime fluctuating between 1.5 and 3.5 s cm^{-1}.

Although 1-MCP treatments were shown to have an effect on stomatal resistance of plants under water-stress condition, daily pot transpiration did not show the same results (Fig. 2). Only a significant effect of water regime treatments was observed, with well-watered plants exhibiting higher transpiration compared to water-stressed plants from d 2 through d 14.

Water potential measurements showed that at d 5 the water stress 1-MCP treatment was statistically different compared to the untreated control under water stress (Fig. 3), with the 1-MCP treatment exhibiting an increase of 0.83 MPa compared to the untreated control. Less negative values were observed in the 1-MCP treatment, indicating lower levels of stress caused by the drought regime. By the end of the second stress cycle (d 10), only a water-stress effect was observed, and at the end of the experiment (d 14), no significant effect of any treatment was recorded. During the three times of measurement, the leaf water potential in the water-stressed treatments became less negative, which could be due to plant acclimation to water deficit. These results can be explained by the stomatal resistance data, where at d 5 a higher stomatal resistance in the 1-MCP treated plants under water deficit resulted in higher water potential values. Whereas at d 10 the 1-MCP treatment effect was small with only a slight positive effect on stomatal resistance, which resulted in a numerical increase in the leaf water potential. At d 14 no 1-MCP effect was detected in either measurement.

Measurements of total plant dry matter, which included leaf, stem, squares, and total dry matter, indicated a significant effect of water regime, but no significant effect of 1-MCP (Table 1). Only a slight, consistent numerical increase in dry matter production was observed in 1-MCP treatments compared to untreated plants. As expected the water stress significantly decreased all dry matter measurements analyzed.

Similar results were observed for leaf area, number of nodes, number of squares, and water use efficiency parameters (Table 2). Water-stressed plants exhibited significantly lower leaf area and numbers of nodes and squares. In contrast, water-stressed plants had higher water-use efficiency than well-watered plants. However, 1-MCP application had no effect on water-use efficiency.

PRACTICAL APPLICATION

We conclude that 1-MCP applications had positive effects on the physiological parameters measured under water deficit, and that the effect of 1-MCP on stomatal resistance and water potential only lasted for about 5 d. The 1-MCP treatments did not have an effect on transpiration measurements, which explains the absence of 1-MCP influence on plant water-use efficiency. It is possible that under conditions of water deficit, multiple applications of 1-MCP applied at 5-d intervals may be needed for improved productivity.

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Table 1. Effect of 1-MCP, with and without water deficit, on leaf dry matter, stem dry matter, squares dry matter, and total dry matter.

	Dry matter			
Treatment	Leaf	Stem	Squares	Total
	---------- (g/plant)----------			
T1- Untreated well-watered	8.42 a[z]	12.27 a	1.04 a	21.73 a
T2- 1-MCP well watered	8.91 a	12.93 a	1.07 a	22.91 a
T3- Untreated water-stressed	6.81 b	8.80 b	0.75 b	16.37 b
T4- 1-MCP water-stressed	6.70 b	8.82 b	0.92 b	16.44 b

[z] Columns with the same letters are not significantly different (P=0.05).

Table 2. Effect of 1-MCP, with and without water deficit, on leaf area, number of nodes, number of squares, and water use efficiency.

Treatment	Leaf area	Number of nodes	Number of squares	Water use efficiency
	(cm^2)	---------- (no.) ----------		(g/ml)
T1- Untreated well-watered	2054.35 a[z]	11.50 a	16.38 a	0.0049 a
T2- 1-MCP well watered	2028.63 a	11.17 a	16.69 a	0.0051 a
T3- Untreated water-stressed	1379.30 b	9.83 b	10.33 b	0.0080 b
T4- 1-MCP water-stressed	1455.29 b	9.92 b	12.42 b	0.0078 b

[z] Columns with the same letters are not significantly different (P=0.05).

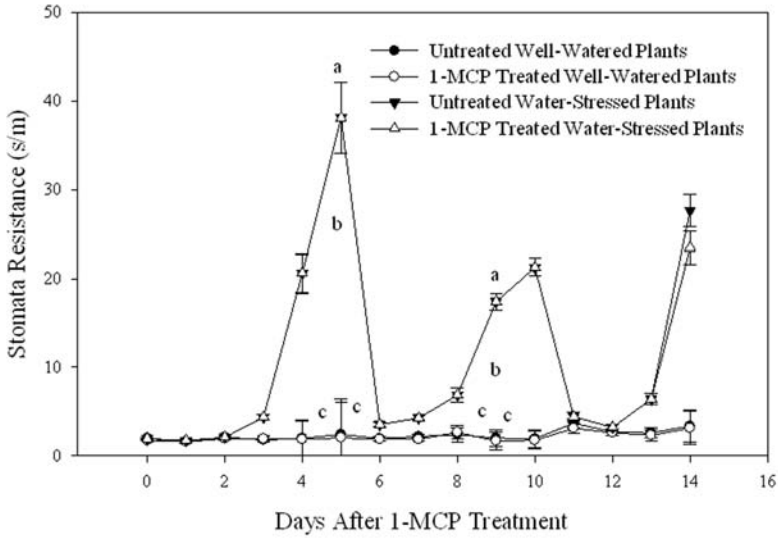

Fig. 1. Effect of 1-MCP on stomatal resistance, with and without water deficit. 1-MCP was applied at day 0 and measurements were made daily at midday. Data points of means with the same letters for each measurement day are not significantly different (P=0.05). Error bars represent ± one standard error.

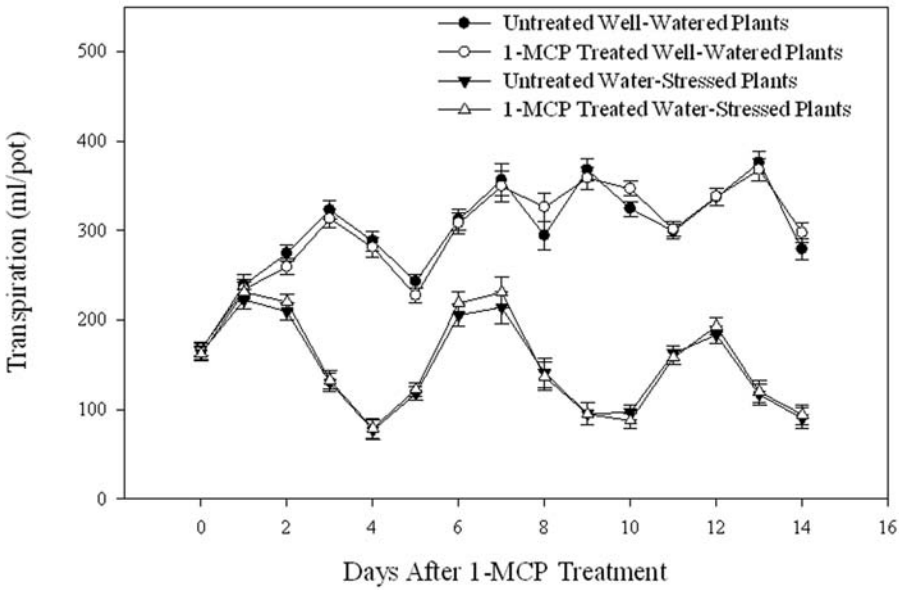

Fig. 2. Effect of 1-MCP in plant transpiration, with and without water deficit. 1-MCP was applied at day 0 and measurements were made daily at midday. Error bars represent ± one standard error.

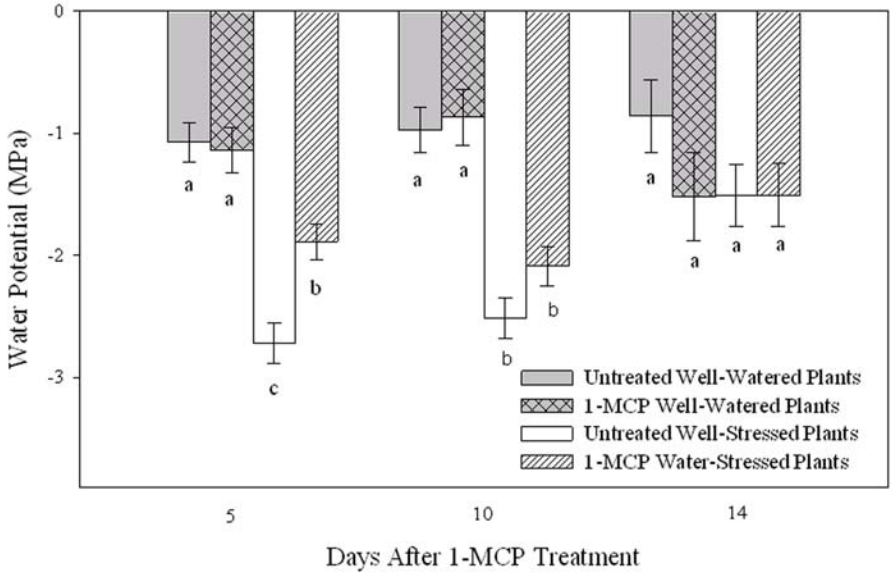

Fig. 3. Effect of 1-MCP on cotton leaf water potential, with and without water deficit. Days 5, 11, and 14 correspond to the end of each stress cycle. Groups of columns within each time interval with the same letters are not significantly different (P=0.05). Error bars represent ± one standard error.

Effect of 1-MCP on Antioxidants, Enzymes, Membrane Leakage, and Protein Content of Drought-Stressed Cotton Plants

Eduardo M. Kawakami, Derrick M. Oosterhuis, and John L. Snider[1]

RESEARCH PROBLEM

Among all abiotic stress factors, drought is the major environmental constraint to crop productivity worldwide (Sharp et al., 2004). According to Bot et al. (2000), 45% of the world agricultural lands are subject to continuous or frequent drought. In cotton production, higher yields are limited in many regions of the U.S. Cotton Belt by inadequate amounts or inadequate distribution of rainfall (Basal et al., 2005). Even in irrigated or high-rainfall areas, short periods of interruption of the water supply can increase fruit shed and decrease yield. Alleviation of plant stress during dry periods could prevent yield loss and increase profits.

BACKGROUND INFORMATION

One of the main effects of drought stress on plants is the initiation of leaf senescence. Senescence in plants is usually triggered by ethylene (Abeles et al., 1992) and it is characterized by changes in cell structures (Inada et al., 1998) and by increases in the concentration of reactive oxygen species (ROS) such as superoxide radical (O_2^-), hydroxyl radicals (OH), and hydrogen peroxide (H_2O_2) (Asada, 1999). Reactive oxygen species are highly reactive and can cause damage to cell structure and functions (Elstner, 1991; Asada, 1999). Decreases in plant growth under stress conditions are mainly associated with increases in ROS synthesis (Grene, 2002). Plant responds to ROS by increasing the synthesis of antioxidant enzymes as a protection mechanism against cell damage (Scandalios, 1997). Antioxidant enzymes in plant cells play a major role in the preservation of membrane integrity, protection of DNA, and proteins degradation (Scandalios, 1997). Measurements of antioxidant enzyme concentrations, protein, and membrane integrity parameters provide an indication of the level of stress in plants.

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1-Methylcyclopropene (1-MCP) is a plant growth regulator approved for use in fruit and vegetables by the EPA. The product works by decreasing or delaying the effect of ethylene, by occupying ethylene receptors such that ethylene cannot bind and elicit reaction (Blankenship and Dole, 2003). The objective of this study was to investigate the effect of 1-MCP on the antioxidant enzymes glutathione reductase (GR) and superoxide dismutase (SOD) in relation to protein concentration and membrane leakage of cotton plants under well-watered and water-stressed conditions.

RESEARCH DESCRIPTION

A growth chamber study was conducted in the Altheimer Laboratory, Arkansas Agricultural Research and Extension Center, Fayetteville, to determine the effect of 1-MCP on drought-stressed cotton plants. In July 2007, cotton (*Gossypium hirsutum* L.) cultivar DP 444BG/RR was planted in one-liter pots filled with Sunshine potting mix (Sun Gro Horticultural Distribution Inc., Bellevue, Wash.). Pots were arranged in a large growth chamber with a day/night temperature regime of 30/20°C, 12-hour photoperiods, and relative humidity of 60%. The pots were wrapped with plastic bags to avoid water evaporation from the soil and to confine water loss to transpiration only. Half of the pots (10 pots) were carried through a water-stress regime. The stress regime was established for five days, after which the stressed plants were re-watered. This process was repeated three times, giving a total of three water-stress cycles at the end of the experiment. The experiment was arranged in a randomized complete block design with five replications. Four weeks after planting, 1-MCP was sprayed according to the treatments. The treatments consisted of: (T1) an untreated control well-watered, (T2) 1-MCP @ 10 g ai/ha well-watered, (T3) untreated control water-stressed, and (T4) 1-MCP @ 10 g ai/ha water-stressed. The 1-MCP was applied with a CO_2 backpack sprayer calibrated to deliver 20 gal/acre. All 1-MCP treatments were applied with the adjuvant AF-400 at 0.375% v/v.

At the end of the experiment, leaf discs from the upper, fully expanded main-stem leaf, four nodes below the terminal of the plant, were sampled for membrane leakage determination. After leaf disc sampling, the same leaves were collected and stored at -80°C for antioxidant enzymes (GR and SOD) and protein content determination.

RESULTS AND DISCUSSION

Both GR activity (Fig. 1) and SOD units (Fig. 2) showed an interaction effect between 1-MCP treatment and water regime. The P-values were 0.0408 for GR and 0.0404 for SOD.

The GR activity indicated no effect of 1-MCP under well-watered conditions (Fig. 1). However, in the water-stressed regime, 1-MCP application significantly increased GR activity in comparison to the untreated control. The overall analyses comparing the four treatments showed no significant differences among untreated well-watered, 1-MCP treated well-watered, and untreated water-stressed plants. Only the water-stressed plants that received the 1-MCP application exhibited a significant increase in

glutathione activity. This increase in antioxidant activity in plants accompanying the application of 1-MCP could be an important key to protect cotton plants from reactive oxygen species under drought stress.

The SOD measurements also showed a significant effect of 1-MCP under water-deficit conditions, in which the 1-MCP treatment exhibited significantly higher SOD units compared with untreated plants (Fig. 2). Plants treated with 1-MCP sustained their levels of SOD equally to non-stressed plants, while water-stressed plants without 1-MCP showed a significant decrease in SOD content. Similar to GR activity, this maintenance of SOD production could be helpful for plants to overcome cellular damage from drought stress in field conditions.

Membrane leakage data showed that the 1-MCP treatment lowered the membrane leakage of leaf samples (Fig. 3), possibly due to higher amount of antioxidant enzymes produced (Figs. 1 and 2). As expected, water-stressed plants exhibited higher values of electrical conductivity than well-watered plants (Fig. 3). These results showed that the maintenance of membrane integrity in cotton plants could be improved by application of 1-MCP. Membrane lipids are extremely important for maintenance of vital cell physiological processes and damaged cell membranes due to water stress could impair physiological functions.

Protein content results indicated a significant interaction effect ($P=0.013$) among treatments (Fig. 4). The effect of 1-MCP and water leaf on protein concentrations was similar to the effects on SOD. Protein concentration measurements showed that untreated plants under water stress exhibited low concentrations of protein, significantly different compared to the rest of the treatments (Fig. 4). In addition, an increase in protein content in 1-MCP treated plants in drought-stress conditions was observed, possibly due to a result of the combination of an increase and maintenance of the antioxidant enzymes and better membrane integrity of the plant cells.

PRATICAL APPLICATION

The growth chamber study showed that 1-MCP increased the activity of the antioxidant enzymes glutathione reductase and superoxide dismutase in water-stressed plants. These effects significantly increased protein concentration and maintained cell membrane integrity. These results indicated that application of 1-MCP to cotton may be beneficial in providing protection against reactive oxygen species produced by plants under stress conditions.

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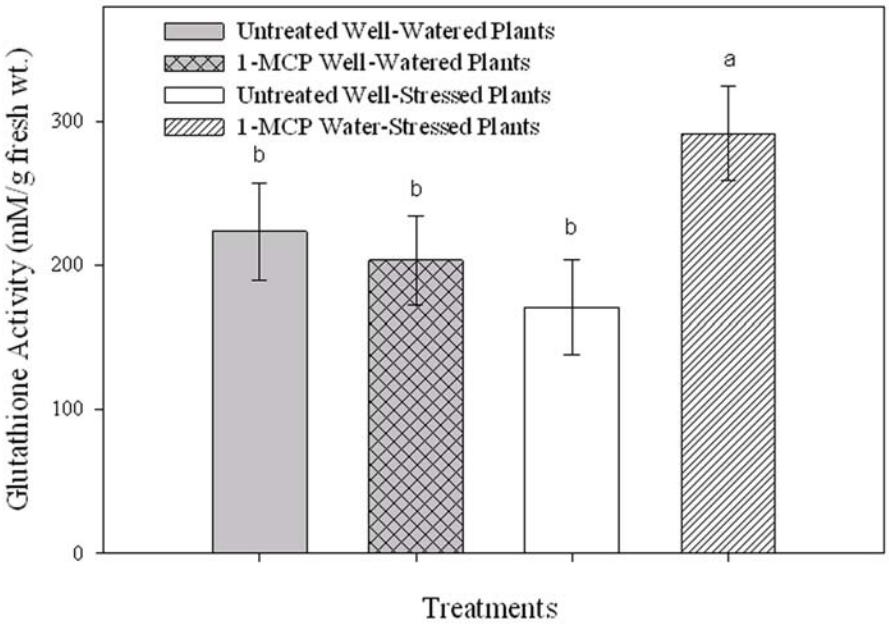

Fig. 1. Effect of 1-MCP on leaf Glutathione reductase activity in cotton plants with and without water deficit. Columns with the same letters are not significantly different (P=0.05). Error bars represent ± one standard error. Measurements were made at the end of the experiment.

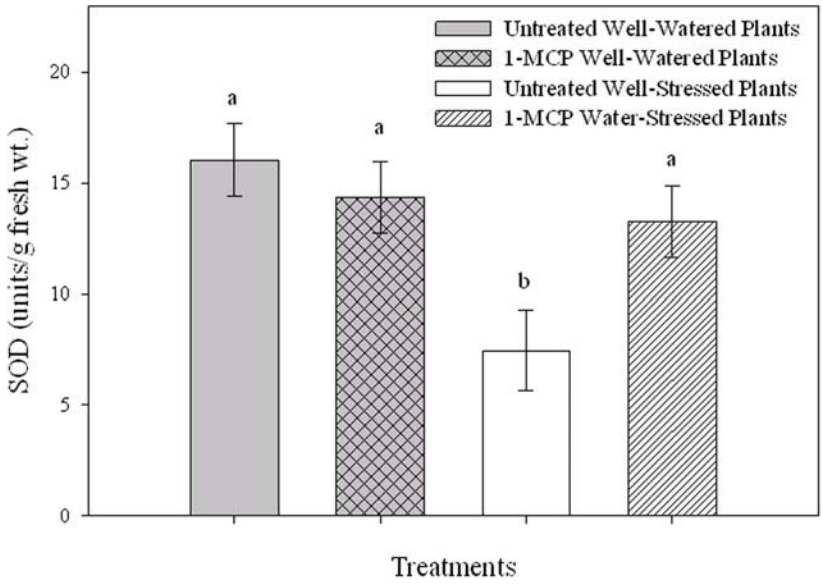

Fig. 2. Effect of 1-MCP on leaf SOD in cotton plants with and without water deficit. Columns with the same letters are not significantly different (P=0.05). Error bars represent ± one standard error. Measurements were made at the end of the experiment.

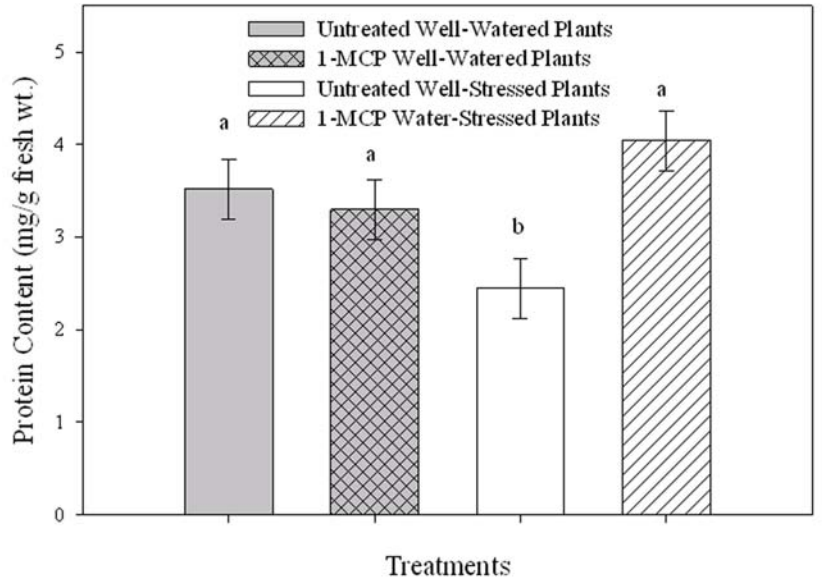

Fig. 3. Effect of 1-MCP on leaf protein content of cotton plants with and without water deficit. Columns with the same letters are not significantly different (P=0.05). Error bars represent ± one standard error. Measurements were made at the end of the experiment.

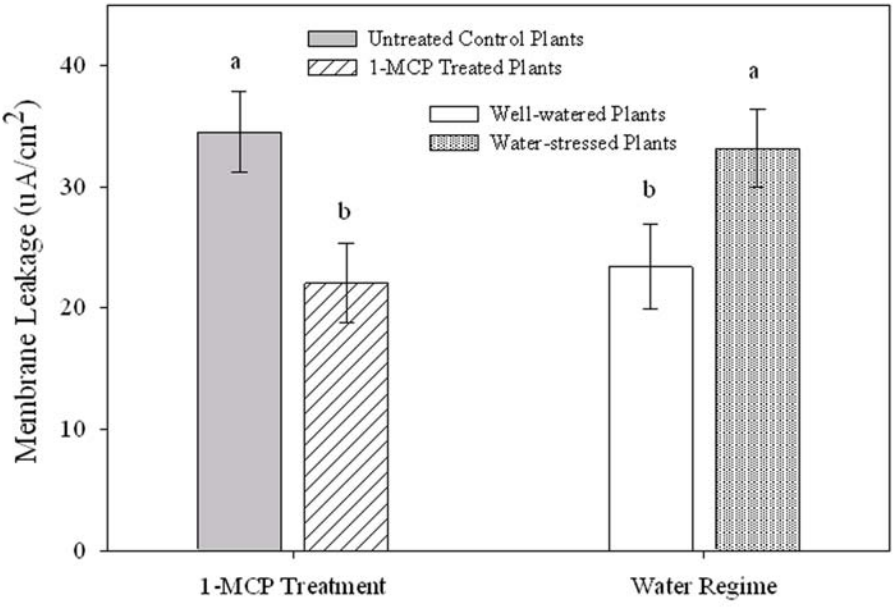

Fig. 4. Effect of 1-MCP and water regime treatment on leaf membrane leakage. Groups of columns within each treatment with the same letters are not significantly different (P=0.05). Error bars represent ± one standard error. Measurements were made at the end of the experiment. Data were averaged across regime treatment for 1-MCP effect and data averaged across 1-MCP treatment for regime effect.

Effect of 1-MCP on Ethylene Synthesis and Development of Cotton Flowers under Normal and High Temperature

Eduardo M. Kawakami, Derrick M. Oosterhuis, and John L. Snider[1]

RESEARCH PROBLEM

With global warming and climate change, high-temperature stress has become a major factor affecting crop growth and yield. Cotton (*Gossypium hirsutum* L.) crops in the U.S. experience periods of extreme high temperatures during flowering and boll development, but information is lacking on the physiological response of cotton to high-temperatures stress and appropriate techniques to ameliorate this response.

BACKGROUND INFORMATION

Even though cotton originates from warm regions, the cotton plant responds negatively to high temperatures (Oosterhuis, 2002; Pettigrew, 2008). The optimum day temperature for cotton development is around 30°C (Reddy et al., 1992). However, in the U.S. Cotton Belt, temperatures reach levels above 35°C during reproductive development (Reddy et al., 1991; Boykin et al., 1995 cited by Pettigrew, 2008). Oosterhuis (2002) suggested that in the U.S. high temperature during reproductive development is the main factor causing lower and variable cotton yields.

Ethylene is produced by plants under stress conditions (Abeles et al., 1992), and plays a major role in the regulation of the abscission process in cotton fruits (Guinn, 1982a and 1982b; Lipe and Morgan, 1972). Cotton fruit abscission is largely controlled by ethylene, which initiates the formation of the abscission layer in the peduncle that results in fruit shed (Lipe and Morgan, 1973). Ethylene also plays a major role in the physiology of heat-stressed plants (Abeles et al., 1992), but it is not clear in the literature if ethylene increases or decreases under high temperature.

1-Methylcyclopropene (1-MCP) is a plant growth regulator that inhibits the action of ethylene by blocking the ethylene receptor sites in the plant cell (Blankenship and Dole, 2003). The effect of 1-MCP was tested by Hays et al. (2007) in a wheat (*Triticum*

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aestivum L.) cultivar susceptible to heat stress, and they found that 1-MCP enhanced wheat tolerance to high-temperature conditions. These authors reported that plants treated with 1-MCP did not exhibit the induction of kernel abortion and reduction in kernel weight as did the untreated heat-stressed plants.

The objective of this study was to determine the effects of 1-MCP on ethylene synthesis and development of cotton reproductive organs under normal and high temperature.

RESEARCH DESCRIPTION

The experiment was conducted in the Altheimer laboratory, Arkansas Agricultural Research and Extension Center in Fayetteville, Ark. Cotton (*Gossypium hirsutum* L.) cultivar DP444 BG/RR was planted in 2-liter pots filled with Sunshine potting mix (Sun Gro Horticultural Distribution Inc., Bellevue, Wash.). The pots were arranged in two large walk-in growth chambers (Model PGW36, Conviron, Winnipeg, Canada) with day/night temperatures of 30/20°C, 12-hour photoperiods, and a relative humidity of 70%. After 6 weeks (about one week prior to flowering), the temperature of one growth chamber was increased in 2°C increments every 2 days until the temperature reached 38°C; the temperature of the other chamber was maintained at 30°C. Plants were watered daily with a half-strength Peter's nutrient solution (Spectrum Group, St. Louis, Mo.). The two chambers with high and normal temperatures were assessed as two distinct experiments. The chamber with normal temperature was label as "Chamber-normal" and the chamber with high temperature as "Chamber-high." The chambers were assumed to be identical in all variables (e.g., light and relative humidity) with differences only in temperatures (30°C and 38°C). The experiments were arranged in a completely randomized design with two factors and six replications. The factors consisted of 1-MCP treatment (treated and untreated) and sample day (0, 1, 2, 4, and 8 days after the white flower stage).

In the 1-MCP treatment, white flowers from the first sympodial position of nodes 5 to 9 were sprayed using an airbrush (Iwata HP-BCS, Iwata Medea, Portland, Ore.). Flowers were sprayed at 9:00 AM with 0.046 ml of a solution containing 0.053 g of 1-MCP active ingredient per liter. This dose corresponded approximately to the recommended field application of 10 g of 1-MCP active ingredient per hectare. A 0.375% v/v of adjuvant (AF-400, Rohm Hass, Philadelphia, Pa.) was added to the spraying solution. A preliminary study was conducted with the objective of analyzing the effect of spraying adjuvant alone compared with untreated flowers and no significant differences were observed in any parameters collected (ethylene production, boll weight, and antioxidant enzymes). These results eliminate the possibilities of the adjuvant interfering in the measurements of the effects of 1-MCP treatment.

Measurements were made of ethylene production and boll weight. Ethylene synthesis was measured by placing a small flexible chamber around each flower at 9 AM and air samples were collected at 3 PM and run through a gas chromatograph. Boll weight was recorded right after ethylene sampling, and ethylene production was expressed as microliters of ethylene produced per gram of fresh weight per hour (µl of ethylene $g^{-1}h^{-1}$).

RESULTS AND DISCUSSION

Statistical analysis of ethylene data showed that there was no significant three-way interaction effect between 1-MCP treatment, sampling days, and chambers. However, the model showed significant interaction between 1-MCP treatment-by-sampling days (P=<0.001) and chambers-by-sampling days (P=0.0005). Since there was a two-way interaction, the factors chamber and 1-MCP treatment were analyzed throughout each sampling day, by averaging chambers over 1-MCP treatments and 1-MCP treatments over chamber, respectively.

The effect of 1-MCP on ethylene concentration compared to the untreated control showed a significant 1.5-fold decrease at day 1 (Fig. 1). However, at 2 days after 1-MCP application, there were no significant differences between 1-MCP treated and untreated control treatments. Thereafter, ethylene concentration declined naturally in both treatments to low background levels at day 8.

Chamber high-temperature had a significant effect on the pattern of ethylene synthesis (Fig. 2). Plants in the chamber-high exhibited a significant decrease in ethylene production at sampling day 2, whereas there was a significant peak in ethylene concentration in the normal temperature treatment at day 2.

Cotton boll weight measurements indicated no significant three-way interaction effect between 1-MCP treatment, sampling days, and chamber, but there were significant two-way interactions between 1-MCP treatment-by-sampling days (P=<0.008) and chamber-by-sampling days (P=0.028). Therefore, the factors treatment and chambers were averaged over each other, by each sampling day. The 1-MCP treatment resulted in a significant increase in boll weight 8 days after application (Fig. 3), in which treated bolls exhibited a gain of 1 g in comparison to untreated bolls. Similarly, the chamber high-temperature also significantly increased the weight of cotton bolls at day 8 (Fig. 4) but there was no significant effect at sampling days 0, 1, 2, and 4.

PRACTICAL APPLICATION

In conclusion, high temperature and 1-MCP changed the pattern of ethylene production of cotton reproductive organs; a decrease in ethylene synthesis was observed in the 1-MCP treatment 1 day after application and in the high temperature 2 days after anthesis. In addition, high temperature and 1-MCP treatment caused an increase in the weight of cotton bolls collected 8 days after anthesis.

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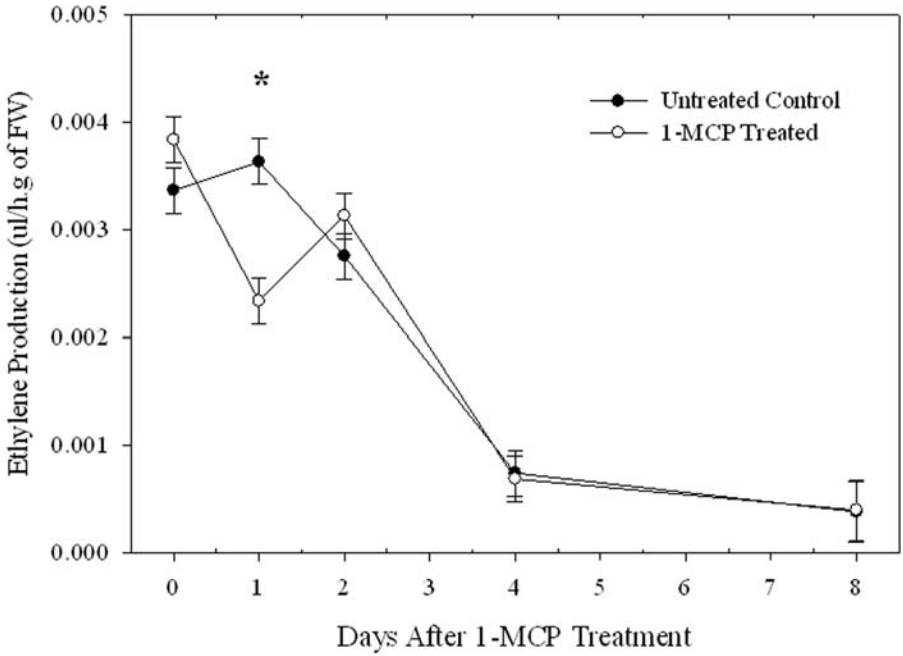


Fig. 1. Effect of 1-MCP on ethylene concentration of cotton flowers measured at 0, 1, 2, 4, and 8 days after anthesis; 1-MCP application was made at day 0. Data points of means with an asterisk are significantly different (P=0.05). Error bars represent ± one standard error. Data were averaged across chambers.

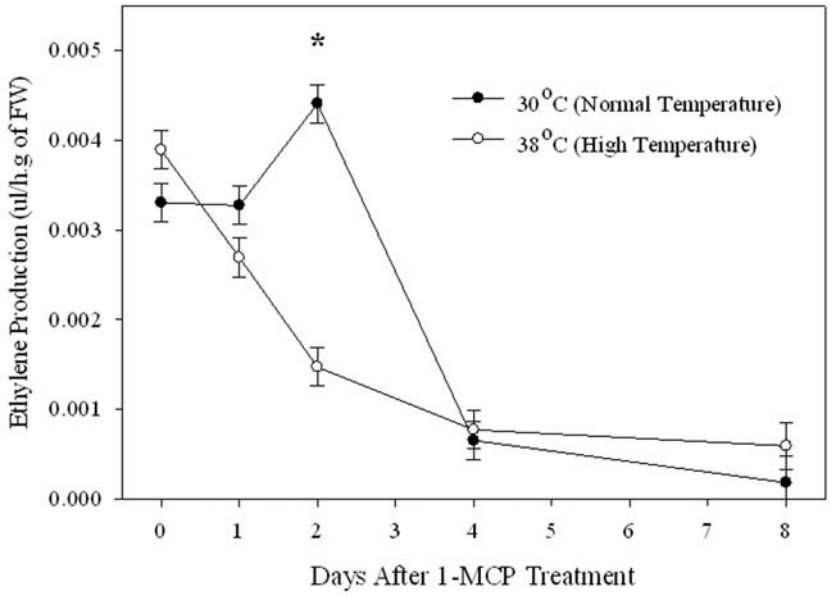
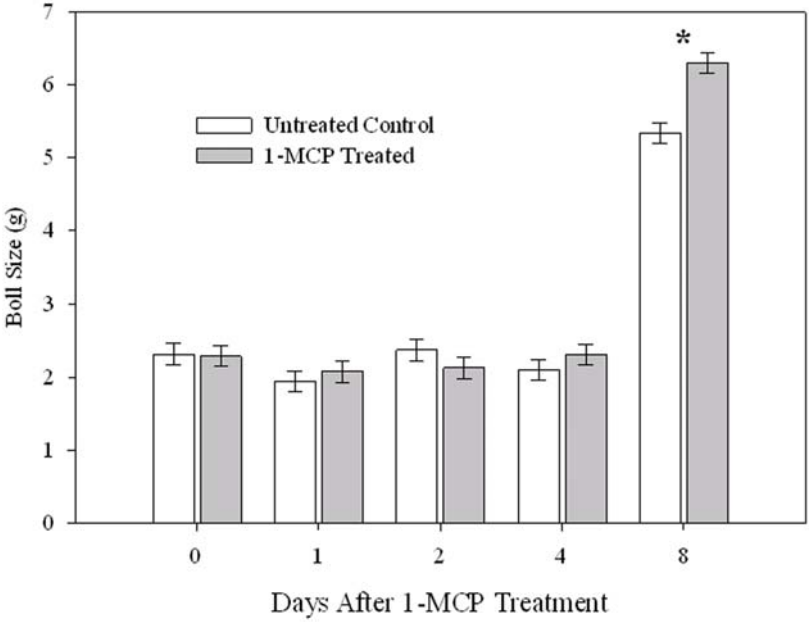
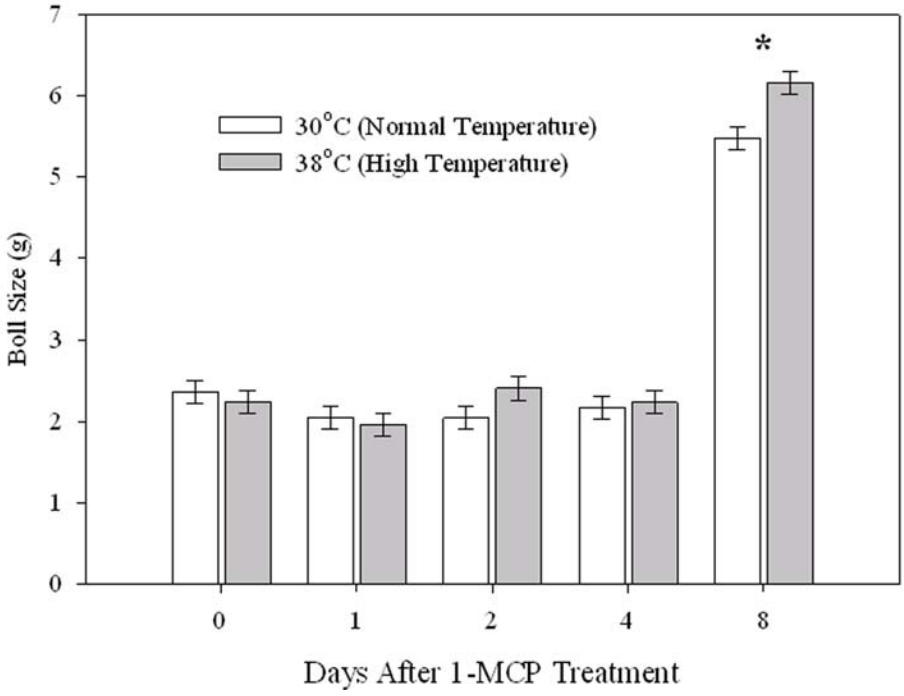


Fig. 2. Effect of temperature on ethylene concentration of cotton flowers measured at 0, 1, 2, 4, and 8 days after anthesis. Data points of means with an asterisk are significantly different (P=0.05). Error bars represent ± one standard error. Data were averaged across 1-MCP treatments.



Fig, 3. Effect of 1-MCP on boll weight. Day zero represents the day of 1-MCP application. Pairs of columns with an asterisk are significantly different (P=0.05). Error bars represent ± one standard error. Data were averaged across chambers.



Fig, 4. Effect of temperature on boll weight. Day zero represents the day of 1-MCP application. Pairs of columns with an asterisk are significantly different (P=0.05). Error bars represent ± one standard error. Data were averaged across 1-MCP treatments.

Final Irrigation Timing 2007–Cotman and Crop Termination in Arkansas Cotton

Tina Gray Teague [1]

RESEARCH PROBLEM

Earlier termination of irrigation could help conserve water resources and benefit producers by reducing irrigation costs. Eliminating unnecessary late irrigation could reduce lush fall crop growth that makes defoliation more difficult and costly and delays harvest operations. In years with moderate mid-season conditions, there has been no penalty for early irrigation termination. In the third year of research at Judd Hill, our focus was to evaluate timing for the final furrow irrigation based on physiological cutout, and to determine if there was a yield and fiber quality penalty for early irrigation termination.

BACKGROUND INFORMATION

Cotton growers across the mid-South and Texas have adopted COTMAN crop-termination guidelines to aid in end-of-season crop-management decision making. The research-based recommendations in the COTMAN system are commonly used for timing termination of insect control and for application of defoliants. Crop-termination decisions are based on physiological cutout—the flowering date of the last effective boll population. The crop has reached physiological cutout when the field average for Nodes Above White Flower is equal to five (NAWF=5). Recent research efforts have been directed at developing a late-season recommendation for timing the final irrigation based on physiological cutout.

Current COTMAN recommendations in Arkansas suggest that decision-makers begin to evaluate the field for the final irrigation at 350 to 500 DD60s after NAWF=5. In previous northeast Arkansas research dating back to 1999, there generally has not been a yield or fiber-quality penalty for early irrigation termination, even as early as physiological cutout (see studies by Vories et al., 2001, 2002, 2003, 2004; Teague et al., 2005, 2006). During hot and dry July conditions in 2004 and 2006 at the Lon Mann Cotton Research Station in Marianna, timing the final irrigation before NAWF=5+360

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DD60s resulted in yield and profit loss (Monge et al., 2007). In northeast Arkansas, in irrigation termination tests conducted in 2005 and 2006 at Judd Hill at the University Research Farm, no differences in lint yield were observed when timing of final irrigation ranged from the early termination during the third week of flowering extending out to 500 DD60s after cutout. Those years were characterized by moderate temperatures and rainfall patterns with lint yields ranging from 1000 to 1200 lb/acre (Teague, 2006). The 2007 season presented an opportunity to measure crop response under severe hot and dry conditions and high yield potential.

RESEARCH DESCRIPTION

The experiment was carried out on the Judd Hill Plantation near Trumann, Ark. The latest possible cutout dates for this production area—that date with a 50% or 85% probability of attaining 850 DD60s from cutout—are 9 August and 31 July, respectively (Danforth and O'Leary, 1996). Crop monitoring using COTMAN™ was used to determine the date of physiological cutout (Bourland et al., 1992). Irrigation timing and schedules for the five irrigation termination treatments in relation to crop cutout are listed in Table 1. Irrigation timing also is shown in relation to rainfall in Fig.1.

The experiment was arranged in randomized complete block with five treatments and three replications. Plots were 500 to 620 ft long, and 6 rows wide. There were 4 rows separating plots. Stoneville 5242 RBG was planted on 4 May at a seeding rate of 3 to 4 Cruiser-treated seeds/ft in rows spaced 38 inches apart. Plants were monitored in each plot from the early squaring period through cutout using the COTMAN crop monitoring system. Two sets of five consecutive plants in the center rows were monitored weekly. Sampling included measurement of plant height, number of sympodia, and presence or absence of first-position squares and bolls. An application of acephate 90 (0.40 lb/acre) was made on 29 May for thrips. Centric (2 oz/acre) + Karate (3 oz/acre) were applied on 24 July for tarnished plant bugs and bollworms. Harvest aid chemicals for defoliation and boll opening were applied 4 September (Finish 6 at 1 qt/acre, Ginstar at 4 oz/acre). Defoliants were applied at 941 DD60s after cutout.

Final, end-of-season plant mapping was performed 19 September using COTMAP protocol (Bourland and Watson, 1990). Ten plants in 2 interior rows per plot were examined for node number of first (lowest) sympodial branch on the main axis, number of monopodia, and number of bolls on sympodia arising from monopodia. Bolls located on main-stem sympodia (first and second position) were recorded, as well as bolls located on the outer positions on sympodial nodes (greater than second position). The highest sympodium with 2 nodal positions and number of bolls on sympodia located on secondary axillary positions were also noted. Plant height was measured as distance from soil to apex. Plots were machine-harvested using a 2-row picker on 21 September—rows 3 and 4 of each plot were harvested. Fifty boll samples taken throughout consecutive plants were collected at harvest, ginned on a laboratory gin, and submitted to the International Textile Center at Texas Tech University for HVI fiber quality determinations. Mean boll size was determined from ginned 50 boll samples—lint plus seed weights. Lint yields were calculated based on percentage lint estimates from laboratory gin turn-out. All crop and insect monitoring and yield data were analyzed using AOV with mean separation using LSD.

RESULTS AND DISCUSSION

Conditions in 2007 were ideal for testing late-season irrigation timing. Rainfall patterns included early-season rains followed by a mid-season dry period (Fig. 2). Temperatures for 2007 growing season were favorable in May and June, but by July, daily high temperatures exceeded 100°F (Fig. 2). COTMAN growth curves show crop response to the favorable early-season conditions with development of first squares prior to the target of 35 days after planting (Fig. 2). The pace of sympodial development was comparable to the COTMAN standard curve through the season; plant structure at the time of first flowers was lower than the standard curve, ranging from 7.1 to 8.2 main-stem sympodia compared to the standard curve value of 9.25. Plants in all treatments reached physiological cutout (mean NAWF=5) on 28 July, 78 days after planting. Irrigation timing did not affect days to cutout.

In final, end-of-season plant mapping, there were no significant differences among irrigation termination treatments in mean plant height, or in number of sympodial or monopodial nodes (Table 2). There were differences in boll retention. Significantly fewer main-stem sympodia with first and second position bolls were observed where irrigation was terminated before NAWF=5+450 DD60s. Fewer total bolls per plant also were observed in early termination treatments. Significant differences among irrigation termination treatments were noted for HVI determinations for micronaire, and for fiber length, uniformity, strength, and elongation (Table 2.). Yield and yield component measures indicated significant effects of final irrigation timing (Table 4, Fig. 3). Significant increases in yield per acre were observed with each additional irrigation after cutout. Boll size was significantly reduced with early irrigation termination. Seed per acre, fibers per seed, and fiber density were all significantly affected by irrigation timing.

PRACTICAL APPLICATION

In the 2007 season at Judd Hill under conditions of high moisture demand—hot, dry weather and high yielding crop—there was a significant yield penalty observed with early termination of irrigation. The COTMAN decision guide suggests evaluating the crop for timing the final irrigation at 350 to 500 DD60s after NAWF=5. Practically speaking, 150 DD60s is one week (approximately 20+ DD60s per day in August). In 2007, availability of water in the extra week was significant. It is interesting to note that one common practice among producers in the northeast Arkansas and the Missouri Bootheel cotton-production region has been to terminate irrigation at first open boll or on 15 August. The final irrigation in the 2007 experiment, NAWF=5+450 DD60s, was made on 16 August, and there were open bolls present in the field.

ACKNOWLEDGMENTS

This project was supported with funding from the Cotton Incorporated core program. Special thanks to Larry Fowler for his excellent assistance at the Judd Hill Research Farm. Additional thanks to summer student assistants, D'Juan Cobbs, Austin Lewis, Michele Johnson, and Lindsey Tindall, and research program assistants

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Table 1. Dates of final irrigation in furrow irrigation termination trial (Judd Hill, 2007).

Date of final irrigation[z]	Days after planting	Crop maturity status at final irrigation[y]
13 Jul	63	NAWF=7.1 (first flowers)
20 Jul	70	NAWF=6.5
02 Aug	83	NAWF=5 + 150 DD60s
09 Aug	90	NAWF=5 + 300 DD60s
16 Aug	97	NAWF=5 + 450 DD60s

[z] Furrow irrigation dates: 8, 15, and 29 June; 20 and 27 July, and 3, 9, and 16 August.
[y] Mean date when plants reached mean NAWF=5 was 28 July.

Table 2. Results from final end-of-season plant mapping using COTMAP for final irrigation timing, Judd Hill, 2007.

	Mean per plant for each irrigation termination treatment[z]						
Category	NAWF=7.1	NAWF=6.5	NAWF=5 +150HU	NAWF=5 +300HU	NAWF=5 +450HU	*P>F*	LSD_{05}
First sympodial node	6.0	5.9	5.8	5.9	5.7	*0.91*	
No. monopodia	2.0	2.2	1.9	1.9	1.8	*0.61*	
Highest sympodia with 2 nodes	11.9	12.2	12.4	12.5	12.6	*0.82*	
Plant height (inches)	48.5	50.0	50.5	49.5	48.8	*0.72*	
No. effective sympodia	7.9	8.2	8.1	8.4	8.9	*0.40*	
No. sympodia	13.8	14.2	14.2	14.4	14.4	*0.88*	
No. sympodia with first-position bolls	4.2	4.6	4.3	4.5	4.2	*0.77*	
No. sympodia with second-position bolls	0.6	0.6	0.6	0.5	0.8	*0.90*	
No. sympodia with first- and second-position bolls	1.6	1.7	1.3	1.6	2.5	*0.03*	*0.7*
Total bolls/plant	8.3	8.8	7.8	8.6	10.7	*0.03*	*1.7*
% Total bolls in first position	70.1	71.6	74.0	72.6	62.8	*0.30*	
% Total bolls in second position	26.8	26.1	23.7	23.3	30.5	*0.43*	
% Total bolls in outer position	2.3	1.2	1.1	3.0	3.1	*0.60*	
% Total bolls on monopodia	0.8	0.7	0.7	1.1	2.2	*0.90*	
% Total bolls on extra–axillary	0.0	0.4	0.4	0.0	1.3	*0.37*	
% Boll retention - first position	42.5	44.4	40.4	42.6	46.5	*0.07*	
% Boll retention - second position	18.7	18.9	14.9	16.7	26.1	*0.13*	
% Early boll retention	49.0	51.3	44.1	49.3	56.3	*0.23*	
Total nodes/plant	18.8	19.2	19.0	19.3	19.1	*0.80*	
Internode length (inches)	2.6	2.6	2.7	2.6	2.6	*0.41*	

[z] Means of 10 plants per plot.

Table 3. Means for HVI classing data[z] and yield component information for 50 boll samples collected in plots from consecutive plants for irrigation termination study, Judd Hill 2007.

Timing of final furrow irrigation	Mic	Length	Unif.	Strength	Elong.	Rd	+b	Leaf
NAWF=7.1 (first flowers)	3.52	1.06	80.42	27.57	4.10	73.78	9.10	2.33
NAWF=6.5	3.63	1.10	81.58	28.73	3.97	73.00	9.03	1.67
NAWF=5 + 150 DD60s	3.55	1.12	82.73	29.60	4.30	74.68	8.93	2.00
NAWF=5 + 300 DD60s	3.67	1.12	82.88	30.08	4.53	76.43	8.67	1.33
NAWF=5 + 450 DD60s	3.95	1.13	83.47	29.92	4.63	75.63	8.73	1.83
P>F	*0.05*	*0.0004*	*0.0001*	*0.0025*	*0.001*	*0.035*	*0.52*	*0.26*
LSD_{05}	*0.39*	*0.03*	*0.74*	*1.20*	*0.29*	*2.24*	*0.62*	*0.93*

[z] Determinations made at International Textile Center, Texas Tech University, Lubbock, Texas.

Table 4. Mean turn-out, seedcotton, and lint yields along with yield component information from 50-boll hand-picked samples collected in plots from consecutive plants for irrigation termination study, Judd Hill, 2007.

Timing of final furrow irrigation	Lint	Weight per boll	Seedcotton yield[z]	Lint	Seed	Fibers per seed	Fiber density
	(%)	(g)	---------- (lb/acre) ----------		(No./acre * 10^6)		
NAWF=7.1 (first flowers)	44.5	4.21	2969	1320	8.74	22979	45.21
NAWF=6.5	42.5	4.47	2986	1270	8.46	20978	38.47
NAWF=5 + 150 DD60s	43.0	4.46	3583	1540	10.05	22631	41.26
NAWF=5 + 300 DD60s	43.1	4.77	4133	1781	11.22	21392	37.89
NAWF=5 + 450 DD60s	44.3	4.94	4474	1980	11.66	20757	35.80
P>F	*0.003*	*0.002*	*0.0001*	*0.0001*	*0.0001*	*0.017*	*0.001*
LSD_{05}	*1.01*	*0.33*	*353*	*185*	*0.5811*	*1463*	*3.80*

[z] Machine harvest was made using 2-row JD research picker in 2 center rows of each plot (ca. 500 to 600 ft long); hand harvest of 50 boll samples was made at 2 sites in each plot.

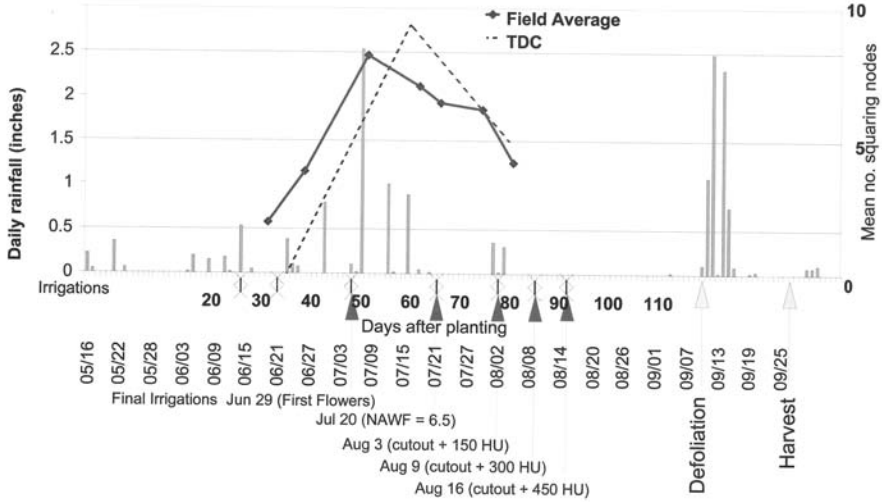

Fig. 1. Daily rainfall amounts observed during the cotton-growing season for the Judd Hill Research Farm in 2007. Green arrows on the x-axis indicate timing of final irrigation for each of the 5 treatments. Also shown are the COTMAN target curve as well as the actual crop growth curve depicting field average squaring nodes for plants in the irrigation termination trial. The mean date of physiological cutout was 28 July.

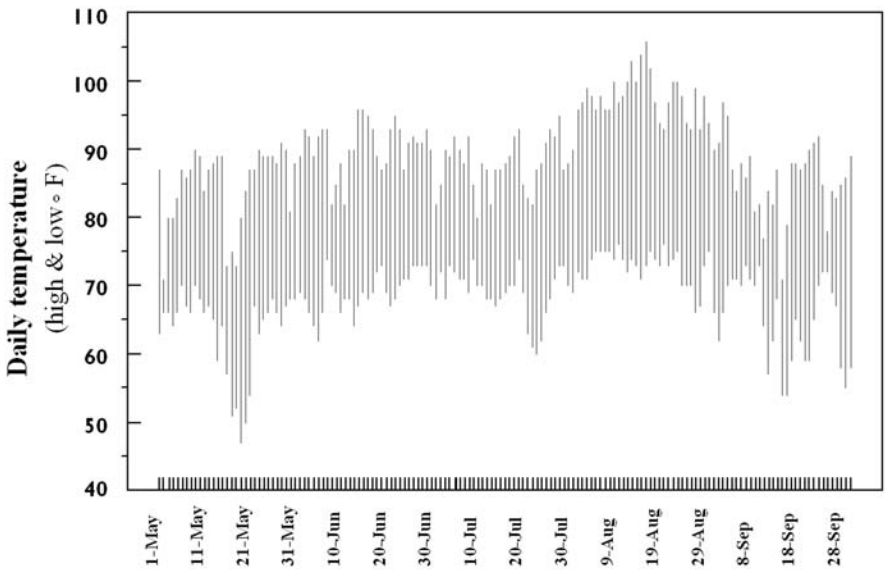

Fig. 2. Daily high and low temperatures for 2007 growing season at Judd Hill Research Farm in 2007.

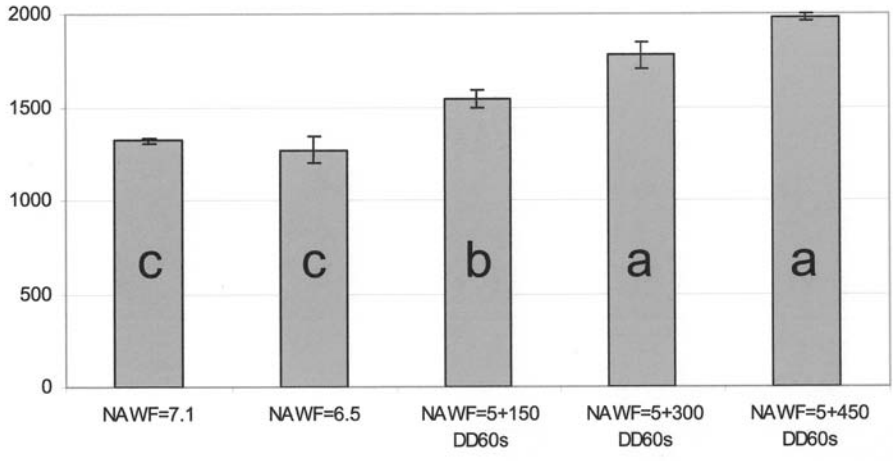

Fig. 3. Effect of final irrigation timing on mean lint yields (±SEM), Judd Hill Research Farm, 2007 (p=0.0001; LSD_{05}=185).

Physiological Mechanism of Nitrogen Mediating the Growth of Cotton Seedlings under Water-Stress Conditions

Zhiguo G. Zhou and Derrick M. Oosterhuis[1]

RESEARCH PROBLEM

Drought and waterlogging from global warming and environmental pollution have become a significant problem in recent years. Drought or waterlogging occurring during the cotton season affects growth, yield, and fiber quality of cotton (*Gossypium hirsutum* L.). However, there are few strategies for ameliorating the detrimental effects of water stress. The objective of this investigation was to study effects of nitrogen (N) on the ability of cotton seedlings to resist water stress (both deficit and excess).

BACKGROUND INFORMATION

There have been reports of applications of N improving the ability of plants to resist drought and water logging, but this has not been tested in cotton. Generally, higher levels of N contribute to drought resistance of plants by preventing cell membrane damage and enhancing osmoregulation. Application of N to cotton may result in improved plant growth and aid in alleviation of damage from water logging.

RESEARCH DESCRIPTION

A pot experiment was conducted in a large growth chamber (Conviron PWG35, Pembina, N.D.) at the University of Arkansas Altheimer Laboratory in Fayetteville, Ark., from October to December 2007. The growth chamber was programmed for 12-h photoperiods, day/night temperatures of 30/20°C, and 60% relative humidity. The cotton cultivar was DPL 444 B/R. The experiment was arranged in a completely randomized design, with three water-stress treatments and three nitrogen levels. The water-stress treatments consisted of well-watered (WW) and drought-stressed (DS) where the water utilization was 66.7 and 33.3ml•day^{-1}•plant^{-1}, respectively; and a water-logged

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treatment (WL) with 2 to 3 cm surfacewater maintained for 10 days (d). The nitrogen treatments consisted of low nitrogen (LN), medium nitrogen (MN), and high nitrogen (HN) applied as 224, 448, or 672 *mg N•l*$^{-1}$ water (132.2, 246.4, or 369.6 *mg N•pot*$^{-1}$), respectively. Measurements were made of plant height, shoot dry matter, and leaf area. Plant N concentration was determined and the carbon/nitrogen ratio calculated. In addition, measurements were made of soluble protein; the antioxidants peroxidase (POD), catalase (CAT), and super oxide dismutase (SOD); and also malondialdehyde (MDA) using standard laboratory analytical techniques. The MDA was determined to estimate membrane damage. Photosynthetic rate was determined with a portable LICOR 6200 photosynthetic system. In all cases the upper fully-expanded leaf, four nodes from the plant terminal, was used. In addition the roots were extracted by careful washing and the total dry matter determined.

RESULTS AND DISCUSSION

Growth Parameters of Cotton Seedlings with Different N Levels Under Different Water Conditions

Plant dry matter, carbon-nitrogen (C/N) ratio, and the dry matter per unit leaf area were all significantly decreased under conditions of water stress (Table 1). Low nitrogen tended to increase C accumulation, but the effect was variable.

Physiological Mechanism of Nitrogen Mediating Cotton Seedlings' Growth under Water-Stress Conditions

Both drought and water logging affected the physiology of cotton seedlings. The effect on SOD and POD was variable, with a slight increase with both stresses (Table 2). CAT was increased slightly by water deficit, and decreased slightly under excess water.

Application of N had a variable effect on the WW cotton seedlings, but under water stress, generally increased the activities of the antioxidant enzymes SOD and POD, and had an intermediate effect on the CAT activity of cotton seedlings. Overall, the activity levels of the antioxidant enzymes were generally higher in the high-N treatments, particularly for SOD and POD. Both water-stress treatments increased MDA content, and MDA content also decreased with increased N in the leaf of water-stressed plants (Table. 2).

The DS decreased root vigor, whereas the WL treatment increased root vigor in the two latter stages. However, the WL treatment roots exhibited a quicker recovery in growth after the water logging was terminated, and root vigor was subsequently higher than that of the WW control. The root vigor in the LN treatment was the highest among the three N levels (Fig. 1).

Net photosynthetic rate was reduced by both water stress treatments (Fig. 2). The higher nitrogen treatments (MH and HN) showed the highest photosynthetic rates, and the WL treatment recovered more after relief of the stress. The results suggest that more nitrogen was beneficial for a quicker recovery of growth in the WL treatment (Fig. 2).

PRACTICAL APPLICATION

The low nitrogen application contributed to resistance to water stress of cotton seedlings by adjusting the antioxidant enzyme activities of seedlings, modifying lipid peroxidation, and boosting root vigor. Additional N should be supplied to cotton seedlings after termination of the water-logged conditions. These results should be beneficial for formulating future nitrogen management strategies for cotton under water stress (i.e., for both deficient and excessive water).

Table 1. Growth parameters, C/N ratio, and soluble protein content of cotton seedlings with different N levels (LN, ML, HN) under different water conditions (WW, DS, WL).

		Plant height			Dry weight			Leaf dry weight per unit area			C/N			Soluble protein content		
Water[z]	N[y]	DAT 22	DAT 29	DAT 36	DAT 22	DAT 29	DAT 36	DAT 22	DAT 29	DAT 36	DAT 22	DAT 29	DAT 36	DAT 22	DAT 29	DAT 36
		----------(cm) ----------			----- (g•seedling^{-1}) --------			--------(mg•cm^{-2})----------						-------(mg•g^{-1}FW)---------		
WW	LN	8.7 b	15.3 b	20.8 b	0.8 b	1.5 b	2.5 b	-[x]	5.4 a	6.3 a	1.7 a	1.4 a	1.6 a	17.7 a	19.2 a	18.7 a
	MN	9.7 a	17.7 a	23.5 a	1.3 a	2.3 a	3.0 a	-	5.4 a	5.6 b	1.4 b	0.9 b	1.2 b	17.1 a	18.0ab	18.3 a
	HN	9.7 a	16.7 a	22.0 a	0.6 b	1.6 b	2.7 b	-	5.8 a	5.9 b	1.0 c	0.8 b	0.8 c	12.4 b	15.2 b	14.9 b
DS	LN	10.5 a	12.3 a	14.5 a	0.7 a	1.2 a	1.8 a	-	5.5 a	5.9 a	1.5 a	0.9 a	1.2 a	15.3 a	17.4 b	17.5 a
	MN	10.2 a	11.8 a	14.5 a	0.6 b	1.1 a	1.5 a	-	5.8 a	5.4 a	0.9 b	0.7 b	0.9 b	12.7 ab	18.8 a	17.4 a
	HN	9.9 a	11.0 a	14.3 a	0.5 c	1.1 a	1.6 a	-	5.7 a	5.7 a	0.7 c	0.6 c	0.8 b	10.5 b	15.5 c	16.2 a
WL	LN	11.2 a	11.6 a	13.1 a	0.7 a	1.2 a	1.6 a	-	5.5 c	5.6 c	0.7 a	2.2 a	2.1 a	8.9 a	16.6 a	15.0 a
	MN	9.5 b	9.7 b	12.3 a	0.6 b	0.8 b	1.6 a	-	7.0 a	7.7 a	0.6 ab	2.0 a	1.6 b	8.7 a	14.9 b	11.1 b
	HN	7.9 c	8.3 c	10.5 b	0.5 c	0.6 b	1.3 a	-	6.0 b	6.4 b	0.5 b	1.4 b	1.0 c	8.6 a	11.0 c	10.4 b

[z] WW = well-watered, DS = drought stressed, and WL = water logged.
[y] LN = low nitrogen, ML = medium nitrogen, and HN = high nitrogen.
[x] Data not recorded.

Table 2. Antioxidant enzyme activity, MDA content of cotton plans with different N levels (LN, ML, HN) under different water conditions (WW, DS, WL).

Water		SOD[x]			POD[x]			CAT[x]			MDA[x]		
treatment[z]	N level[y]	DAT 22	DAT 29	DAT 36	DAT 22	DAT 29	DAT 36	DAT 22	DAT 29	DAT 36	DAT 22	DAT 29	DAT 36
		----- (umol•g^{-1}FW•min^{-1}) -----			- (ΔOD470nm•g^{-1}FW•min^{-1}) -			----- (umol•g^{-1}FW•min^{-1}) -----			----- (umol•g^{-1}FW•min^{-1}) ------		
WW	LN	380 b	327 a	354 b	436 b	424 c	410 b	1753 b	2144 b	2215 a	14.9 b	16.4 a	20.9 a
	MN	354 b	324 a	363 b	576 a	609 b	624 a	2000 a	2680 a	2340 a	15.6 b	17.1 a	20.2 a
	HN	541a	311 a	449 a	271 c	761 a	700 a	1254 c	1624 b	1925 b	23.0 a	17.9 a	20.1 a
DS	LN	384 c	374 b	454 b	396 a	538 b	674 a	1244 a	2448 a	2563 a	24.6 c	20.4 b	25.6 a
	MN	438 b	399 b	446 b	463 a	842 a	663 a	1366 a	2568 a	2622 a	27.6 b	25.8 a	25.1 a
	HN	578 a	532 a	517 a	214 b	845 a	769 a	1010 b	1781 b	2318 b	30.9 a	27.2 a	24.9 a
WL	LN	279 c	384 b	369 b	538 a	292 a	339 a	1299 a	1809 b	1573 a	20.3 c	15.3 a	19.2 a
	MN	352 b	368 b	419 b	553 a	269 a	285 a	1388 a	2208 a	1786 a	22.6 b	14.8 a	18.1 a
	HN	460 a	471 a	495 a	365 b	338 a	350 a	910 b	1336 c	1215 b	26.4 a	15.6 a	18.4 a

[z] WW = well-watered, DS = drought stressed, and WL = water logged.
[y] LN = low nitrogen, ML = medium nitrogen, and HN = high nitrogen.
[x] SOD = superoxide dismutase, POD = peroxidase, CAT = catalase, and MDA = malondialdehyde.

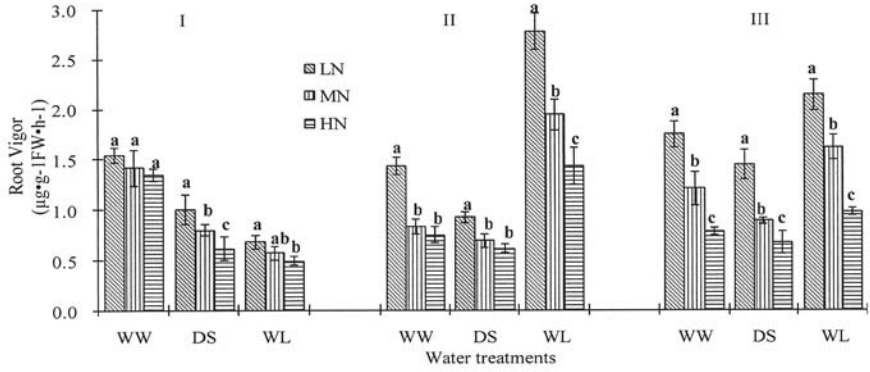

Fig. 1. Root vigor of cotton seedlings with different N levels under different water conditions.

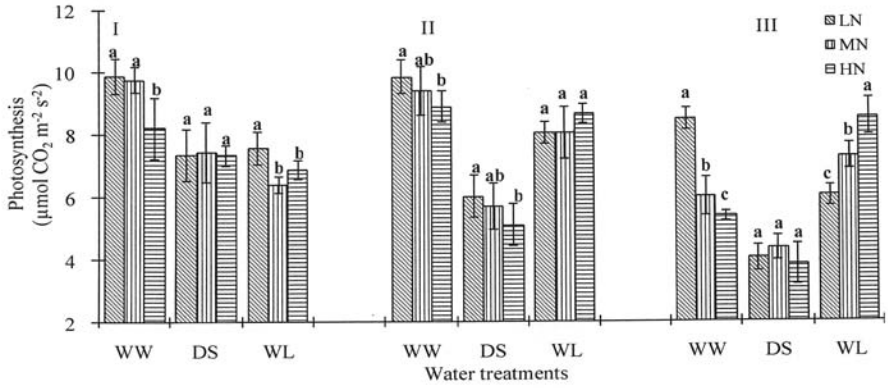

Fig. 2. Photosynthesis (Pn) of cotton seedlings with different N levels under different water conditions.

Efficacy of Seed Treatment Chemicals, Including Fungicides and Host Resistance Inducers, in Controlling the Black Root Rot Pathogen, *Thielaviopsis basicola,* on Cotton

Harun Toksoz and Craig S. Rothrock[1]

RESEARCH PROBLEM

Black root rot, caused by *Thielaviopsis basicola,* is an important seedling disease of cotton throughout the world. The fungus invades the roots of seedlings during the first 2 to 8 weeks of the crop. The fungus causes a dark-brown to black discoloration of the roots and hypocotyl, resulting in stunted, less vigorous seedlings and delayed flowering or maturity. Black root rot is most severe early in the growing season when soil temperatures are below 24°C and soil water content is high. There are limited management options for the control of black root rot. Seed treatment fungicides are universally used on cotton for the control of various pathogens in the seedling disease complex. However, only limited information is available on their value for the control of black root rot.

BACKGROUND INFORMATION

Seed treatment fungicides are universally used on cotton for the control of various pathogens in the seedling disease complex. However, the control of black root rot with these fungicide seed treatments is limited. Myclobutanil (Butler et al., 1996) and triadimenol (Arthur et al., 1991) have been shown to have some efficacy for the control of black root rot. However, they are generally not used at rates thought to be sufficient to provide significant control. Recently, Bion (Acibenzolar-S-methyl), one of the systematic acquired resistant (SAR) chemicals, has been shown to induce resistance in cotton against *T. basicola* (Mondal et al., 2005) and was registered recently in Australia for the control of black root rot. The objective of this study was to evaluate the efficacy of seed treatment chemicals, including fungicides and host resistance inducers, individually and in combination for controlling black root rot on cotton. The efficacy of seed treatments was examined in both artificially infested and naturally infested soil.

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RESEARCH DESCRIPTION

An artificially infested experiment was conducted in controlled environmental conditions to examine the efficacy of Systhane (myclobutanil) and Bion (acibenzolar-S-methyl) alone and in combination for black root rot control. A Rilla silt loam soil (40% sand, 56% silt, and 4% clay) from a field known to be infested with *T. basicola* was used in this experiment. The soil was pasteurized for 0.5 h at 70°C to eliminate potential cotton pathogens and infested with 60 viable chlamydospores of *T. basicola* per g of soil (odw). Four different seed treatment combinations, including no seed treatment, were used. Fourteen seeds of the cotton (*Gossypium hirsutum* L.) cultivar DP 555 BG/RR were planted per treatment in tubs (40 x 25 x 13 cm).

A controlled environmental study was conducted using naturally infested soil. A loamy sand soil (70% sand, 26% silt, 4% clay) was used in this experiment. Six different seed treatment combinations were used. Six seed of the cotton cultivar DP 444 BG/RR were planted in pots (10.5 x 7.5 cm) that contained approximately 450 g of soil (odw). The soil had a population of *T. basicola* of 68 cfu/g soil.

At the conclusion of the experiments, root and hypocotyl discoloration were rated. After disease evaluation, roots were disinfested and plated on the amended TB-CEN medium and rated at 7 to 10 days for the percentage (0 to 100%) of the root system having *T. basicola* growing onto the medium.

RESULTS AND DISCUSSION

In the artificially infested experiment using only 4 seed treatments, root and hypocotyl discoloration, caused by *T. basicola*, was significantly reduced by both Systhane and Bion compared to nontreated seed (Table 1). When Systhane and Bion were combined, root and hypocotyl discoloration was numerically lower than using either chemical alone, but these differences were not significant from Systhane alone.

T. basicola incidence and colonization of seedlings also were significantly reduced by either Systhane or Systhane with Bion, compared to the nontreated seed. In this study, Systhane, when combined with Bion or alone, was found to be more effective than Bion for reducing hypocotyl discoloration and colonization of seedlings by *T. basicola*.

In naturally infested soil, root discoloration was reduced by all treatments containing Systhane or Systhane with Bion, compared to the base seed treatment (Table 2). Hypocotyl discoloration also was reduced by all the treatments containing Systhane or Systhane with Bion, compared to the base seed treatment. Colonization of seedlings by *T. basicola* was significantly reduced by the treatments containing Systhane or Systhane with Bion, compared to the seed treatment, except for the treatments containing Systhane at the high rate and Systhane with Bion at the low rate. Incidence of black root rot was 100% for all treatments in this study.

PRACTICAL APPLICATION

This study demonstrated that current rates of Systhane have some efficacy for the control of black root rot. Bion is also effective in reducing black root rot; however, it

appears to be less effective than Systhane. When both of these chemicals are combined on seed, additional control of black root rot may be expected.

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Table 1. Efficacy of seed treatments for the control of black root rot in artificially infested soil.[z]

Treatments	Rate	Root dis.[y]	Hypocotyl[x]	Colon.[w]	Incidence
	(g ai/100 kg)	(0-10)	(1-4)	(%)[y]	(%)
Nontreated	---	35.1 A[w]	68.9 A	87.3 A	100.0 A
Bion	1	12.5 B	37.3 B	49.0 B	91.7 AB
Systhane	21	6.5 BC	11.5 C	27.4 C	82.3 B
Bion + Systhane	1 + 21	2.4 C	3.3 C	25.9 C	84.3 B

[z] Experiments were conducted in growth chamber with average temperatures of 24°C day and 15°C night, and light intensity of 207 µmol $m^{-2}s^{-1}$.

[y] Root discoloration was assessed on a 0-to-10 scale, where 0 = 0%, 1 = 1 to 10%, 2 = 11 to 20%, 3 = 21 to 30%, 4 = 31 to 40%, 5 = 41 to 50, 6 = 51 to 60%, 7 = 61 to 70%, 8 = 71 to 80, 9 = 81 to 90%, and 10 = 91 to 100% of the root system discolored. Analyses were conducted on mid-percentile values.

[x] Hypocotyl discoloration was assessed on a 1 to 4 scale, where 1 = healthy, 2 = slight discoloration, 3 = lesions, and 4 = girdling lesions. Only, the percentage of plants that had hypocotyl ratings of 3 or 4 was analyzed and presented.

[w] Colonization was assessed on a 0 to-10 scale, where 0 = 0%, 1 = 1 to 10%, 2 = 11 to 20%, 3 = 21 to 30%, 4 = 31 to 40%, 5 = 41 to 50, 6 = 51 to 60%, 7 = 61 to 70%, 8 = 71 to 80, 9 = 81 to 90%, and 10 = 91 to 100% of the root system having *T. basicola* growing on the medium. Analyses were conducted on mid-percentile values.

[v] Means in a column followed by a common letter are not significantly different according to least significance difference at $P \leq 0.05$.

Table 2. Efficacy of seed treatments for the control of black root rot in naturally infested soil.[z]

Treatments[y,x]	Rate	Root[w]	Hypocotyl[v]	Colon.[u]	Incidence
	(g ai/100 kg seed)	(0-10)	(1-4)	(%)	
Base seed treatment[y]		75.1 A[t]	92.5 A	95.5 A	100 A
Systhane[yx]	21	51.4 B	44.1 B	81.6 BC	100 A
Systhane + Avicta (Abamectin)[yx]	42 + 208.04	50.7 B	48.5 B	88.0 AB	100 A
Systhane + Avicta + Bion[yx]	21 + 208.04 + 0.6	49.7 B	45.1 B	88.1 AB	100 A
Systhane + Avicta + Bion[yx]	21 + 208.04 + 1.0	49.4 B	67.3 B	76.3 C	100 A
Systhane + Avicta + Bion[yx]	42 + 208.04 + 1.0	41.7 B	49.5 B	75.0 C	100 A

[z] Soil had a population of *T. basicola* of 68 cfu/g soil.

[y] Seed treated with Dynasty CST (Azoxystrobin + Fludioxonil + Mefenoxam, 41.60 g a.i./100 kg seed).

[x] Seed treated with Cruiser (Thiamethoxam)+Apron XL (Mefenoxam)+Maxim (Fludioxonil) (471.56 + 7.5 +2.5 g a.i./100 kg seed).

[w] Root discoloration was assessed on a 0-to-10 scale, where 0 = 0%, 1 = 1 to 10%, 2 = 11 to 20%, 3 = 21 to 30%, 4 = 31 to 40%, 5 = 41 to 50, 6 = 51 to 60%, 7 = 61 to 70%, 8 = 71 to 80, 9 = 81 to 90%, and 10 = 91 to 100% of the root system discolored. Analyses were conducted on mid-percentile values.

[v] Hypocotyl discoloration was assessed on a 1 to 4 scale, where 1 = healthy, 2 = slight discoloration, 3 = lesions, and 4 = girdling lesions. Only, the percentage of plants that had hypocotyl ratings of 3 or 4 was analyzed and presented.

[u] Colonization was assessed on a 0 to-10 scale, where 0 = 0%, 1 = 1 to 10%, 2 = 11 to 20%, 3 = 21 to 30%, 4 = 31 to 40%, 5 = 41 to 50, 6 = 51 to 60%, 7 = 61 to 70%, 8 = 71 to 80, 9 = 81 to 90%, and 10 = 91 to 100% of the root system having *T. basicola* growing on the medium. Analyses were conducted on mid-percentile values.

[t] Means in a column followed by a common letter are not significantly different according to least significance difference at $P \leq 0.05$.

Evaluation of Reflex and Valor for Preplant and Preemergence Control of Palmer Amaranth in Cotton

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RESEARCH PROBLEM

Palmer amaranth is a common and very troublesome weed in cotton fields throughout the southern United States. It has been effectively controlled with glyphosate in Roundup Ready® cotton; however, glyphosate-tolerant Palmer amaranth is present in 11 counties in Arkansas. The ability of these plants to tolerate high rates of glyphosate has caused major problems and requires a different weed control system. The objective of this research was to evaluate the efficacy of preplant and preemergence residual herbicides for control of glyphosate-tolerant Palmer amaranth in Arkansas cotton.

RESEARCH DESCRIPTION

In 2006 and 2007, duplicate experiments were established in Rohwer, Ark., on the Southeast Research and Extension Center (Rohwer Branch) in a Hebert silt loam soil and in Keiser, Ark., on the Northeast Research and Extension Center in a Sharkey clay soil.The trials were arranged in a randomized complete block design with four replications. These trials were sprayed with a small-plot tractor equipped with a multi-boom and air mix 110015 nozzles on 19-inch spacing. The operating pressure was 55 PSI provided by CO_2 gas propellant and the spray volume was 12 GPA. Parameters evaluated were visual ratings of Palmer amaranth control, visual ratings of cotton injury, and cotton yield. Herbicides used in this experiment were Reflex at 0.187 and 0.25 lb ai/acre, Valor at 0.063 lb ai/acre, Cotoran at 1 lb ai/acre, Caparol at 1 lb ai/acre, Direx at 0.5 lb ai/acre, and Prowl H_2O at 1 lb ai/acre.

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RESULTS AND DISCUSSION

In 2006, cotton injury was noted with Reflex applied 14 and 0 days preplant (DPP) at 0.25 lb ai/acre; Reflex applied 7 and 0 DPP at 0.187 lb ai/acre; Valor, Cotoran, and Caparol applied 0 DPP; and Prowl H_2O applied 21 and 0 DPP at Rohwer and only with Valor 0 DPP at Keiser. Cotton yield was affected only by Valor applied 0 DPP, which caused death of the cotton at the Rohwer location. Fifty-one days after planting (DAP) at Rohwer, Reflex at 0.25 lb ai/acre and Prowl H_2O applied 14 DPP provided 98% control of Palmer amaranth, while Valor applied 21 DPP provided 99% control. Valor applied 14 and 7 DPP and Direx applied 0 DPP provided 100% control, while Cotoran and Caparol applied 14 DPP provided 96 and 83% control, respectively. Thirty DAP at Keiser, Reflex applied 21 and 14 DPP at 0.25 lb ai/acre and Valor applied 21, 14, and 7 DPP provided 99% control, while Reflex applied 14 DPP at 0.187 lb ai/acre, Cotoran applied 21 DPP, Caparol applied 14 DPP, Direx applied 14 DPP, and Prowl H_2O applied 21 DPP provided 97, 95, 97, 98, and 94% control, respectively.

In 2007, cotton injury was not noted with any treatment at Rohwer, while Valor applied 21, 14, 7, and 0 DPP caused injury at Keiser. Thirty-seven DAP at Rohwer, Reflex at 0.25 lb ai/acre applied 21, 7, and 0 DPP provided 92, 97, and 91% control, respectively, of Palmer amaranth, while Reflex at 0.187 lb ai/acre applied 14 and 7 DPP provided 90 and 93% control, respectively. Direx applied 0 DPP provided 93% control of Palmer amaranth. Twenty-eight DAP at Keiser; Valor applied 21, 14, and 7 DPP provided 95, 96, and 92% control of Palmer amaranth, respectively, while Reflex at 0.187 lb ai/acre applied 7 DPP provided 88% control. Residual herbicides applied preplant and preemergence did provide excellent control of glyphosate-tolerant Palmer amaranth in Arkansas cotton.

PRACTICAL APPLICATIONS

The information from this study is being used to make recommendations to county agents and growers. Knowing the presence of glyphosate-resistant Palmer amaranth provides growers the opportunity to make herbicide applications that will control this invasive weed. This information also aids in updating the Arkansas weed control recommendations (Scott et al., 2006).

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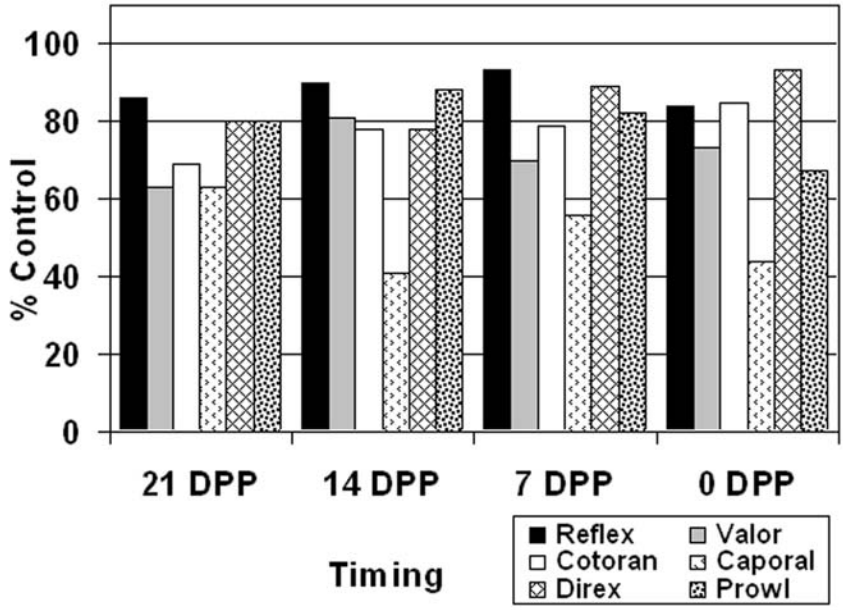

Fig. 1. Percent Palmer amaranth control 37 days after planting at Rohwer, Ark., in 2007 with preplant and preemergence applications.

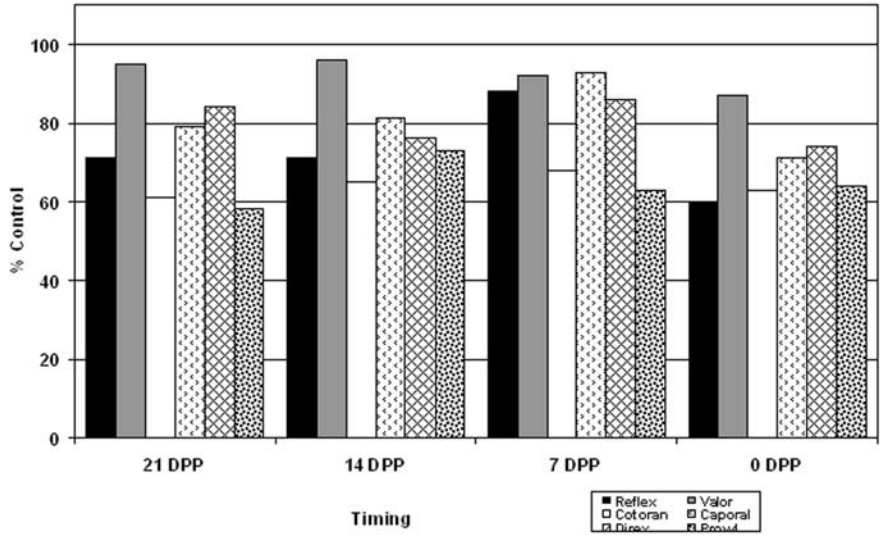

Fig. 2. Percent Palmer amaranth control 28 days after planting at Keiser, Ark., in 2007 with preplant and preemergence applications.

Sensitivity of Palmer Amaranth in Northeast Arkansas to a Labeled Rate of Glyphosate

Jason K. Norsworthy, Kenneth L. Smith, Robert C. Scott, and Lawrence R. Oliver[1]

RESEARCH PROBLEM

Cotton (*Gossypium hirsutum* L.) consultants in Arkansas reported that lower-than-label glyphosate rates were sometimes used for weed control in Roundup Ready cotton; however, glyphosate rates have had to be increased in recent years to obtain satisfactory control (Norsworthy et al., 2007). Even then, the existence of Palmer amaranth (*Amaranthus palmeri*) in cotton fields continues to increase, making it one of the most problematic and difficult-to-control weeds in cotton. It is not known whether Palmer amaranth plants have become insensitive to a labeled rate of glyphosate or whether other factors are contributing to the failure to consistently and effectively control this weed.

BACKGROUND INFORMATION

Multiple glyphosate applications are relied upon for weed management in Roundup Ready and Roundup Ready Flex cotton, which comprise approximately 98% of the cotton acres in Arkansas (Norsworthy et al., 2007). Repeated glyphosate applications have been relied upon for controlling Palmer amaranth that is resistant to pyrithiobac and trifloxysulfuron in cotton. However, the recent evolution of glyphosate-resistant Palmer amaranth in Arkansas is a concern because of the almost sole reliance on glyphosate for weed control in cotton. In addition to Arkansas, glyphosate-resistant Palmer amaranth has been confirmed in Georgia, South Carolina, North Carolina, and Tennessee, with the resistance spreading at a rapid rate in each of these states (Culpepper et al., 2006; Steckel et al., 2008; York et al., 2007).

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RESEARCH DESCRIPTION

Palmer amaranth seeds were collected from a total of 21 fields across Mississippi, Crittenden, and Lee counties in Arkansas in the fall of 2006. Seedlings from each field (accession) were treated with the potassium salt of glyphosate (Roundup WeatherMax) at 0.78 lb ae/acre at the 5- to 7-leaf stage (3- to 4-inches tall) and returned to the greenhouse for an additional 28 days. The number of treated plants differed among fields based on seed availability. The experiment was conducted from November, 2006 through September, 2007, with 225 to 1,191 plants evaluated from each field. Plant survival was recorded 28 days after treatment.

Because of the high frequency of survival of the AR19 accession, thirty-five surviving plants from the above trial were repotted into larger pots and placed in a growth chamber prior to anthesis to enable cross-pollination and to prevent ingress of foreign pollen. Male plants were shaken daily to facilitate pollen dispersal. Seeds were collected at maturity, and a rate-response experiment was conducted on the second selection (AR19S2) as well as the initial AR19 accession and the AR14 accession. The AR14 accession was chosen because of its close proximity to the AR19 accession (4 miles) and the absence of survivors following treatment with glyphosate at 0.78 lb/acre.

Survival frequency of the AR19S2 accession was determined in the same manner as that previously described for other accessions. A total of 422 plants were treated with glyphosate at 0.78 lb/acre at the 5- to 7-leaf stage.

RESULTS AND DISCUSSION

The mean survival frequency was 2.2% across all accessions when 0.78 lb/acre glyphosate (labeled rate) was applied to 5- to 7-leaf plants (Table 1). Sixteen of the accessions had at least one plant survive the labeled rate of glyphosate. The AR18 and AR19 accessions had a survival frequency of 6.3% and 11.8%, respectively. Following an additional cycle of selection with glyphosate, 44.3% of the progeny from the AR19 accession survived glyphosate at 0.78 lb/acre, and its LD_{50} value (rate of glyphosate needed to kill 50% of the plants) increased to 0.577 lb/acre glyphosate (Fig. 1). This difference in survival probability and sensitivity to glyphosate is probably due to the AR19 accession collected from the field having the opportunity to mate with glyphosate-susceptible and -resistant plants, unlike the survivors from a glyphosate application from the second selection, which were pollinated inside a growth chamber.

Although glyphosate resistance had not been reported at any of these sites, except AR1 (Norsworthy et al., 2008), it is possible that gene flow from other glyphosate-resistant sites may have caused this higher-than-expected survival frequency across these accessions. In a recent study, viable pollen from glyphosate-resistant Palmer amaranth successfully fertilized glyphosate-susceptible female plants at distances up to 660 ft (Sosnoskie et al., 2007). Flooding along the Mississippi River, movement of field and harvest equipment, and disposal of cotton gin trash on production fields are other possible seed dispersal mechanisms that may be contributing to movement of glyphosate-resistant Palmer amaranth.

Failure of glyphosate at 0.78 lb/acre to completely control seedling Palmer amaranth does not confirm resistance. However, there is considerable concern with the lack of complete control of seedling Palmer amaranth with glyphosate at this labeled rate. Progeny from Palmer amaranth accessions collected in fall, 2000 throughout Arkansas were controlled 99 to 100% with glyphosate at 0.75 lb/acre applied to 24-inch-tall plants (Bond et al., 2006). The glyphosate rate used in our controlled environment experiment was slightly higher and the plants were smaller than those used in the field experiment reported by Bond et al. (2006).

Although the second selection from the AR19 accession was less sensitive to glyphosate than the first selection, it is not known whether sensitivity to glyphosate will continue to decrease with subsequent generations. It is possible that death of highly susceptible plants within this accession has reduced overall sensitivity to glyphosate rather than the least sensitive plants becoming increasingly resistant to glyphosate.

PRACTICAL APPLICATION

This research has shown that there is a low percentage of Palmer amaranth plants currently present in production fields throughout northeastern Arkansas that is capable of surviving a single glyphosate application at the labeled rate and that further selection with glyphosate can increase the frequency of survival. Five accessions had no plants survive glyphosate; however, sixteen accessions had at least one plant survive glyphosate. Based on the severity of chlorosis and necrosis to the leaves and apex of most surviving plants, it is possible that timely sequential applications of glyphosate may have controlled these plants under field conditions. Furthermore, under field conditions, these injured plants would be subjected to crop competition, which would further suppress their growth and reduce or eliminate seed production. None of the plants from the AR19S2 accession survived glyphosate at 2.0 lb/acre. However, most of the plants that survived glyphosate at 0.78 g/ha had resumed growth by 4 weeks after treatment.

ACKNOWLEDGMENTS

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Table 1. Survival frequency of 21 Arkansas Palmer amaranth accessions at 28 days after treatment with glyphosate at 0.78 lb ae/acre applied at the 5- to 7-leaf stage.

Accession	County	Latitude	Longitude	Treated	Survivors	Survival rate
		(°N)	(°W)	----------(No.)--------		(%)
AR1	Mississippi	35.38128	90.15057	393	4	1.0
AR2	Mississippi	35.39691	90.17051	852	0	0.0
AR3	Mississippi	35.42809	90.13889	269	1	0.4
AR4	Mississippi	35.46599	90.18079	469	3	0.6
AR5	Mississippi	35.51494	90.18004	311	8	2.5
AR6	Mississippi	35.67519	90.08045	291	4	1.4
AR7	Lee	34.72964	90.75176	1129	15	1.3
AR8	Crittenden	35.16958	90.29281	431	0	0.0
AR9	Crittenden	35.21801	90.32631	343	8	2.3
AR10	Crittenden	35.21786	90.32699	411	12	2.8
AR11	Crittenden	35.21442	90.32645	316	13	4.0
AR12	Crittenden	35.12235	90.32909	249	0	0.0
AR13	Crittenden	35.10407	90.36474	257	0	0.0
AR14	Crittenden	35.09771	90.40084	301	0	0.0
AR15	Crittenden	35.08431	90.28940	225	8	3.4
AR16	Crittenden	35.16134	90.25548	901	2	0.2
AR17	Crittenden	35.08968	90.32577	676	5	0.7
AR18	Crittenden	35.08949	90.32922	789	53	6.3
AR19	Crittenden	35.08975	90.32894	517	69	11.8
AR20	Crittenden	35.09008	90.37819	764	3	0.4
AR21	Crittenden	35.09009	90.38710	516	25	4.8
Total				10,410	233	2.2

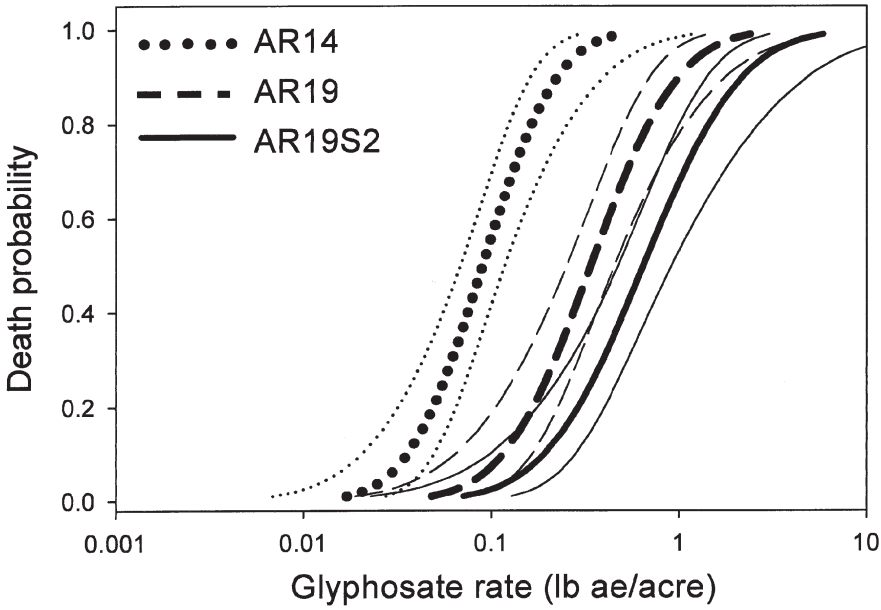

Fig. 1. Probit analysis with 95% confidence intervals (thin lines) to predict the lethal glyphosate rate needed to kill Palmer amaranth accessions (thick lines) when treated at the five- to seven-leaf growth stage. The AR14 and AR19 accessions were the first selection from two field sites in Crittenden County, Ark. The AR19S2 accession was the second selection from the AR19 accession treated with glyphosate at 0.78 lb/acre applied at a similar stage.

Variability in Response of Palmer Amaranth to Glyphosate in Northeast Arkansas

Jason K. Norsworthy, Kenneth L. Smith, Robert C. Scott, and Lawrence R. Oliver[1]

RESEARCH PROBLEM

Palmer amaranth (*Amaranthus palmeri*) is one of the most common, prolific, and competitive weeds of crops in the southern United States (Klingaman and Oliver, 1994) driving weed-management decisions in cotton (*Gossypium hirsutum* L.). Biotypes resistant to pyrithiobac and trifloxysulfuron are widespread throughout the mid-South (Heap, 2008), complicating Palmer amaranth management. Fortunately, glyphosate has been effective for controlling Palmer amaranth in Arkansas until recently, when glyphosate-resistant Palmer amaranth was documented in Mississippi County (Norsworthy et al., 2008). It is not known if Palmer amaranth from northeastern Arkansas production fields responds similarly to glyphosate over lower-than-labeled and labeled rates. Therefore, research was conducted to determine if Palmer amaranth from 21 fields from northeastern Arkansas differs in response to glyphosate.

BACKGROUND INFORMATION

Variation exists within and between weed populations in response to low herbicide rates (Smith and Hallett, 2006; Volenberg et al., 2007). It has been documented by Neve and Powles (2005) that low or sub-optimal herbicide rates can lead to rapid evolution of herbicide resistance in weed populations that have a high amount of genetic diversity, which is characteristic of Palmer amaranth. Neve and Powles (2005) attribute widespread herbicide resistance in rigid ryegrass in Australia partially to frequent use of low or sub-optimal rates. If this is so, the same may be occurring for Palmer amaranth in the southern United States based on differences in selection intensity with glyphosate among production fields.

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RESEARCH DESCRIPTION

Palmer amaranth seeds were collected from 21 fields in three counties in northeastern Arkansas in October and November of 2006 (Table 1). Accession AR1 was the site from which Palmer amaranth seeds had been collected the previous year and later confirmed to be resistant to glyphosate (Norsworthy et al., 2008). Sites were chosen solely on the presence of Palmer amaranth prior to crop harvest rather than previous failure of glyphosate to control the weed. All of the fields, except AR1, were planted to cotton in 2006. It was not known if plants present in the fields had been treated with glyphosate or other herbicides that year or whether plants emerged after the final herbicide application, but it is most likely that each field did receive one or more applications of glyphosate, considering the extensive planting of Roundup Ready and Roundup Ready Flex cotton.

Greenhouse rate-response experiments were conducted in November, 2006 through March, 2007. Seedlings from a field (accession) were treated with one of eight glyphosate rates ranging from 0.016 to 2 lb ae/acre at the 5- to 7-leaf stage (3- to 4-inches tall). The lowest rate corresponds to 1/48 of a labeled glyphosate rate of 0.75 lb/acre. After treatment, plants were returned to the greenhouse for an additional 28 days. Plant survival (live or dead) was recorded at 28 days after treatment. The experiment was repeated. The lethal rate needed to kill 50% of the plants (LD_{50}) from each field was determined.

RESULTS AND DISCUSSION

The LD_{50} values were similar among accessions, but with a few exceptions (Fig. 1). The AR10 accession had an LD_{50} of only 0.037 lb/acre glyphosate, which was lower than all other accessions based on 95% confidence intervals, except AR11. In contrast, the AR18 and AR19 accessions were the least sensitive to glyphosate.

The AR1 accession responded to glyphosate similarly to most other accessions based on the LD_{50} values (Fig. 1). Interestingly, the AR1 accession was collected from the same site in which Palmer amaranth had been collected in 2005 and later confirmed resistant to glyphosate (Norsworthy et al., 2008). The AR1 accession had an LD_{50} of 0.108 lb/acre, which was 18.8-fold less than the LD_{50} of 2,517 lb/acre determined for the glyphosate-resistant biotype collected from the same site the previous year (Norsworthy et al., 2008). The difference in response to glyphosate is probably because the resistant biotype in the earlier greenhouse evaluation had gone through several generations of selection, which removed susceptible progeny that were initially present.

Within most accessions, the response to glyphosate was quite variable, especially at rates of 0.063 and 0.125 lb/acre glyphosate, which was near the LD_{50} of most accessions. Seventeen of the 21 accessions had an LD_{50} of 0.064 to 0.165 lb/acre. Some of the plants that survived glyphosate at 0.063 and 0.125 lb/acre showed little effect from the herbicide, whereas other plants were killed at these rates. As the glyphosate rate increased, plant response generally became less variable as more individuals within each accession were killed. The exceptions, however, were AR18 and AR19 that had an LD_{50} of 0.279 and 0.303 lb/acre glyphosate, respectively. The AR18 accession had

two of 16 plants and the AR19 accession had three of 16 plants survive glyphosate at 1.0 lb/acre, an amount exceeding the 0.75 lb/acre rate that generally provides complete control (Bond et al., 2006).

Because all plants in our experiment were treated in an enclosed chamber in the absence of an overlying crop or other weeds, spray interception was optimal. Under field conditions at a labeled rate of 0.75 lb/acre glyphosate, it is probable that even a greater percentage of Palmer amaranth plants from the AR18 and AR19 accessions would have survived. It is known that lower-than-labeled rates of glyphosate were frequently being used in Arkansas cotton in the late 1990s (Norsworthy et al., 2007). If removal of the most sensitive Palmer amaranth plants occurred with lower-than-labeled rates, it is probable that the Palmer amaranth population as a whole in these fields is less sensitive to glyphosate than in the past due to selective removal of the most sensitive plants.

PRACTICAL APPLICATION

This research confirms that Palmer amaranth collected from fields throughout northeastern Arkansas generally respond similarly to glyphosate, with a few exceptions. The Palmer amaranth populations in two cotton fields in Crittenden County were less sensitive to glyphosate compared with Palmer amaranth from other fields in northeastern Arkansas. Furthermore, there was variability among plants in sensitivity to glyphosate within all fields, which may be contributing to the difficulty in controlling Palmer amaranth, especially when less than the full dose reaches the weed because of poor spray coverage or use of lower-than-labeled rates. Hence, the labeled rate of glyphosate should always be used to minimize the probability of Palmer amaranth plants surviving glyphosate and producing progeny.

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Support for this research was provided by the Division of Agriculture, University of Arkansas.

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Table 1. Twenty-one Palmer amaranth accessions from Arkansas collected in fall, 2006 listed by county, the coordinates from which they were collected, and distance from the site where glyphosate-resistant Palmer amaranth was first documented in Mississippi County, Ark.

Accession	County	Latitude	Longitude	Distance from AR1
		(°N)	(°W)	(miles)
AR1	Mississippi	35.38128	90.15057	0.00
AR2	Mississippi	35.39691	90.17051	2.41
AR3	Mississippi	35.42809	90.13889	5.31
AR4	Mississippi	35.46599	90.18079	9.81
AR5	Mississippi	35.51494	90.18004	15.12
AR6	Mississippi	35.67519	90.08045	33.15
AR7	Lee	34.72964	90.75176	90.75
AR8	Crittenden	35.16958	90.29281	26.87
AR9	Crittenden	35.21801	90.32631	24.14
AR10	Crittenden	35.21786	90.32699	24.30
AR11	Crittenden	35.21442	90.32645	24.46
AR12	Crittenden	35.12235	90.32909	32.98
AR13	Crittenden	35.10407	90.36474	36.36
AR14	Crittenden	35.09771	90.40084	38.94
AR15	Crittenden	35.08431	90.2894	35.24
AR16	Crittenden	35.16134	90.25548	26.23
AR17	Crittenden	35.08968	90.32577	36.52
AR18	Crittenden	35.08949	90.32922	36.20
AR19	Crittenden	35.08975	90.32894	36.20
AR20	Crittenden	35.09008	90.37819	38.46
AR21	Crittenden	35.09009	90.3871	38.78

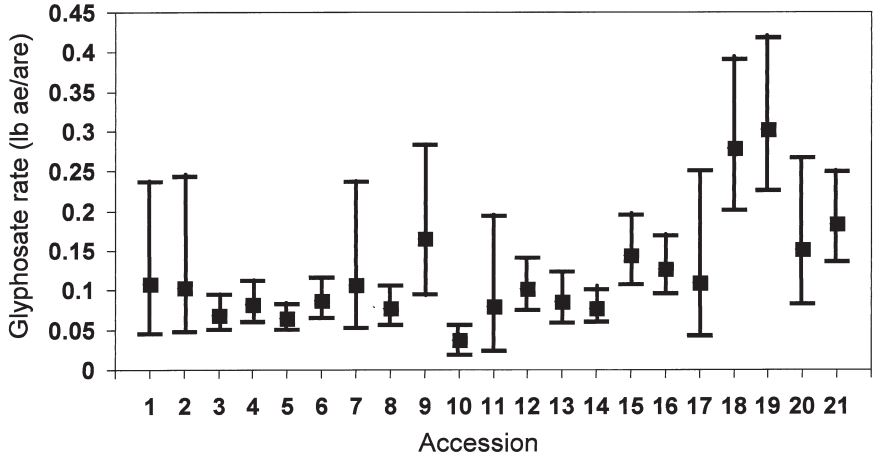

Fig. 1. The glyphosate rate with 95% confidence intervals (vertical lines) required to kill 50% of Palmer amaranth plants (LD_{50} - solid square, derived from Probit analysis) from 21 accessions in Arkansas when applied at the 5- to 7-leaf stage (location of each accession listed in Table 1).

Performance of Selected Insecticides for Control of Tarnished Plant Bug *(Lygus lineolaris)* in Southeast Arkansas

D. Scott Akin, Eric Howard, Gus M. Lorenz, Glenn Studebaker, and Kyle Colwell[1]

RESEARCH PROBLEM

Two field experiments were conducted to evaluate the performance of selected insecticides for the control of tarnished plant bug (*Lygus lineolaris*). In trial 1, treatments containing Bidrin, acephate, and Endigo reduced plant bug numbers compared to the check at 7 DAT. In trial 2, most treatments in the trial controlled plant bugs compared to the untreated check at 7 DAT including Bidrin, acephate, Vydate, dimethoate, Carbine, Centric, and Trimax Pro. These data suggest that growers currently have a multitude of insecticide options for control of tarnished plant bug in cotton.

BACKGROUND INFORMATION

Since the success of the Boll Weevil Eradication Program (BWEP) and widespread adoption of *Bt* cotton for Lepidopteran pests, the resulting low-spray environment has allowed a new insect, the tarnished plant bug (*Lygus lineolaris*) to emerge as a major pest in mid-South cotton (*Gossypium hirsutum* L.). Tarnished plant bugs have historically been troublesome pests in cotton (Hollingsworth et al., 1997; Kharboutli et al., 1998; Robbins et al., 1998), and can cause significant economic injury if left untreated. Tarnished plant bugs cause yield losses by puncturing and feeding on young squares, often resulting in square loss. These pests can also feed on blooms and young bolls, resulting in dirty blooms and damaged seed/lint, respectively. It is because of this detriment to yield loss and lint quality that the tarnished plant bug must be controlled in mid-South cotton from year to year.

From 2004 to 2006, fields in southeast Arkansas averaged ca. 3.5 sprays dedicated only to tarnished plant bug per season (Williams, 2007). During the 2007 growing season, fields in this region averaged five dedicated plant bug sprays per year (Lorenz,

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2007). Populations of tarnished plant bug were particularly high in areas of southeast Arkansas, and several fields received justified sprays of ten or more for this pest.

There are numerous insecticides labeled for control or suppression of tarnished plant bug. Due to this wide selection of insecticides, coupled with the ability of insect pests to develop tolerance/resistance to insecticides, there is a great need to investigate efficacy of labeled insecticides in a given season. The purpose of this study was to evaluate several of the available insecticides labeled for tarnished plant bug control.

RESEARCH DESCRIPTION

Both trials were planted using ST4554 (B2RF) at the Southast Research and Extension Center, Rohwer Station (SEREC) near Rohwer, Ark. Plots were treated at first bloom using a MudMaster sprayer equipped with R&D plot boom system. Booms were equipped with TX-6 hollow-cone tips (8-row swath, 20-inch nozzle spacing). Sprayer was calibrated to 8 gpa at 2.8 mph at 30 psi. Plots were planted as 8 rows (38-inch spacing) x 50 feet and 4 replications in a randomized complete block design.

For both trials, sampling was performed at 4 and 7 days after treatment (DAT) using a 2.5-foot black drop cloth in rows 4 and 5 (sampling 5 feet of row per sample, 2 samples per plot) and a 15-inch diameter sweep-net in rows 3 and 6. Due to the low number of adults encountered at the time of trial initiation and the difficulty of sampling nymphs with a sweep-net, only drop cloth data are presented in this paper.

Treatments and rates for both trials are listed in the results section.

RESULTS AND DISCUSSION

Trial 1

At 4 DAT, TriMax Pro did not reduce plant bug numbers compared to the check, unless tank-mixed with Bidrin or Diamond (Table 1). Acephate and Bidrin, both considered industry standards for tarnished plant bug control, reduced plant bug numbers compared to the check. Both rates of Endigo (i.e., 4 and 5 fl oz/acre) also controlled tarnished plant bugs compared to the check. The tank-mix treatment of Karate + acephate, a treatment commonly used for mixed populations of tarnished plant bugs and bollworms in cotton, also reduced plant bug numbers. The same trends were observed at 7 DAT. At both evaluation timings, there was no significant difference between effective treatments. These observations are likely due to the low numbers of tarnished plant bugs at the time of trial initiation.

Trial 2

Trial 2 sustained much higher populations of tarnished plant bug than Trial 1 (Table 2). Also in contrast to Trial 1, TriMax Pro significantly reduced plant bug numbers compared to the check at both 4 and 7 DAT. Prolex (pyrethroid class alone) provided suppression of plant bugs at 4 and 7 DAT. Centric, although labeled and recommended at 2 oz/acre, provided significant control of tarnished plant bugs at 1.5 oz/acre. Although

this was the case with Centric in this trial, more consistent control and sufficient residual control will likely be more effectively achieved with the 2 oz/acre rate. Carbine, a relatively new product that has been reported as being a fairly slow product to kill, reduced plant bug numbers as soon as 4 DAT in this trial. Cobalt, a product only labeled for plant bug suppression, provided suppression at 4 DAT. However, the low rate (19 fl oz/acre) provided no control at 7 DAT while the high rate (29 fl oz/acre) only provided moderate suppression at this time. Vydate controlled plant bugs with the highest labeled rate (nematode suppression rate) at both 4 and 7 DAT. Both industry standards (i.e., acephate and Bidrin) provided significant control of tarnished plant bug at both 4 and 7 DAT. Dimethoate, applied at the highest rate recommended for plant bugs in Arkansas (Studebaker et al., 2007), provided control of plant bugs at both evaluation dates.

PRACTICAL APPLICATION

These data suggest that several effective insecticide options exist for the control of tarnished plant bugs in Arkansas cotton. However, if populations of this pest continue to build each year, repeated applications of some of the more cost-effective insecticides (e.g., acephate) are likely to increase across southeast Arkansas. This may, in turn, place greater selection pressure on this pest, subsequently resulting in resistance. As a result, insecticide use alone may not be sustainable in the future of plant bug control in cotton production.

ACKNOWLEDGMENTS

The author would like to thank BASF, Bayer, Cheminova, Dow Agrosciences, DuPont, FMC, and Syngenta for supporting our tarnished plant bug program in 2007. We also recognize the student workers who worked in extreme conditions for these data.

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Table 1. Trial 1 – Number of tarnished plant bug nymphs per 10 row-feet, Rohwer, Ark., 2007.

		Number of nymphs	
Insecticide	Rate	4 DAT	7 DAT
Untreated		8 a[z]	15 a
TriMax Pro	1.8 fl oz/acre	6 ab	10 ab
Trimax Pro + Diamond	1.8 fl oz/acre + 8 fl oz/acre	3 b	2 c
TriMax Pro + Baythroud	1.8 fl oz/acre 2 fl oz/acre	7 a	9 ab
TriMax Pro + Bidrin	1.8 fl oz/acre 6 fl oz/acre	4 b	5 bc
Acephate	0.4 lb ai/acre	4 b	5 bc
Bidrin	6 fl oz/acre	5 b	6 bc
Endigo	4 fl oz/acre	5 b	5 bc
Endigo	5 fl oz/acre	5 b	5 bc
Karate + acephate	1.8 fl oz/acre + 0.5 lb ai/acre	3 b	5 bc
LSD (p<0.05)		3	5.7

[z] Means in the same column not followed by a common letter are not significantly different.

Table 2. Trial 2–Number of tarnished plant bug nymphs per 10 row-feet, Rohwer, Ark., 2007.

		Number of nymphs	
Insecticide	Rate	4 DAT	7 DAT
Untreated	---	38 a[z]	39 a
Carbine	2.3 oz/acre	16 cde	20 bc
Centric	1.5 oz/acre	13 cde	16 cd
Centric	2.0 oz/acre	16 cde	13 cd
Cobalt	19 fl oz/acre	21 bc	37 a
Cobalt	29 fl oz/acre	14 cde	26 b
Prolex	1.5 oz/acre	27 b	21 bc
Vydate	17 fl oz/acre	11 e	11 d
Acephate	0.5 lb ai/acre	10 e	13 cd
Bidrin	8 fl oz/acre	12 de	15 cd
TriMax Pro	1.8 fl oz/acre	13 cde	16 cd
Dimethoate	16 fl oz/acre	12 de	11 d
LSD (p<0.05)		8.0	9.2

[z] Means in the same column not followed by a common letter are not significantly different.

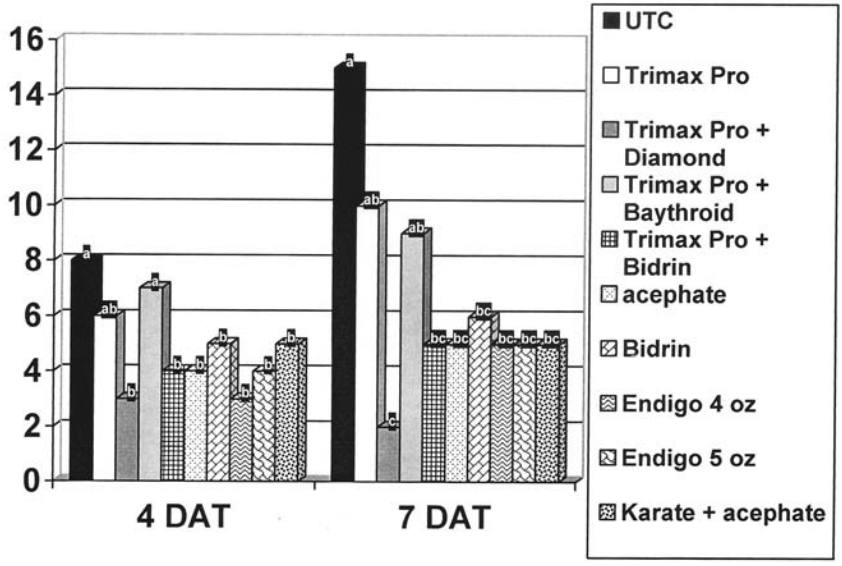

Fig. 1. Trial 1–Number of plant bug nymphs per 10 row-feet, Rohwer, Ark., 2007.

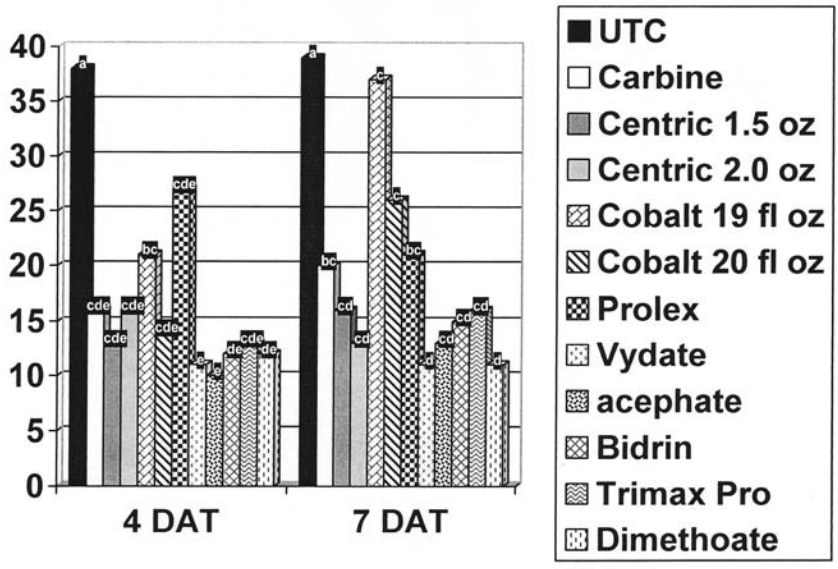

Fig. 2. Trial 2–Number of tarnished plant bug nymphs per 10 row-feet, Rohwer, Ark., 2007.

Efficacy of Endigo ZC: a New Insecticide for Cotton in Arkansas, 2007

Kyle Colwell, Gus M. Lorenz III, Heather Wilf, Craig Shelton, Robert Goodson, Eric Howard, and Glenn Studebaker[1]

RESEARCH PROBLEM

Endigo is a new, enhanced product with two modes of action, including lambda-cyhalothrin (a synthetic pyrethroid) and thiamethoxam (a neonicotinoid). Endigo offers effective knockdown and residual control of several economically damaging cotton pests such as cotton fleahoppers, tarnished plant bugs, bollworms, budworms, and stink bugs. Endigo is targeted for mid- to late-season insect pest control and gives us another tool to reduce insecticide resistance issues and offers a wide spectrum of activity of cotton insect pests. The purpose of these studies was to determine the efficacy of Endigo against other commonly used insecticides.

BACKGROUND INFORMATION

Reduction of insecticides due to the Boll Weevil Eradication Program, and transgenic cotton are two main reasons for the elevated status of the tarnished plant bug (Greene et at., 2005). These changes in the cotton production system have resulted in a change in status of plant bugs from secondary or occasional pests to one of the primary insects of cotton. The emergence of heightened status for the tarnished plant bug has led producers to look for new control options.

RESEARCH DESCRIPTION

Test one was conducted on Sites Farms, Lonoke County, Ark. The variety of cotton was Stoneville 4427 B2RF. Data were collected on 26 June (4 DAT), and 29 June (7 DAT), 2007. Test two was located at the Lonn Mann Cotton Research Station

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in Marianna, Ark. Insecticide treatments were applied on 1 August 2007. Data were collected on 7 August DAT), 10 August (9 DAT), and 15 August (14 DAT) 2007. Both trials were 4 rows by 50 ft. arranged in a randomized complete block design with four replications. Applications were made with a mud master spray tractor. The boom was fitted with TX6 hollow-cone nozzles at 19-inch nozzle spacing. Spray volume was 10 gal/acre at 45 psi. Treatments are listed in the results section. Tarnished plant bug density was determined by counting adults and nymphs from two randomly selected locations in each plot using a drop cloth. Data were compared against each treatment and the check. Data were processed using Agriculture Research Manager Version 7. Analysis of variance was conducted using Duncan's New Multiple Range Test (P=0.10).

RESULTS AND DISCUSSION

The results of Test 1 (Fig. 1) indicated Endigo was comparable to all other treatments and had significantly fewer plant bugs than the untreated check (UTC). In Test 2 (Fig. 2) at 6 DAT, the untreated check had significantly more plant bugs than all treatments. EXP 1 had less control for plant bugs than all other treatments in the trial, except the UTC and Carbine at 2.3 oz/acre. Seasonal totals (Fig. 3) indicate Endigo was statistically better for tarnished plant bug control than the UTC, Carbine at 2.3 oz/acre, and EXP 1.

PRACTICAL APPLICATION

The results of this study provide growers and consultants with knowledge of a new insecticide for control of tarnished plant bugs. Results also indicate Endigo ZC will provide producers and consultants with another tool to reduce insecticide resistance issues and offers a wide spectrum of activity against cotton insect pests in mid- to late-season insect control.

ACKNOWLEDGMENTS

The authors thank David Sites and the Lonn Mann Cotton Research Station for their cooperation in these studies. We also acknowledge Chemtura, DuPont Ag, Syngenta Crop Protection, FMC, and AmVac for their support.

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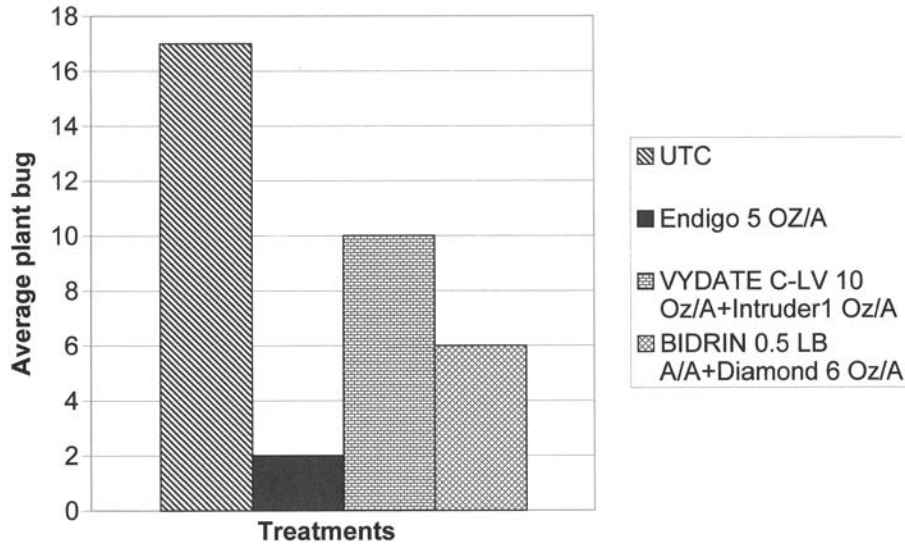

Fig. 1. Test 1–Efficacy of selected insecticides for tarnished plant bugs, Altheimer, Ark., 2007.

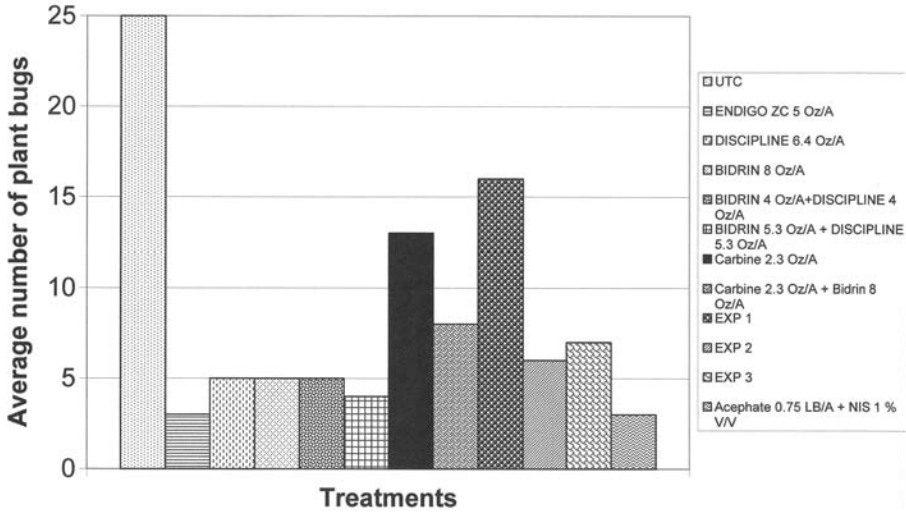

Fig. 2. Test 2–Efficacy of selected insecticides for tarnished plant bugs, Marianna, Ark., 2007, 6 DAT.

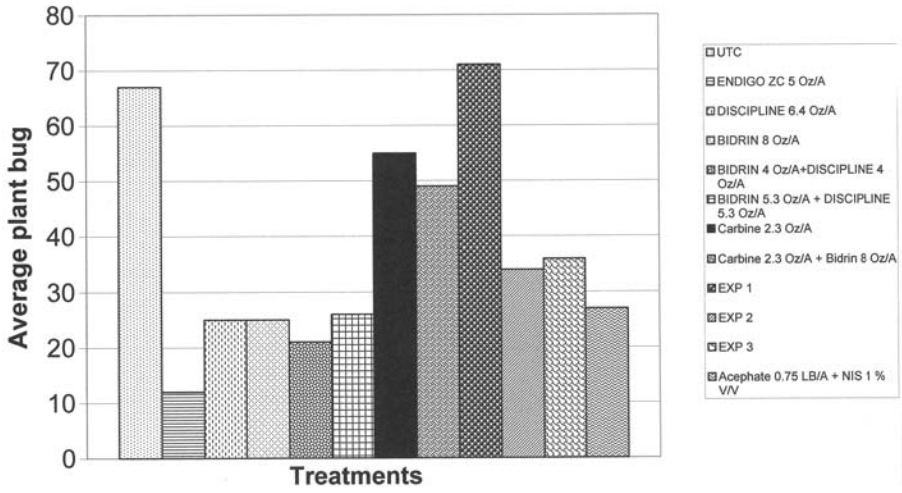

Fig. 3. Test 2–Efficacy of selected insecticides for tarnished plant bugs, Marianna, Ark., seasonal totals 2007.

Efficacy of Selected Compounds for Control of Heliothines in Arkansas Cotton

Heather Wilf, Gus Lorenz III, Kyle Colwell, Craig Shelton, Robert Goodson, Eric Howard, Steven Stone, Chad Norton, and Ben Von Kanel

RESEARCH PROBLEM

The bollworm, *Helicoverpa zea* (Boddie), is the most damaging pest of cotton in the southeastern United States (Gore and Adamczyk, 2004). Foliar insecticides have played a great role in management of this insect pest in cotton. Young larvae usually feed first on terminals and small squares and may sometimes destroy the terminal bud. The squares and bolls are fed upon extensively by larvae and serious damage occurs in a relatively short period of time.

BACKGROUND INFORMATION

In 2006, Arkansas cotton growers spent on average $11.85/acre for control of heliothines. A total of 1,100,000 acres was infested and 820,000 acres were treated for bollworms in Arkansas. The purpose of the experiment was to assess the performance of selected compounds for control of heliothines in Arkansas cotton.

RESEARCH DESCRIPTION

Test 1 was located on the Hooker Farm in Jefferson County, Ark., in 2007. The variety of cotton was DPL 434. Plots were set up in a randomized complete block with four replications. Insecticide treatments were applied with a mud master spray tractor. The boom was fitted with TX6 hollow-cone nozzles at 19-inch nozzle spacing. Spray volume was 10 gal/acre at 45 psi. Data from test 1 were collected on 23 July (5DAT),

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27 July (9DAT), 30 July (4DAT), 2 August (7DAT), 9 August (13DAT), and 16 August (7DAT).

Test 2 was also located on the Hooker Farm in Jefferson County, Ark., in 2007. Plots were set up in a randomized complete block with four replications. Ratings from test 2 were collected on 20 July, 25 July, 10 August, and 16 August. Treatments are listed in the results section. All data were collected from random samples of 25 terminals, squares, blooms, and bolls. Data were processed using Agriculture Research Manager Version 7.

RESULTS AND DISCUSSION

In test 1 (Fig. 1) at 5 DAT, the untreated check and BAS 320 05 116.1 had more damage than all other compounds. Results were similar at 9 DAT (Fig. 2). Overall seasonal damage (Fig.3) indicated that the untreated check was significantly higher than all other compounds.

In test 2 (Fig. 4) the PHY 425 RF had a significantly higher level of seasonal damage than all other varieties.

PRACTICAL APPLICATAION

The results of this study provided growers and consultants with vital information about the changing efficacy of commercial insecticides.

ACKNOWLEDGMENTS

The authors thank Chuck Hooker for providing a test location. We also acknowledge BASF, Bayer CropScience, Belt, Chemtura, Dow Agro Science, DuPont, FMC, and Makhteshim Agan for their cooperation with these studies.

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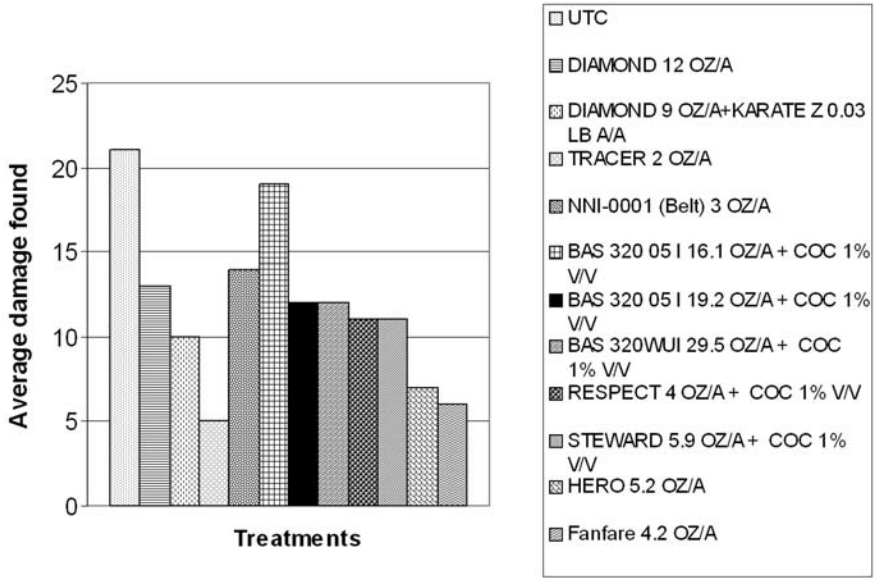

Fig. 1. Test 1, Average fruit damage 5 DAT for selected insecticides.

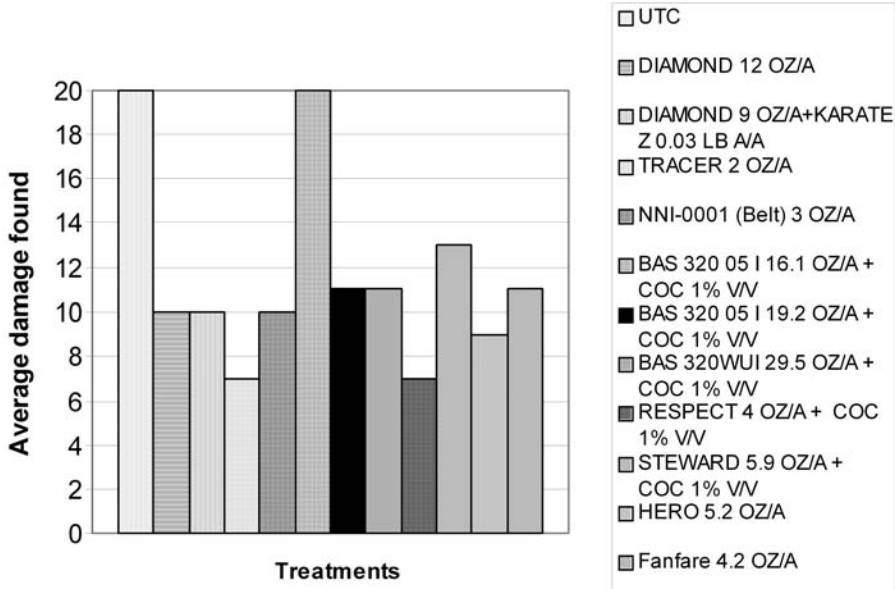

Fig. 2. Test 1, Average fruit damage 9 DAT for selected insecticides.

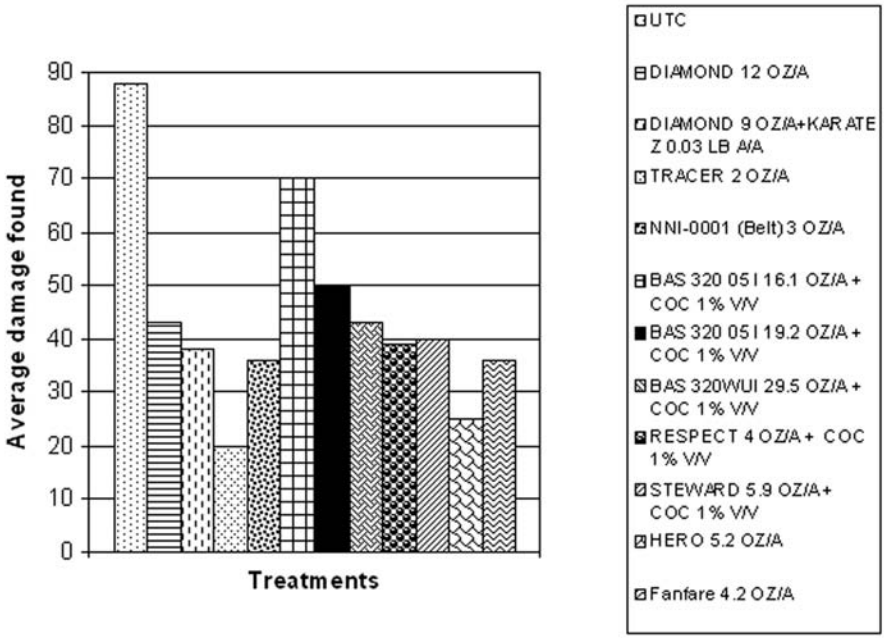

Fig. 3. Test 1, Total seasonal damage for selected insecticides.

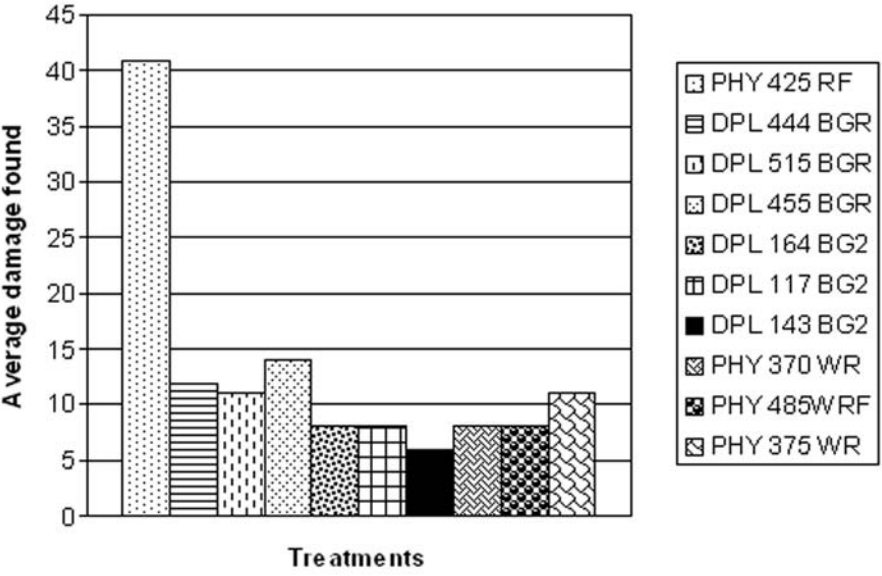

Fig. 4. Test 2, Total seasonal damage for selected insecticides.

Gene Expression Changes Induced by Reniform Nematode Infection in Cotton Roots

Carlos A. Avila and James McD. Stewart[1]

RESEARCH PROBLEM

Host resistance to the Reniform Nematode (RN), *Rotylenchulus reniformis* Lindford and Oliveira, has been identified in diploid cottons *Gossypium arboreum*, *G. herbaceum*, and *G. longicalyx* (Stewart and Robbins, 1994). Histological studies have identified two possible mechanisms of resistance: first, a darkened, necrotic syncytial cavity occurs (hypersensitive reaction); and second, a less frequent mechanism may occur that consists of the absence of hypertrophy of the syncytial cells. In this case the female reaches maturity but has reduced fecundity (Carter, 1981; Agudelo et al., 2005). The objectives of this study were to describe cotton root gene responses to reniform nematode infection in resistant and susceptible accessions, and to identify potential genes involved in feeding site formation and resistance reactions.

BACKGROUND INFORMATION

Observations under the microscope on different crops have shown that there is no difference in reniform nematode penetration behavior in resistant and susceptible roots. The syncytia on both host types formed through cell wall dissolution and coalescence of cytoplasmic contents of adjacent cells. The feeding site induced in both hosts by RN had dense cytoplasm, increased number and size of organelles, and hypertrophy (Rebois et al., 1975; Carter, 1981; Agudelo et al., 2005). We hypothesize that the events that occur at the feeding site (syncytium) determine the degree of susceptibility to the RN.

RESEARCH DESCRIPTION

Cotton seeds of *G. arboreum* resistant (accession A2-194) and susceptible (accession A2-128) phenotypes were surface sterilized in a 20% bleach solution, germinated, and transplanted into 500-cc clay pots filled with autoclaved fine sand. Plants were kept

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in a growth chamber with a 16 h photoperiod at 28°C day/24°C night. Four treatments, each of which included 3 biological replications and a dye swap, were applied to 1-month-old plants: 1) resistant-inoculated (RI), 2) resistant non-inoculated (RNI), 3) susceptible-inoculated (SI), and 4) susceptible non-inoculated (SNI). Inoculated treatments received 37,500 vermiform-stage nematodes per pot. After 16 days, roots for each treatment were harvested and immediately frozen in liquid nitrogen. Total root RNA was extracted using a method similar to that reported by Wilkins and Smart (1996).

The cotton microarray chips developed by Udall et al. (2007), each consisting of 22,787 oligonucleotide probes, were used to estimate expression at the transcriptome level. Data were acquired using Genepix Pro v.6 (Axon Molecular Devices, Calif.). All analyses were performed with the TM4 microarray analysis suite (Saeed et al., 2003). False positives were minimized using a one-sample T-test procedure to identify genes whose mean Log_2 expression ratios were statistically different from zero, setting a p-value ≤ 0.001 as threshold.

RESULTS AND DISCUSSION

Normalized and standardized intensity values for treatments involving resistant *G. arboreum* (A2-194), were compared by dividing the RI intensity values by the RN intensity values and Log_2 transformed (Log_2RI/RN) to obtain a fold-ratio for each gene. Sixteen genes were significantly different at $p \leq 0.001$. As expected, the number of genes detected in this way was low, but with an increased confidence level. In order to have a better understanding of what is happening in resistant *G. arboreum*, differentially expressed transcripts were grouped according to their putative biological process. Blast2GO v.1.2.7 (Conesa et al., 2005) was used for functional annotation and analysis of gene sequences. A descriptive analysis was performed by combining the annotation terms for all significant genes to give biological meaning of the set of sequences. Four main biological processes were altered by reniform nematode in A2-194, which included cellular processes, response to stimulus, biological regulation, and metabolic processes (Fig. 1).

Since we were interested in describing genes either involved in syncytia formation or the resistance mechanism, the set of genes identified in the resistant accession was compared with the expression of those from the same set of genes in the susceptible accession (Fig. 2). In this form, the genes were classified into two groups. The first group included the genes putatively involved in syncytia formation. These genes had similar expression patterns in both the resistant and susceptible accessions. On the other hand, genes whose expression contrasted in resistant and susceptible accession were selected as putatively involved in the resistance mechanism.

As expected, genes involved in cell wall modification were equally regulated in resistant and susceptible *G. arboreum,* since there is no difference in feeding site establishment between accessions. It is hypothesized that down-regulation of pectinesterase and ferulate-5-hydroxylate facilitate syncytia establishment. Also, our findings suggest that the hypersensitive reaction observed in the resistant accession is led by up-regulation of senescence associated genes (MYB transcription factor and leaf senescence) and down-regulation of superoxide removal enzymes (Peroxidase and Su-

peroxide dismutase). Finally, at 16-DPI nutrient availability for nematode is reduced in the resistance accession due to lower translocation of assimilates and down-regulation of carbohydrate kinase, an enzyme that phosphorylates starch for its degradation into glucose, the energy source for the nematode.

PRACTICAL APPLICATIONS

Characterization of the RN resistance reaction found in *G. arboreum* can be used as a tool for the potential development of rational strategies for nematode control, such as rotation and pyramiding resistance genes with different mechanisms in order to delay the appearance of nematodes that overcome host resistance. Also, certain technology (e.g., iRNA) that targets genes that are involved in syncytium formation could be used to enhance resistance by preventing formation of the feeding structure.

ACKNOWLEDGMENTS

Support for this research was provided by the Division of Agriculture, University of Arkansas, and by a grant from Delta and Pineland Company.

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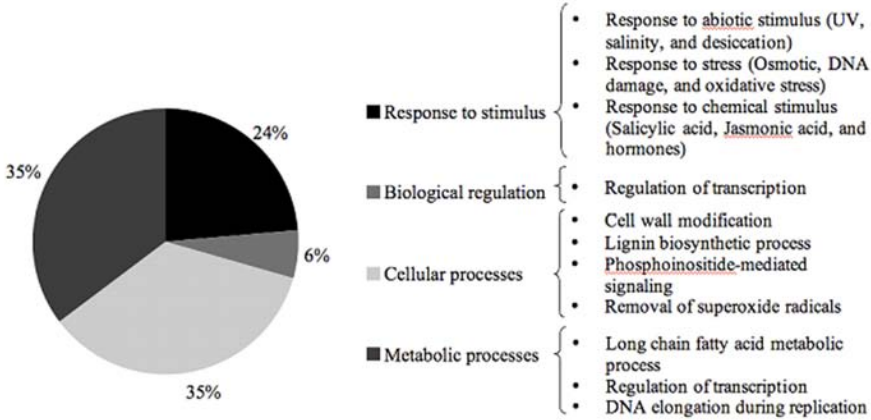

Fig. 1. Biological processes regulated in reniform nematode-resistant *G. arboreum* (A2-194) during nematode infection classified by gene activity.

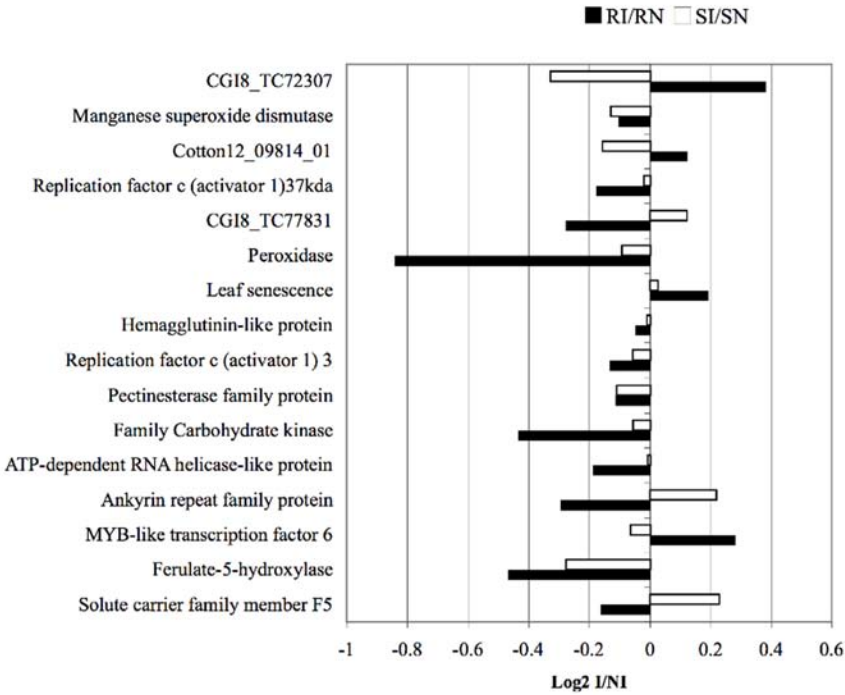

Fig. 2. Root gene expression induced by reniform nematode in resistant (A2-194) and susceptible (A2-128) cotton accessions.

Effect of Antimicrobial Peptides (AMPS) on Micorrhizal Associations

James McD. Stewart, Camila Nader, and Kanniah Rajasekaran[1]

RESEARCH PROBLEM

The purpose of this research project is to provide information with which regulatory agencies can make informed decisions. The present study assessed the ability of genetically modified tobacco plants expressing antimicrobial genes to establish mycorrhizal associations. Since the mycorrhizal associations are fungal in nature, antimicrobial peptides (AMPs) are expected to be detrimental to the associations. The effects of these AMPs on mycorrhizal fungi are accepted as good indicators of their effect on soil microbiota in general. The objective of the current research is to evaluate the effect of expression of the antimicrobial peptides MSI-99 and D4E1 on the formation of mycorrhizal associations in roots of tobacco plants transformed with the respective genes.

BACKGROUND INFORMATION

AMPs expressed in genetically modified organisms (GMOs) have the potential to affect non-target organisms. From the perspective of environmental risk-assessment, the effect of each new integrated gene on soil-borne microbiota must be evaluated. Due to the difficulty of conducting full-scale field trials and the potential of (unknown) environmental consequences of field releases, laboratory-scale methodologies provide a good alternative for the initial evaluation (Kowalchuk et al., 2003). Tobacco, a species that is easy to regenerate and prone to develop mycorrhizal associations (Harley and Harley, 1987; Wang and Qiu, 2006), provides a valuable tool for relatively rapid assessment of risks associated with microbe-transgenic plant interactions before more recalcitrant crop species, such as cotton, are genetically engineered to express the AMPs. The hypothesis upon which this work is based is that expression of AMPs in the roots of transgenic tobacco plants will interfere with recognition events and establishment of symbiotic mycorrhizal associations because of their deleterious effect on mycorrhizal fungi.

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RESEARCH DESCRIPTION

The mycorrhizal fungal species *Glomus mosseae* and *Gigaspora rosea* were tested for their ability to form mycorrhizal associations in two transgenic tobacco lines and a control wild-type plant. Transgenic *Nicotiana tabacum* L. cv. 'Petit Havana' and 'Petit Havana' seeds expressing D4E1, an analog of cecropin under the control of an enhanced 35 S promoter (Cary et al., 2000), and MSI-99, an analog of Magainin 2 expressed in the plastids (DeGray et al., 2001), under the control of the 16S promoter, respectively, were tested. Wild-type *Nicotiana tabacum* L. cv. Xanthi plants, which have the same genetic background as the other two cultivars, were used as controls.

Tobacco seeds were sterilized by placing them in a microwave oven on high for 7 minutes. After being cooled for two minutes and microwaved once again for 8 minutes (Franco, non-published), transgenic and control seeds were germinated on 1% agar–0.25 MS medium containing 50 µg/mL of kanamycin or 500 µg/mL of spectinomycin for D4E1 and MSI-99 lines, respectively. Wild-type plants were germinated without antibiotic. After five weeks, seedlings were transplanted to culture tubes filled one-third with sterile vermiculite and watered with 8 mL of one-half strength Hoagland's solution. The tops of the tubes were covered with plastic wrap, and the seedlings grown at 25°C and 16-hr photoperiod.

The 'sandwich system' described by Giovannetti et al. (1993) was used. Sterile plants including roots were washed to remove vermiculite particles, and then the root systems were carefully spread on a cellulose nitrate filter (Whatman®, Kent, U.K.). Ten to 12 fungal spores were collected with forceps under a dissecting microscope and placed in direct contact with the root where lateral roots emerged. The roots were then covered with a second membrane, forming a "sandwich." Two absorbent pads were added to ensure constant moisture and to provide support in the planting medium. The inoculated seedlings were planted in vermiculite in 36 cm^2 plastic pots, watered, and the pot covered with a plastic bag to avoid dehydration. Five replicates of each line/fungus were inoculated. The plants were grown at 25°C and 16-hr photoperiod and watered as needed. No nutrients were applied during this time.

Four weeks after inoculation, the roots were cleared and stained with 0.05% trypan blue in lacto-glycerol (Phillip and Hayman, 1970), then evenly distributed in a 88 mm diameter Petri dish. A grid of 20 lines (10 vertical and 10 horizontal; 9 x 9-mm squares) was placed on the bottom of the dish. Vertical and horizontal gridlines were scanned and the presence or absence of infection by mycorrhizal fungus was recorded at each point where the roots intersected a line. The total root length and mycorrhizal length were calculated by multiplying the number of root gridline intersects by 1.4141 (Giovannetti and Mosse, 1980). Data from each were collected and submitted to one-way ANOVA using JMP (version 6.0) after confirming equal variances and normal distribution of the samples. Means were compared using Student's t LSD and Tukey-Kramer HSD test.

RESULTS AND DISCUSSION

The mean percentages of colonization by *G. mosseae* and *Gi resea* in the expressing lines and wild type are given in Tables 1 and 2, respectively. Statistical analysis

showed no significant differences in the percentage of colonization between D4E1 and WT plants by either *G. mosseae* or *Gi. rosea*. Surprisingly, transplastomic lines with MSI-99 showed a higher percentage of mycorrhizal colonization than control plants. Non-significant effects on mycorrhizal associations were observed previously in lines over-expressing pathogenesis-related genes (Vierheilig et al., 1995). Additionally, the expression of a defensin affected pathogenic fungus, but not AMFs (Turrini et al., 2004).

Since the transgene did not inhibit development of mycorrhizal associations, the original thesis (inhibition of mycorrhizal associations by AMPs) is false under the conditions and plant materials used in these experiments.

PRACTICAL APPLICATION

Considerable economic loss occurs in crops due to microbial pests. The tendency is to genetically engineer the crop plant to express AMPs without fully understanding the beneficial role certain microbes play in crop production. This is especially true for fungi that are involved in the formation of mycorrhizal associations. The results from the research reported here provide information about the ability of the transgenic plants to establish mycorrhizal associations in the presence of endogenous AMP concentrations that inhibit fungal pathogens.

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Table 1. Percentage of colonization by *Glomus mosseae*. Means from one-way anova.

Genotype	% of colonization[z]
D4E1	64.23 ± 2.53
MSI-99	81.64 ± 2.53[y]
WT	58.65 ± 2.53

[z] Mean ± std. error.

[y] Mean significantly different (P = 0.05) from wild-type plants.

Table 2. Percentage of tobacco root colonization *by Gigaspora rosea*. Means from one-way anova.

Genotype	% of colonization[z]
D4E1	55.70 ± 3.81
MSI-99	74.27 ± 3.31[y]
WT	52.00 ± 3.81

[z] Mean ± std. error.

[y] Mean significantly different (P = 0.05) from wild-type plants.

Valuing Transgenic Cotton Technologies Using a Risk/Return Framework

Kelly J. Bryant, Jeanne M. Reeves, Robert L. Nichols, Jeremy K. Greene, Christopher H. Tingle, Glenn E. Studebaker, Fred M. Bourland, Charles D. Capps, Jr., and Frank E. Groves[1]

RESEARCH PROBLEM

Transgenic cotton (*Gossypium hirsutum* L.) cultivars provide growers with additional management options for weed and insect control. Producers now have more options for managing production risks associated with lepidoteran insects and weeds. The Bollgard gene acts as an insurance policy while the Roundup Ready gene adds efficiency and convenience to weed control in cotton. This insurance, convenience, and flexibility comes at a price equal to a premium for the seed and an annual fee for licensed use of the transgenic technology.

Since transgenic technologies are inherent in the seed when purchased, the producer must decide before planting what level of flexibility, insurance, and time-saving he/she desires. With the advent of pest-managing transgenic traits, the decision to purchase a cultivar and the choice of pest control are complicated. A good means of comparing the relative advantages of cultivars is by costs and returns (Nichols et al., 2003). Hurley et al. (2006) point out that risk is important when making the decision to plant a *Bt* crop because farmers make planting decisions before knowing the severity of insect infestations.

Another variable in the production decision equation is the expected yield of the cultivar chosen. Since yield is an important component of net returns, a cultivar could be chosen for its yield potential alone regardless of its technology traits.

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BACKGROUND INFORMATION

For some or all of the reasons above, cotton cultivars containing the Roundup Ready gene, the Bollgard gene, or both have been widely adopted in Arkansas. The demand for a transgenic cotton cultivar is a function of expected yield, production cost, and production risk associated with the cultivar. Different production regions have different production risks. Thus, these transgenic cultivars are expected to have different values in different markets (production regions) due to different growing environments in those markets. This study determines the value of four transgenic-cotton technology groups in two production regions important to Arkansas cotton producers.

RESEARCH DESCRIPTION

Field studies were conducted in 2001, 2002, and 2003 at the Northeast Research and Extension Center (NEREC) at Keiser, Ark., and the Southeast Branch Experiment Station (SEBES) at Rohwer, Ark. The experimental design was a randomized complete block with 4 replications. Roundup Ready, Bollgard, and Roundup Ready plus Bollgard cultivars were chosen based on their performance in the University of Arkansas Official Variety Tests (Benson et al., 2001) and percentage of acreage planted in Arkansas (Anon., 2001). All plots were managed to maximize yields. Returns over weed and insect controls were calculated for each cultivar. Return measured in this way is the amount of money available to cover all the remaining costs of production including the cost of the seed and technology.

A total of thirteen cultivars were grown over the three-year period. The 13 cultivars were divided into four technology groups: conventional cultivars, Roundup Ready cultivars, Bollgard cultivars, and stacked gene cultivars. Means and standard deviations were calculated for each technology group. Empirical cumulative distributions were constructed for each technology group, assuming an equally likely probability of occurrence for each observation.

Stochastic Efficiency with Respect to a Function (SERF) as outlined by Hardaker et al. (2004) was used to analyze the four technology alternatives. The software developed by Richardson et al. (2007) was used to apply the SERF method and graph the results.

RESULTS AND DISCUSSION

Means and standard deviations of returns over weed and insect control for each technology group are displayed in Table 1. The seed costs and technology fees are not included. In southeast Arkansas the stacked gene technology has the greatest expected value and the smallest standard deviation. This indicates a good choice for risk-neutral and risk-averse decision makers provided that the seed and technology are acceptably priced. In northeast Arkansas the Roundup Ready technology has the greatest expected value.

A per-acre value of the dominant technology over the alternative technologies was determined by subtracting the certainty equivalent of the alternative from the dominant

technology at each Absolute Risk Aversion Coefficient (ARAC) level. The per-acre value of the stacked gene technology in southeast Arkansas and the Roundup Ready technology in northeast Arkansas at the lower and upper bounds of the ARACs are displayed in Table 2. During the study period, the stacked gene technology was priced below the lower bounds reported in Table 2 for southeast Arkansas. Thus, we would expect to see widespread adoption of stacked gene cotton in southeast Arkansas. Similarly during the study period, the Roundup Ready technology was priced well below the lower bounds in Table 2 for northeast Arkansas. Thus, we would expect to see widespread adoption of Roundup Ready cotton in northeast Arkansas.

PRACTICAL APPLICATION

A large number of risk-neutral and risk-averse producers would prefer the stacked gene technology in southeast Arkansas and the Roundup Ready technology in northeast Arkansas, provided the costs of the technology and seed for these technologies relative to that of the other technologies are below the lower bounds listed in Table 2. The price differences in these respective markets have in fact been below these lower bounds and cotton producers in Arkansas have widely adopted stacked gene cotton and Roundup Ready cotton since its development (Anon., 2006). If the price difference between the technologies changes, a farmer's preference for that technology will change depending on his attitude toward risk.

Segmenting the market is important. This study shows that the preferred technology is different for the two markets in Arkansas.

This study uses an accepted methodology to place upper and lower bounds on the value of a dominant cotton technology with respect to a set of dominated technologies. Multiple technologies are compared simultaneously and risk is appropriately considered. This approach can be used to assess the value of newer transgenic crop technologies as they are developed.

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Table 1. Returns for four cotton seed technology options.

	Southeast Arkansas		Northeast Arkansas	
Technology	Average returns	Standard deviation of returns	Average returns	Standard deviation of returns
	($/acre)			
Conventional	567	273	306	122
Roundup Ready gene	529	266	350	119
Bollgard gene	580	273	327	108
Stacked gene	614	191	346	124

Table 2. Value of the dominant cotton seed technology over the dominated technologies.

Dominated technology	Lower bound	Upper bound
	($/acre)	
Value of the stacked gene technology in southeast Arkansas		
Bollgard gene	34.10	127.56
Conventional	47.30	163.72
Roundup Ready gene	85.60	138.65
Value of the Roundup Ready gene technology in northeast Arkansas		
Stacked gene	3.15	9.61
Bollgard gene	22.56	23.47
Conventional	43.70	41.58

APPENDIX I

STUDENT THESES AND DISSERTATIONS RELATED TO COTTON RESEARCH IN PROGRESS IN 2007

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: Dr. Luttrell)

Avila, Carlos A. Transfer of reniform nematode resistance from diploid cotton species to tetraploid cultivated cotton. (PhD, advisor: Dr. Stewart)

Bibi, Androniki. Effect of high temperatures on the biochemistry of the reproductive process in cotton genotypes. (Ph.D., advisor: Dr. 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: Dr. Lorenz)

Galligan, Larry. Optimizing release strategies of *Neozygites fresenii* (Entomophthorales: Neozygitaceae) for induction of epizootics in *Aphis gossypii* (Heteroptera: Aphididae). (M.S., advisor: Dr. Steinkraus)

Griffith, Griff. Erratic cotton responses to trifloxysulfuron applications. (M.S., advisor: Dr. Barrentine)

Groves, Frank. Inheritance of cotton yield components and relationships among yield, yield components, and fiber quality. (Ph.D., advisor: Dr. Bourland)

Gonias, Evangelos. Light interception and radiation use efficiency in cotton. (Ph.D., advisor: Dr. Oosterhuis)

Jackson, Sarah. Relationshps of marginal trichomes on cotton bracts to yield and fiber quality. (MS., advisor: Dr. Bourland)

Kawakami, Eduardo. Agronomic, physiological, and biochemical effects of 1-MCP on the growth and yield of cotton. (M.S., advisor: Dr. Oosterhuis)

Kulkarni, Subodh. Soil compaction modeling in cotton. (Ph.D., advisor: Dr. Bajwa)

Loka, Dimitra. Effect of high night temperature on cotton gas exchange and carbohydrates. (M.S., advisor: Dr. Oosterhuis)

Nader, Anna Camila. Effect of transgenic antifungal peptides on mycorrhizal associations. (M.S., advisor: Dr. 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: Dr. Rothrock)

Osorio, Juliana. Comparison of BC_1 and F_2 maps of an interspecific hybrid (*G. darwinii* x *G. hirsutum*). (M.S., advisor: Dr. Stewart)

Still, Josh. Ecology and overwintering ability of *Rotylenchulus* reniforms in Arkansas. (M.S., advisor: Dr. Kirkpatrick)

Tiwari, Rashmi. Molecular characterization of the diversity and natural hybridization of the *Gossypium* species of the arid zone of Australia. (M.S., advisor: Dr. Stewart)

Snider, John. Effects of high temperature stress on the anatomy and biochemistry of pollen-pistil interactions in cotton. (Ph.D., advisor: Dr. Oosterhuis)

Storch, Diana. Physiological and biochemical response of cotton to temperature stress during reproductive development. (M.S., advisor: Dr. Oosterhuis)

APPENDIX II

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