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Oosterhuis

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Edited by Derrick M. Oosterhuis

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SUMMARIES OF ARKANSAS COTTON RESEARCH 2011

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SUMMARIES OF ARKANSAS COTTON RESEARCH 2011

PREFACE

Arkansas cotton acres increased approximately 25% from 2010 reaching approximately 660,000 acres in 2011, the highest cotton acreage in Arkansas since 2007. Increased commodity prices of cotton were responsible for the increase. Total cotton produced in Arkansas in 2011 was 1.29 million bales, ranking third in the nation behind Texas and Georgia and grossing a total of $694 million in value of production with an average lint price of approximately $0.93/lb. Arkansas cotton lint yields in 2011 were below the five year average at 938 lb lint/acre. Prices for cotton have recently dropped, with corn and soybean market values steady or increasing for the 2012 season. Therefore the outlook for cotton acreage is down, possibly 100,000 acre deduction to 550,000 acres in 2012.

The 2011 production season started with record flooding, cool temperatures and delayed planting (Fig 1). The 2011 crop was one of the latest planted in history with the bulk of the cotton planted past the optimum window of May 20th. Numerous thunderstorms brought wind, hail and flooding to many areas. Several thousand acres of cotton had to be replanted do to extreme sand blasting, hail damage or both. Temperatures in June and July were higher than normal, but decreased the later part of August and September. Producers were hoping for a warm fall in 2011 to mature the upper bolls in the late crop. September temperatures were cooler than normal and producers did not receive the much needed heat units required. The result was a lower yield; however, higher prices for the crop resulted in a positive outcome.

Weed resistance, particularly glyphosate-resistant Palmer amaranth (pigweed) continued to be an emerging problem for many producers across Arkansas. In 2011 all cotton producing counties were identified as having a population of resistant Palmer amaranth. The severity of this problem weed in cotton will encourage increased utilization of residual herbicides and new technologies for weed management in 2012. Insect pests for 2011 were heavy in areas, especially with cotton bollworm and budworm numbers, which were higher than any year in recent memory. Plant bugs continue to be the number one insect pest problem in Arkansas cotton production.

Tom Barber

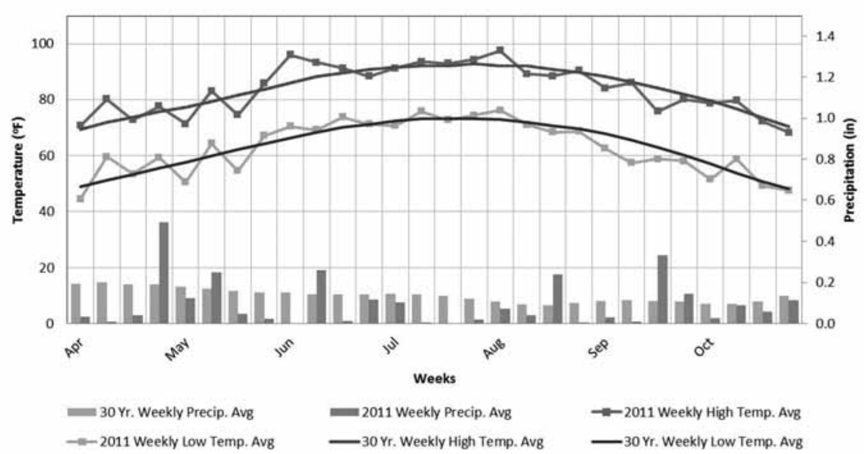

Fig. 1. Weekly maximum and minimum temperatures and rainfall for 2011 compared with the long term 30 year averages in Eastern Arkansas.

COTTON INCORPORATED AND THE ARKANSAS STATE SUPPORT COMMITTEE

The *Summaries of Arkansas Cotton Research 2011* was published with funds supplied by the Arkansas State Support Committee through Cotton Incorporated.

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

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

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

Table 1. Arkansas Cotton State Support Committee/Cotton Incorporated Funding 2010

	2010	2011
New Funds	$362,000	$321,000
Previous Undesignated	$33,529	$72,347
Total	$395,529	$393,347

Researcher	Short Title	2010	2011
Oosterhuis	Cotton Research In Progress	$5,000	$5,000
Barber	Irrigation Start & Stop	$23,780	
Barber	Defoliation Timing	$14,600	
Burgos	Resistant Pigweeds - Genetics	$11,455	$11,455
Kirkpatrick	Soils & Nematode Thresholds	$24,094	$22,659
Norsworthy	Resistant Pigweeds - Prediction	$11,907	
Teague	Irrigation, TPB & Crop Vigor	$26,544	
Windham	AR: Site-Specific Seeding Rate	$28,500	$28,500
Lorenz	Profitable TPB Management: AR I	$5,513	$5,513
Akin	Profitable TPB Management: AR II	$5,513	$5,513
Studebaker	Profitable TPB Management: AR III	$5,512	$5,512
Bourland	Cotton Improvement	$26,000	$26,000
Barber	Verification Program	$58,000	$74,208
K. Smith	Resistant Pigweed	$20,000	$20,000
Oosterhuis	Nitrogen Inhibitors	$8,150	$8,150
Oosterhuis	Heat Tolerance Screening	$5,250	$5,250
Teague	Extension Sustainability	$60,000	$30,000
Akin	Rainfastness of Insecticides		$18,495
Barber	Management of New Cultivars		$23,275
Norsworthy	Modeling Glyphosate-Resistant Barnyardgrass		$12,251
Lorenz	Evaluating New Insecticidal Traits		$24,364
		$339,818	$326,145
Uncommitted		$55,711	$67,202
Total		**$395,529**	**$393,347**

ACKNOWLEDGMENTS

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

SUMMARIES OF
ARKANSAS COTTON RESEARCH
— 2011 —

University of Arkansas Cotton Breeding Program – 2011 Progress Report

F. M. Bourland[1]

RESEARCH PROBLEM

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

BACKGROUND INFORMATION

Cotton breeding programs have existed at the University of Arkansas since the 1920s (Bourland and Waddle, 1988). Throughout this time, the primary emphases of the programs have been to identify and develop lines that are highly adapted to Arkansas environments and possess good host-plant resistance traits. Bourland (2011) provided the most recent update of the current program. The breeding program has primarily focused on conventional genotypes. The recent advent of glyphosate-resistant pigweed has renewed some interest in conventional cotton cultivars, but no highly adapted conventional cultivars have been available.

RESEARCH DESCRIPTION

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

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

multiple Arkansas locations to determine yield, quality, host-plant resistance and adaptation properties. Superior strains are subsequently evaluated over multiple years and in regional tests. Improved strains are used as parents in the breeding program and/or released as germplasm or cultivars. Bourland (2004) described the selection criteria presently being used.

RESULTS

Breeding Lines

The primary objectives of the 2006 through 2011 crosses (F_1 through F_6 generations) have included development of enhanced nectariless lines (with goal of improving resistance to tarnished plant bug), improvement of yield components (how lines achieve yield), and improvement of fiber quality (with specific use of Q-score). Breeding line development is almost entirely focused on conventional cotton lines.

Each of the 24 sets of crosses made in 2011 was between conventional cotton lines. The primary focus of these crosses was to combine lines having specific morphological traits, enhanced yield components and improved fiber characteristics. The 2011 breeding line effort also included evaluation of 30 F_2 populations, 24 F_3 populations, 23 F_4 populations, 661 1st year progeny, and 192 advanced progeny. Bolls were harvested from superior plants in F_2 and F_3 populations and bulked by population. Individual plants (1810) were selected from the F_4 populations. After discarding individual plants for fiber traits, 962 progeny from the individual plant selections will be evaluated in 2012. Also, 132 superior F_5 progeny were advanced, and 72 F_6 advanced progeny were promoted to strain status.

Strain Evaluation

In 2011, 108 conventional and 8 transgenic strains (preliminary, new and advanced) were evaluated at multiple locations. Screening for host-plant resistance included evaluation for resistance to seed deterioration, bacterial blight, verticillium wilt, tarnished plant bug, and root knot nematode (in greenhouse). Work to improve yield stability by focusing on yield components and to improve fiber quality by reducing bract trichomes continued.

Two approaches for improving cotton yield stability are being used. The first approach focuses on yield components. Increased lint index and fiber density are being used as selection criteria to improve yield stability (Groves and Bourland, 2010). The second approach focuses on host-plant resistance, with specific emphasis on improving heat tolerance and resistance to tarnished plant bug. A method for evaluating heat tolerance is still being refined. Response of all entries in the Arkansas Cotton Variety Test, two Regional Strain Tests, and two Arkansas Strain Tests to tarnished plant bug was evaluated. Consistent response over years has been found. Lines resistant to tarnished plant bug, as determined in these small plot tests, have been found to reach treatment threshold at a slower rate and require less insecticides than more susceptible lines.

Germplasm Releases

Germplasm releases are a major function of public breeding programs. The Arkansas Agricultural Experiment Station released three cotton germplasm lines in 2011. These lines included Arkot 0111, Arkot 0113 and Arkot 0114. Variation with respect to yield, adaptation, yield components, fiber properties, and specific morphological and host-plant resistance traits are represented in these lines. The lines provide new genetic material to public and private cotton breeders with documented adaptation to the Mid-south cotton region. In addition, two conventional varieties, 'UA103' and 'UA222' were released in 2011.

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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Influence of Soil Hardpan, *Thielaviopsis Basicola* and *Meloidogyne Incognita* on Cotton Root Architecture and Plant Growth in a Microplot Study

J. Ma[1], T.L. Kirkpatrick[2], C.S. Rothrock[1]

RESEARCH PROBLEM

Soil hardpans (HP) are frequently observed in Arkansas cotton production areas. These compacted zones may be detrimental to root penetration and plant growth. Cotton plants tend to grow poorly in soils with HP due to the high soil strength and high bulk densities. Suppressed cotton height and lint yield due to increased soil strength was documented as early as 1963 (Taylor and Burnett, 1963). Two commonly found soilborne pathogens in Arkansas cotton fields are root-knot nematodes, *Meloidogyne incognita,* and the black root rot fungal pathogen, *Thielaviopsis basicola* (Rothrock and Kirkpatrick, 1998). Soil HP associated with these two soilborne pathogens may suppress cotton growth and result in reduced yield. Studies of the effects of soil HP, root-knot nematodes, and *T. basicola* on cotton root architecture and plant growth have not been conducted previously.

BACKGROUND INFORMATION

Plant roots usually encounter mechanical stress when penetrating and developing in compacted soil (Lipiec et al., 2003). Several factors may induce soil compaction, including machinery traffic during planting and harvesting (Harveson et al., 2005). Increased soil strength, decreased air and water permeability, and reduced hydraulic conductivity were reported in compacted soil (Whalley et al., 1995). A negative linear correlation (r = 0.96) between soil strength and root penetration percentage was also reported (Taylor and Gardner, 1963). Root infection by the root-knot nematode causes gall formation thus reducing root function including water and mineral uptake and translocation (Kirkpatrick, et al., 1995). Infection by *T. basicola* leads to black root-rot on cotton seedlings and causes necrosis and discoloration in the root cortex (Rothrock, 1992). An interaction between these two soilborne pathogens has also been documented on cotton (Walker et al., 1998). Infection by both pathogens resulted in decreased root vol-

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[2] Professor, University of Arkansas, Southwest Research and Extension Center, Hope.

ume compared with unaffected roots, and both pathogens reduce root architecture parameters such as root magnitude, altitude and exterior pathlength (Ma et al., unpublished). Recent tools to measure root topology provide us an opportunity to quantify root system damage caused by soil HP, root-knot nematodes, and *T. basicola* where they occur together.

RESEARCH DESCRIPTION

A two-year microplot study (2010-2011) was conducted at the Southwest Research and Extension Center, Hope, Arkansas. Concrete microplots (76 cm in diameter buried 80 cm deep) were used. An artificial HP was created 20 cm below the soil surface in half of the microplots by compaction. The soil above the HP was cultivated. The non-HP (NHP) plots were not subjected to compaction. The pathogen treatments included soil infested with *T. basicola* (40 chlamydospore chains/cm^3 soil) associated with four different *M. incognita* levels (0, 4, 8, 12 eggs/cm^3 soil). Two additional pathogen treatments were non-infested soil and soil infested with *M. incognita* alone (4 eggs/cm^3 soil). Plant samples were taken in early season (31 DAP) and late season (at harvest). Plant growth parameters such as height, number of nodes, leaf area, and biomass were measured in early season. Cotton growth mapping and seedcotton yield were recorded immediately prior to harvest. Soil penetration resistance (0-45 cm) was determined and soil water matric potential was monitored through all the growing seasons. The WinRHIZO image analysis software was utilized to analyze the root topological attributes including magnitude, altitude and exterior pathlength (*Pe*) as well as root morphological characteristics such as surface area, root volume and links. SAS version 9.2 (SAS Institute Inc., Cary, N.C.) was utilized to analyze plant growth and root architecture data. Means were separated using Fisher's protected least significant difference test (LSD) at $P \leq 0.05$. Mean values of each parameter were determined and LSD were calculated when interactions were significant ($P \leq 0.05$).

RESULTS AND DISCUSSION

In the early season of both 2010 and 2011, greater plant height, height-to-node ratio, leaf areas and root fresh weight were found in HP plots (Table 1). Soil HP tended to reduce root altitude, magnitude and exterior pathlength. However, soil HP increased root radius, root surface area and root volume (data not shown). The soil HP and *M. incognita* interaction was more obvious in HP plot (Fig. 1), and *M. incognita* tended to decrease plant height, leaf dry weight and fresh biomass (Table 2).

In the late season of both years, soil HP reduced total root length and root dry weight below the HP layer (data not shown). *M. incognita* infestation decreased total bolls, numbers of sympodial branches and the number of sympodial branches with two bolls (Fig. 2). Seed cotton yield was also reduced after *M. incognita* infestation (Fig. 2).

Our data indicate that in the early season, soil HP tended to suppress root growth. However, since soil penetration resistance was likely not extremely high because the soil was wet, the presence of a HP actually improved cotton plant growth probably by retaining soil moisture for the seedling to exploit. However, as the season progressed and plants matured, increased soil penetration resistance inhibited root penetration and development. Soil HP effects on cotton root architecture and plant growth were more complicated when associated with soilborne pathogens. Usually, the pathogens suppressed root growth. Although compacted soil likely exaggerates the effects, a higher population of soilborne pathogens, competition for food or other resources may also affect the overall impact on the plant. This may explain the quadratic or cubic trends effects of soil HP by *M. incognita* rate interaction.

PRACTICAL APPLICATION

A better understanding of the adverse effects of soil hardpans and soilborne pathogens toward root architecture and plant growth could guide crop cultivation strategies and provide practical advice for disease management in cotton.

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Table 1. Hardpan (HP) effect on cotton seedlings growth[1] in the early seasons of 2010 and 2011.

	Stand		Height-to-node ratio		Leaf areas (cm2)		Root wet weight (g)	
	2010	2011	2010	2011	2010	2011	2010	2011
HP								
0	0.782 a	0.916 a	1.301 a	1.825 a	21.458 a	32.923 a	0.297 a	0.555 a
1	0.897 b	0.917 a	1.393 b	2.028 b	46.945 b	105.161 b	0.397 a	0.923 b

[1] Means within the same column followed by the same letter are not significantly different ($P \leq 0.05$) according to Fisher's protected least significant difference test.

Table 2. Treatment effects on cotton seedling growth in the early season of 2011.

Treatment[1]	Height[2] (cm)	Leaf dry weight (g)	Total above ground dry weight (g)
0-0	7.814	0.640	1.067
0-1	7.494	0.754	1.217
4-0	7.023	0.591	0.918
4-1	5.766	0.438	0.746
8-1	6.261	0.400	0.723
12-1	6.457	0.417	0.765
P value	0.012	0.0014	0.0026

[1] 0-0: non-infested soil; 0-1: only *T. basicola* (40 chlam. chains/ \cm^3 soil); 4-0: only *M. incognita* (4 eggs/cm^3 soil); 4-1: *M. incognita* (4 eggs/cm^3 soil) + *T. basicola* (40 chlam. chains/cm^3 soil); 8-1: *M. incognita* (8 eggs/cm^3 soil) + *T. basicola* (40 chlam. chains/cm^3 soil); 12-1: *M. incognita* (12 eggs/cm^3 soil) + *T. basicola* (40 chlam. chains/cm^3 soil).

[2] Means within same column are significantly different according to Fisher's protected least significant difference test at $P \leq 0.05$.

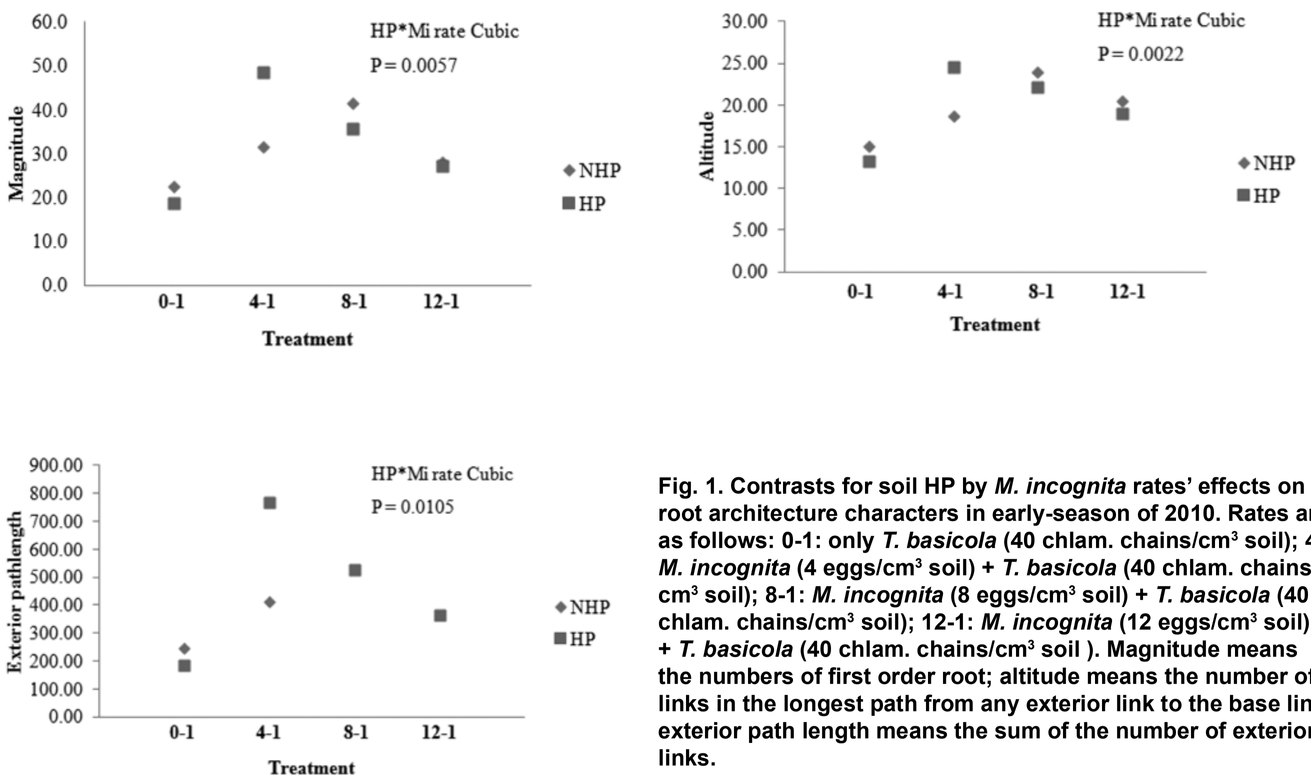

Fig. 1. Contrasts for soil HP by *M. incognita* rates' effects on root architecture characters in early-season of 2010. Rates are as follows: 0-1: only *T. basicola* (40 chlam. chains/cm^3 soil); 4-1: *M. incognita* (4 eggs/cm^3 soil) + *T. basicola* (40 chlam. chains/cm^3 soil); 8-1: *M. incognita* (8 eggs/cm^3 soil) + *T. basicola* (40 chlam. chains/cm^3 soil); 12-1: *M. incognita* (12 eggs/cm^3 soil) + *T. basicola* (40 chlam. chains/cm^3 soil). Magnitude means the numbers of first order root; altitude means the number of links in the longest path from any exterior link to the base link; exterior path length means the sum of the number of exterior links.

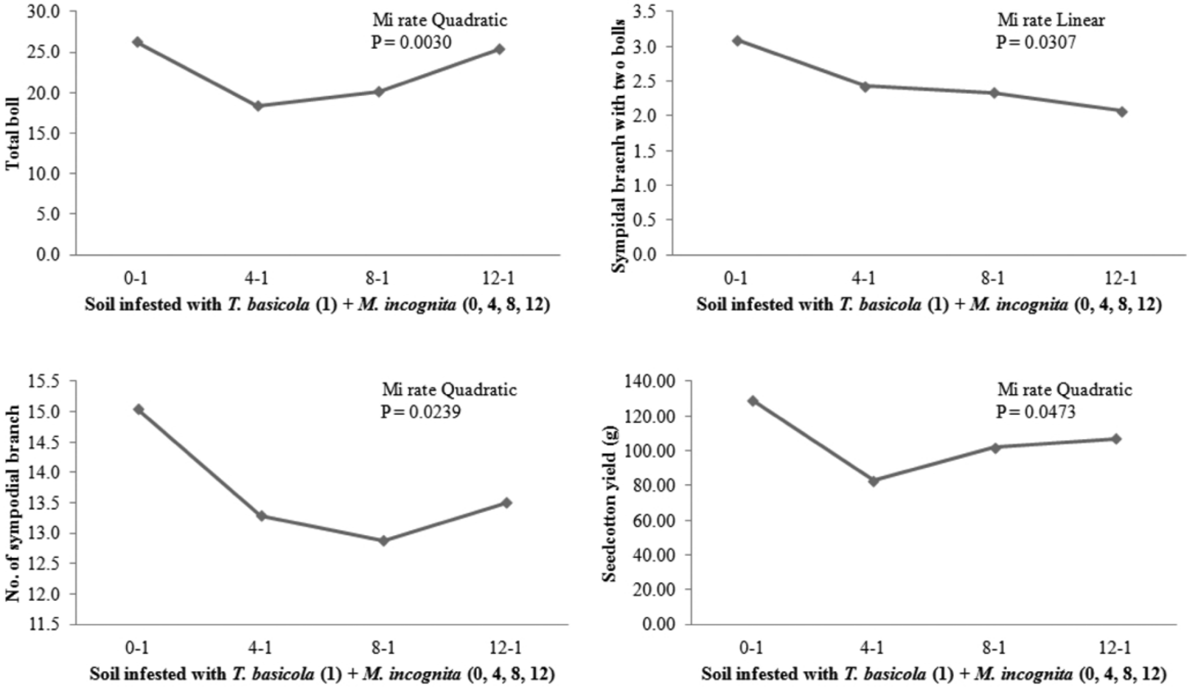

Fig. 2. *M. incognita* rates' effects on cotton development and seed cotton yield in the late season of 2010. Rates are as follows: 0-1: only *T. basicola* (40 chlam. chains/cm^3 soil); 4-1: *M. incognita* (4 eggs/cm^3 soil) + *T. basicola* (40 chlam. chains/cm^3 soil); 8-1: *M. incognita* (8 eggs/cm^3 soil) + *T. basicola* (40 chlam. chains/cm^3 soil); 12-1: *M. incognita* (12 eggs/cm^3 soil) + *T. basicola* (40 chlam. chains/cm^3 soil).

Modeling the Evolution of Glyphosate Resistance in Barnyardgrass in Arkansas Cotton

M.V. Bagavathiannan[1], J.K. Norsworthy[1], K.L. Smith[2], and P. Neve[3]

RESEARCH PROBLEM

Barnyardgrass is one of the most problematic grass weeds in Arkansas cotton. The intensive cultivation of glyphosate-resistant cotton, coupled with a lack of herbicide and crop rotation is causing enormous selection pressure for the evolution of glyphosate-resistant weeds. Glyphosate-resistant Palmer amaranth is a major weed management issue in Arkansas cotton production. Suitable resistance management programs were identified with the use of a simulation model (Neve et al., 2010), but resistance could have been prevented, or at least delayed, if such models were available earlier. Thus, a proactive approach is necessary to prevent future incidences of herbicide resistance in this system. The objectives of this study were to i) understand the risks of glyphosate resistance in barnyardgrass, a species with a high likelihood for evolving glyphosate resistance in Arkansas cotton, and ii) identify best management practices for resistance mitigation.

BACKGROUND INFORMATION

In Arkansas, the vast majority of the cotton production area is planted to Roundup Ready Flex® cotton. Glyphosate is a frequently used herbicide in this system, with some cotton fields receiving as many as five glyphosate applications per year since 2006 (Norsworthy et al., 2007). This exerts severe selection pressure for the evolution of herbicide resistance in weed populations, and we have already witnessed glyphosate-resistant horseweed and Palmer amaranth in Arkansas cotton. Barnyardgrass is a species with high risks of evolving herbicide resistance, with confirmed resistance to at least six herbicide modes of action worldwide (Heap, 2012). In Arkansas rice production systems, barnyardgrass resistance has been confirmed for propanil, quinclorac, clomazone, and imazethapyr. Evidence suggests that barnyardgrass resistance to glyphosate is likely, and it is not a question of “if” but “when”. Thus, proactive measures are vital to prevent such a situation; herbicide resistance simulation models are useful in predicting resistance evolution and identifying suitable management approaches in this respect.

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RESEARCH DESCRIPTION

A glyphosate-resistance simulation model has been developed for barnyardgrass, using the STELLA® modeling environment (Bagavathiannan et al., 2012). The modeling approach previously used for simulating glyphosate resistance in Palmer amaranth (Neve et al., 2010) was followed for the barnyardgrass model. The model consists of three elements: the ecology and demography of barnyardgrass, the genetics of resistance (mode of inheritance, dominance, and fitness), and the response of barnyardgrass to various management scenarios. The structure of the model represents the overall life cycle of barnyardgrass, which consists of key life-history stages including soil seedbank, emerged seedlings, and mature plants. The lifecycle starts with the seedbank and the transition of individuals through different stages and finally the return of fresh seeds to the seedbank. The model consists of various sub-models representing different processes within the life cycle. The model accounts for the presence of density-dependent effects on the survival and fecundity of barnyardgrass. Additionally, the model assumes environmental and demographic stochasticity on initial seedbank size, annual seedbank survival, seedling emergence, seedling survival, and fecundity. Stochasticity is simulated by drawing random samples from a suitable distribution.

The model was parameterized using field-collected data, information sourced from the literature, and using expert opinion. The model assumes a mutation rate of 5×10^{-8} for glyphosate resistance in barnyardgrass. There have been no published studies documenting the mechanism of inheritance of glyphosate resistance in barnyardgrass. In all other species investigated, glyphosate resistance is inherited as a single nuclear gene with incomplete dominance and this is assumed in the model for barnyardgrass. However, the model assumes no fitness penalty for glyphosate resistance, because resistance-induced fitness penalty is less common for non-photosystem-II inhibitors in weed communities. Barnyardgrass is a selfing species, and an outcrossing of 3% is assumed.

A homogeneous field with a size of 150 acre was assigned to the model, and the model simulated resistance across 250 cotton fields in Arkansas over a 30-year period. A population is considered to have evolved resistance if at least 20% of the seedbank consists of resistant individuals. The model was analyzed under a range of management scenarios for predicting the risks of resistance for each scenario.

RESULTS AND DISCUSSION

When simulating a worst-case scenario, i.e., use of a glyphosate-only program with five glyphosate applications in a year under a continuous Roundup Ready Flex® cotton, the model predicts that resistance will evolve in about 5% of the fields by year 10 and about 80% of the fields by year 15 (Fig.1). The Flex® cotton was commercialized in 2006, and prior to that growers used other modes of action for late-season weed control in glyphosate-resistant cotton. Thus, the worst-case scenario could have been practiced only in few fields for about 7 years now, and it is unlikely that many fields are still using a glyphosate-only system due to the presence of glyphosate-resistant Palmer amaranth. Most farmers use Reflex® (fomesafen), a preplant residual herbicide, for controlling Palmer amaranth in cotton. With the inclusion of Reflex®, the model predicts that the onset of resistance is delayed for up to 15 years, with about 65% chance for resistance by year 25. However, when including an at-plant residual (Cotoran® with no glyphosate application at this stage), instead of Reflex® preplant, there was a similar risk for resistance. It is possible that some farmers apply Gramaxone® plus Cotoran® at planting, and in this scenario, the risks of resistance are not different from the previous program. A rotation of glyphosate-resistant cotton with glufosinate-resistant cotton was effective in delaying the onset of resistance for up to 18 years, under the worst-case scenario (i.e., five glyphosate/glufosinate applications in a season). When simulating alternate application of glyphosate and glufosinate in a GlyTol® cotton (glyphosate at-planting followed by (fb) glufosinate first POST fb glyphosate second POST fb glufosinate third POST fb glyphosate layby), the risks of resistance was substantially low with the onset of resistance at year 18 with about 40% chance for resistance by year 30.

The model was used to identify a best weed management program that will effectively mitigate the evolution of glyphosate-resistant barnyardgrass in Roundup Ready Flex® cotton. It was evident that the best management program recommended for controlling glyphosate-resistant Palmer amaranth will be effective in this respect. This program consists of Reflex (preplant) fb Gramoxone® plus Cotoran® (at planting) fb glyphosate plus Dual Magnum® (first POST) fb glyphosate plus Dual Magnum® (second POST) fb glyphosate plus Caparol® (third POST) fb MSMA® plus Valor® (layby).The model also suggests that application timing is critical to achieve better results. For instance, when SelectMax® was applied at second POST it was very effective (onset at year 20) in delaying resistance compared to application at first POST (onset at year 12). Likewise, mechanical cultivation at third POST was very effective (onset at year 18) compared with cultivation at second POST (onset at year 13). More importantly, the model indicates that the risks for resistance are very low in fields with a good weed management history. If more weeds were allowed to produce seeds, the chances for a resistant mutation to occur and establish in the seedbank are greater and vice versa. Therefore, growers need to implement tactics for effectively preventing seed production in late-season escapes.

PRACTICAL APPLICATION

The model allows us to understand the risks of barnyardgrass evolving resistance to glyphosate under a given weed management scenario and to devise suitable preventive measures. Such measures will be vital in preserving the long-term utility of available herbicide chemistries.

ACKNOWLEDGMENTS

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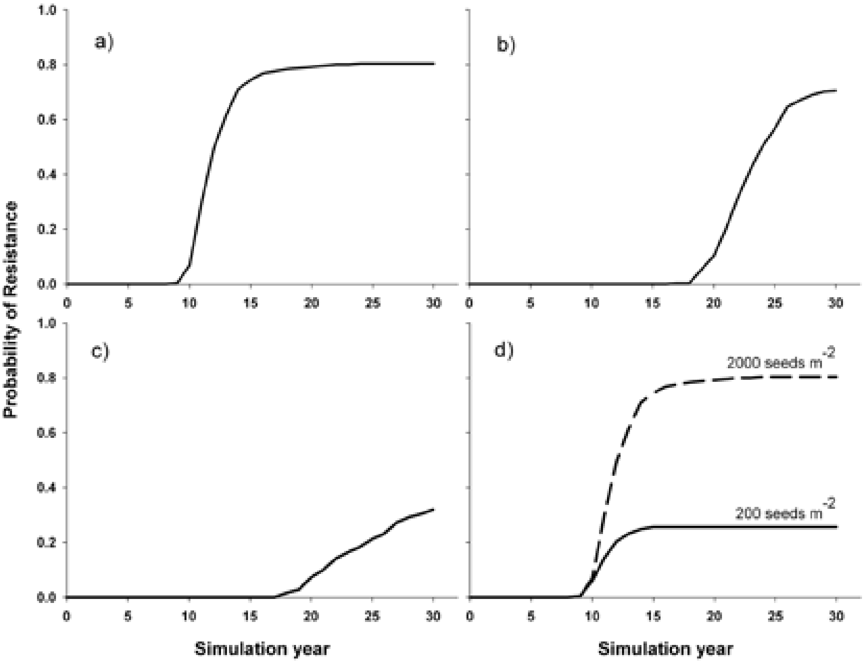

Fig. 1. The risks of barnyardgrass evolving resistance to glyphosate in Roundup Ready Flex® cotton, under a) a worst-case scenario, b) glyphosate-glufosinate rotation, c) GlyTol® cotton, and d) low initial seedbank.

Efficacy and Cotton Tolerance to Warrant Herbicide

D.S. Riar, J.K. Norsworthy, D.B. Johnson, C.E. Starkey, and A. Lewis[1]

RESEARCH PROBLEM

Residual herbicides are essential for effective weed management in cotton production systems. However, growers have limited options for over-the-top residual herbicides in cotton for controlling weeds such as Palmer amaranth (*Amaranthus palmeri*). Warrant (acetochlor), a new formulation of a residual herbicide developed by Monsanto, has recently been registered for over-the-top application in cotton and soybean. The objectives of this study were (i) to evaluate early-season weed control efficacy of Warrant compared to the commonly used early-season cotton residual herbicide, Dual Magnum (*S*-metolachlor), at different rates and timings; and (ii) to determine whether Warrant injures Phytogen cotton [resistant to both Roundup (glyphosate) and Liberty (glufosinate)] or affects seedcotton yield.

BACKGROUND INFORMATION

In Arkansas, Roundup Ready® (glyphosate-resistant) cotton (*Gossypium hirsutum* L.) cultivars represented more than 98% of cotton planted in 2011. At the same time, evolution of glyphosate-resistant weed species all over the world increased from one in 1996 to 22 in 2012 (Heap, 2012). Six weed species, including common ragweed (*Ambrosia artemissiifolia*), giant ragweed (*Ambrosia trifida*), horseweed (*Conyza canadensis*), Italian ryegrass (*Lolium multiflorum*), johnsongrass (*Sorghum halepense*), and Palmer amaranth have evolved resistance to glyphosate in Arkansas (Heap, 2012). Residual herbicides can reduce the selection pressure on postemergence (POST) herbicides such as glyphosate and glufosinate and increase control of glyphosate-susceptible and -resistant weed species, including Palmer amaranth in Roundup Ready® and LibertyLink® (glufosinate-resistant) cotton (Everman et al., 2009; Riar et al., 2011). The most commonly used residual herbicides applied over-the-top of cotton are Dual Magnum, Envoke (trifloxysulfuron), and Staple (pyrithiobac). However, widespread resistance to acetolactate synthase (ALS)-inhibiting herbicides in Palmer amaranth has limited the use of Envoke and Staple in cotton (Bond et al., 2006; Norsworthy et

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al., 2008). Addition of residual over-the-top herbicides in cotton will increase options for growers to control economically important weeds. Warrant, an encapsulated formulation of acetochlor, can be applied POST from crop emergence to the first-flower stage of cotton and may be an effective option for growers to control small-seeded broadleaf and grass weeds, including Palmer amaranth and barnyardgrass (*Echinochloa crus-galli*).

RESEARCH DESCRIPTION

Field experiments were conducted at Marianna, Arkansas, in 2011 on a Zachary silt loam soil. Four rows of Phytogen cotton (cv. PHY375 WRF) were planted at a row spacing of 38 inches in 25-ft long by 12-ft wide plots. The experiment was arranged as a randomized complete block design with 11 treatments and 4 replications. Treatments included Warrant at 3 or 6 pt/acre (1.13 or 2.25 lb ai/acre) applied 14 days before planting (DPP) or preemergence (PRE); Warrant at 6 pt/acre plus Reflex (fomesafen) at 1.5 pt/acre (0.38 lb ai/acre) applied 14 DPP; Dual Magnum at 1.3 or 2.6 pt/acre (1.25 or 2.50 lb ai/acre) applied PRE; two applications of Warrant at 3 pt/acre applied 14 DPP and PRE; and three applications of Warrant or Dual Magnum at 3 and 1.3 pt/acre, respectively, applied 14 DPP, PRE, and early POST (EPOST). The PRE and EPOST treatments were applied at planting and 1 week after planting (WAP), respectively. Roundup PowerMax (glyphosate) at 22 fl oz/acre (0.77 lb ae/acre) was added to all treatments. A non-treated control was included.

Percentage control of barnyardgrass, entireleaf morningglory (*Ipomoea hederacea* var. *integriuscula*), and a mixed population of glyphosate-resistant and -susceptible Palmer amaranth was evaluated at planting and 1 and 2 WAP. Cotton injury was rated at 1, 2, 4, and 6 WAP. Visual ratings were based on a scale of 0 to 100%, where 0 is no injury and 100% is weed or crop mortality. Seedcotton was harvested from the middle two rows of each plot, and data for seed-cotton yield were recorded as lb/acre. Data for weed control, cotton injury, and seed-cotton yield were subjected to ANOVA using PROC MIXED in SAS (SAS Institute Inc., Cary, N.C.), and means were separated using Fisher's protected LSD test at $\alpha = 0.05$. Preplanned contrast comparisons were conducted between respective Warrant and Dual Magnum treatments to determine if weed control with Warrant treatments was at par with Dual Magnum treatments.

RESULTS AND DISCUSSION

Palmer amaranth control with Warrant plus Reflex was ≥ 91% at all evaluation times (Table 1). Preplanned contrasts revealed that, at planting, Palmer amaranth control with Warrant at 3 pt/acre applied 14 DPP (90%) was less than Warrant at 6 pt/acre (97%) and Dual Magnum at 1.3 pt/acre applied 14 DPP (first application of Dual Magnum in the 3-application treatment) (94%). Palmer amaranth control at 1 WAP was similar among respective Warrant and Dual Magnum treatments

(61% to 82%). At 2 WAP, Palmer amaranth control with a single application of Warrant at 3 pt/acre (45%) was less than Warrant at 6 pt/acre (82%) and three applications of Warrant or Dual Magnum (> 73%), but was similar to all other treatments. Less Palmer amaranth control in general with all Warrant and Dual Magnum treatments was because of the high density of Palmer amaranth at the time of application and the inability of these herbicides to control weeds after emergence.

According to preplanned contrasts, barnyardgrass control with a single application of Warrant 14 DPP at 3 pt/acre (93% at planting and 64% and 43% at 1 and 2 WAP, respectively) was less than Dual Magnum at 1.3 or 2.6 pt/acre applied PRE (69% to 85% at 1 and 2 WAP), and two or three applications of Warrant (83% to 99% at 1 and 2 WAP) and Dual Magnum (97% to 99% at 1 and 2 WAP) (Table 1). Barnyardgrass control with a single application of Warrant applied 14 DPP at 6 pt/acre was 96%, 73% and 69% at planting and at 1 and 2 WAP, respectively, which was similar to Dual Magnum applied PRE, but was less than two and three applications of Warrant and Dual Magnum (83% to 99% at 1 and 2 WAP). Entireleaf morningglory control with all the treatments was ≤ 66%.

Cotton injury was <5% for all treatments (data not shown). Seed-cotton yield following Warrant plus Reflex was 4,210 lb/A, while the nontreated control yielded 2,000 lb/acre (Table 2). Seedcotton yields of all other Warrant and Dual Magnum treatments were similar (2940 to 3710 lb/A). In general, early-season Palmer amaranth control and seed-cotton yield with respective Warrant and Dual Magnum treatments was similar and both herbicides can be useful for controlling Palmer amaranth and barnyardgrass in cotton.

PRACTICAL APPLICATION

Weed control and seed cotton yield with Warrant was comparable to Dual Magnum. Furthermore, neither herbicide caused unacceptable injury to cotton. Therefore, Warrant appears to be an option equally effective to Dual Magnum for residual weed control in cotton. Product cost along with company incentives (if any) will likely result in differentiation of these products among growers.

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Table 1. Palmer amaranth, barnyardgrass, and entireleaf morningglory control in cotton at planting and 1 and 2 weeks after planting (WAP) at Marianna, Ark., in 2011.[1,2,3,4,5]

			Palmer amaranth			Barnyardgrass			Entireleaf morningglory	
Treatment	Appl. Timing	Rate	At planting	1 WAP	2 WAP	At planting	1 WAP	2 WAP	1 WAP	2 WAP
		pt/acre	%							
Warrant	14 DPP	3	90 cd[6]	66 bc	45 d	93 c	64 c	43 c	43 ab	30 c
Warrant	14 DPP	6	97 ab	76 a-c	82 ab	96 b	73 bc	69 bc	39 ab	65 a
Warrant + Reflex	14 DPP	6 + 1.5	100 a	91 a	92 a	99 ab	71 bc	69 bc	53 a	64 ab
Warrant 2 appl.	14 DPP fb PRE	3 fb 3	85 e	73 a-c	47 cd	91 c	88 ab	83 ab	35 ab	64 ab
Dual Magnum	PRE	1.3	NA	61 cd	50 cd	NA	85 ab	85 ab	34 ab	38 bc
Warrant	PRE	3	NA	65 bc	60 b-d	NA	76 bc	71 a-c	29 b	43 a-c
Dual Magnum	PRE	2.6	NA	75 a-c	56 b-d	NA	84 ab	69 bc	39 ab	66 a
Warrant	PRE	6	NA	77 a-c	67 a-d	NA	80 a-c	78 ab	44 ab	63 ab
Warrant 3 appl.	14 DPP fb PRE fb EPOST	3 fb 3 fb 3	89 de	78 a-c	75 a-c	91 c	96 a	99 a	36 ab	58 ab
Dual Magnum 3 appl.	14 DPP fb PRE fb EPOST	1.3 fb 1.3 fb 1.3	94 bc	82 ab	73 a-c	99 a	97 a	97 ab	29 b	56 a-c
CONTRASTS										
Warrant 14 DPP at 3 pt/A vs										
Warrant	14 DPP	6	+	NS	NS	+	NS	NS	NS	+
Warrant 2 appl.	14 DPP fb PRE	3 fb 3	NS	NS	NS	NS	+	+	NS	+
Dual Magnum	PRE	1.3	NA	NS	NS	NA	+	+	NS	NS
Warrant 3 appl.	14 DPP fb PRE fb EPOST	3 fb 3 fb 3	NS	NS	+	NS	+	+	NS	NS
Warrant	PRE	3	NA	NS	+	NA	NS	NS	NS	NS
Warrant 14 DPP at 6 pt/A vs										
Warrant 2 appl.	14 DPP fb PRE	3 fb 3	-	NS	NS	-	NS	NS	NS	NS
Warrant + Reflex	14 DPP	6 +1.5	NS	NS	+	NS	NS	NS	NS	NS
Dual Magnum	PRE	2.6	NA	NS	NS	NA	NS	NS	NS	NS
Warrant 3 appl.	14 DPP fb PRE fb EPOST	3 fb 3 fb 3	-	NS	NS	-	+	+	NS	NS
Warrant	PRE	6	NA	NS	NS	NA	NS	NS	NS	NS
Warrant PRE at 3 pt/A vs										
Warrant	PRE	6	NA	NS	NS	NA	NS	NS	NS	NS
Dual Magnum	PRE	1.3	NA	NS	NS	NA	+	+	NS	NS
Warrant PRE at 6 pt/A vs										
Dual Magnum	PRE	2.6	NA	NS	NS	NA	NS	NS	NS	
Warrant 3 appl. (14 DPP fb PRE fb EPOST) at 3 pt/A vs										
Warrant 2 appl.	14 DPP fb PRE	3 fb 3	NS	NS	-	NS	NS	NS	NS	NS
Dual Magnum 3 appl.	14 DPP fb PRE fb EPOST	1.3 fb 1.3 fb 1.3	+	NS	NS	+	NS	NS	NS	NS
Dual Magnum PRE at 1.3 pt/A vs										
Dual Magnum	PRE	2.6	NA	NS	NS	NA	NS	NS	NS	+
Dual Magnum 3 appl.	14 DPP fb PRE fb EPOST	1.3 fb 1.3 fb 1.3	NA	+	+	NA	NS	NS	NS	NS

[1] Abbreviations: appl., application; DPP, days before planting; EPOST, early-POST; fb, followed by; NS, non significant; NA, denotes that treatment was not applied at the time of evaluation.

[2] The PRE and EPOST treatments were applied at planting and 1 WAP, respectively.

[3] Roundup PowerMax at 22 fl oz/A was added to all treatments.

[4] Entireleaf morningglory did not emerge before planting; thus, control was not evaluated at the time of planting.

[5] Symbols: '+' denotes more control and '-' denotes less control of specific weed species compared to the treatment with which preplanned contrast is conducted at $\alpha = 0.05$.

[6] Values in a column followed by the same letter are not significant ($P = 0.05$).

Table 2. Seed-cotton yield with Warrant and Dual II Magnum treatments applied at different timings at Marianna, Ark., in 2011[1,2].

Treatment	Application timing	Rate	Seed-cotton yield
		pt/acre	lb/acre
Warrant	14 DPP	3	3170 bc[3]
Warrant	14 DPP	6	3690 a-c
Warrant + Reflex	14 DPP	6 + 1.5	4210 a
Warrant (2 applications)	14 DPP fb PRE	3 fb 3	3400 a-c
Dual Magnum	PRE	1.3	3030 bc
Warrant	PRE	3	3420 a-c
Dual Magnum	PRE	2.6	3710 ab
Warrant	PRE	6	3300 bc
Warrant (3 applications)	14 DPP fb PRE fb EPOST	3 fb 3 fb 3	3000 bc
Dual Magnum (3 applications)	14 DPP fb PRE fb EPOST	1.3 fb 1.3 fb 1.3	2940 bc
Nontreated	---	---	2000 d

[1] Abbreviations: DPP, days before planting; EPOST, early POST; fb, followed by.
[2] Roundup PowerMax at 22 fl oz/acre was added to all treatments.
[3] Values in a column followed by the same letter are not significant (*P* = 0.05).

Layby Timing for Ideal Late-Season Weed Control in Arkansas Cotton

R.C. Doherty, K.L. Smith, J.A. Bullington, and J.R. Meier[1]

RESEARCH PROBLEM

Glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) is present in all cotton growing counties in Arkansas. This pest has driven weed control programs to herbicide systems that must contain overlapping residual herbicides. The application timing of the residual herbicides in the system may influence season-long control of this troublesome pest. Most of the cotton grown in Arkansas is furrow irrigated. Late season herbicide applications require driving over the plastic irrigation pipe often puncturing the pipe, thus, causing expensive repairs. Earlier layby applications would avoid or reduce the number of trips across the irrigation pipe and reduce repair costs. The objective was to determine the layby application timing and herbicide system that would provide optimum late-season weed control in Arkansas cotton.

BACKGROUND INFORMATION

Cotton weed control has changed drastically in the last five years, because of the presence of glyphosate-resistant Palmer amaranth. Currently there is no herbicide that will control glyphosate-resistant Palmer amaranth after it reaches 4 inches in height. More information was needed on the timing and herbicides used for control of Palmer amaranth with overlapping-residual herbicide systems.

RESEARCH DESCRIPTION

One trial was established in Rohwer, Arkansas, on the Southeast Research and Extension Center in a Hebert silt loam soil in 2011 to evaluate Palmer amaranth control in cotton. The trial was arranged in a randomized complete block design with four replications. Eight herbicide systems were evaluated at one or more of the three layby timings (8, 10, or 12 lf cotton). Parameters evaluated were visual control ratings of Palmer amaranth and cotton yield. Weed control was recorded on a 0-100 scale with 0 being no control and 100 being complete control.

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[1] Program technician, weed scientist/professor/program technician, and program associate, respectively, Southeast Research and Extension Center, Monticello.

RESULTS AND DISCUSSION

At 95 days after the 8-leaf application, Cotoran at 1 lb ai/acre PRE followed by (fb) Roundup PowerMax at 0.77 lb ae/acre plus Dual Magnum at 0.95 lb ai/acre applied at 4-leaf cotton fb MSMA at 2 lb ai/acre plus Valor at 0.064lb ai/acre applied at 8-leaf cotton provided 100% control of Palmer amaranth (Fig. 1). At 80 days after the 12-leaf application, Cotoran at 1 lb ai/acre PRE fb Roundup PowerMax at 0.77 lb ae/acre plus Dual Magnum at 0.95 lb ai/acre applied at 2-leaf cotton fb Roundup PowerMax at 0.77 lb ae/acre plus Dual Magnum at 0.95 lb ai/acre applied at 6-leaf cotton fb MSMA at 2 lb ai/acre plus Valor at 0.064lb ai/acre applied at 12-leaf cotton provided 100% control of Palmer amaranth. All other herbicide systems applied at 10- and 12-leaf layby timings provided 93-100% control of Palmer amaranth (Fig. 2). Cotoran at 1 lb ai/acre PRE fb Roundup PowerMax at 0.77 lb ae/acre plus Dual Magnum at 0.95 lb ai/acre applied at 2-leaf cotton fb Roundup PowerMax at 0.77 lb ae/acre plus Dual Magnum at 0.95 lb ai/acre applied at 6-leaf cotton fb MSMA at 2 lb ai/acre plus Valor at 0.096 lb ai/acre applied at 8-leaf cotton provided the highest cotton yield numerically with 3320 lb/acre of seed cotton (Fig. 3). All other herbicide systems applied at 10- and 12-leaf layby timings provided statistically equal cotton yields. Herbicide systems that contained a 12-leaf layby did provide numerically higher weed control than the same system with the layby applied at 8- or 10-leaf cotton.

PRACTICAL APPLICATIONS

Residual-herbicides are a valuable tool in zero-tolerance weed control systems. These herbicide systems will aid in providing a sustainable cotton production system. When used in an aggressive Palmer management program, layby applications as early as the 12-leaf stage can provide excellent weed control and reduce the trips across irrigation pipe. The information from this trial will be used to make Palmer amaranth control recommendations throughout the state.

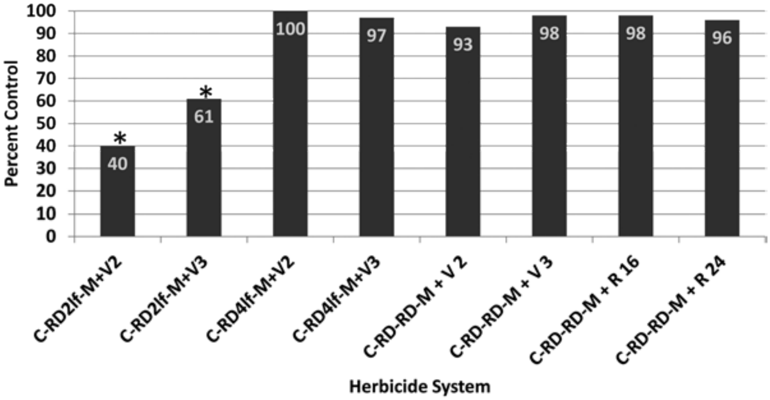

Fig. 1. 2011 Palmer Control, 95 DA 8-leaf stage. LSD(0.05) = 22.
*** = significantly different at *P* = (0.05).**

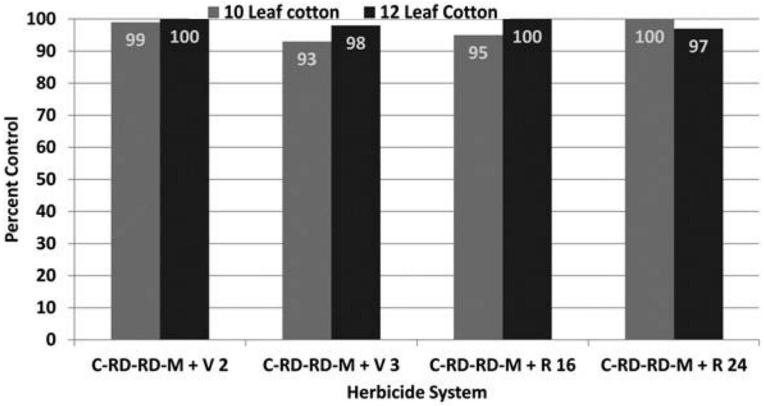

Fig. 2. 2011 Palmer control 90 DA for 10-leaf and 80 DA for 12-leaf cotton.
LSD(0.05) = 22.

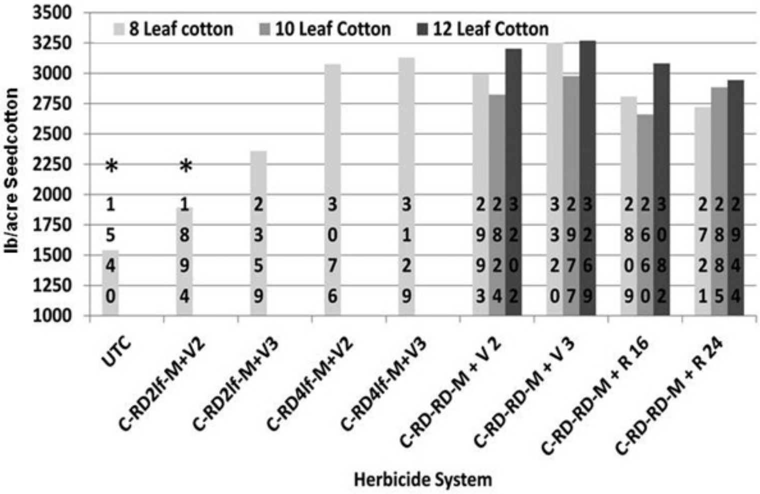

Fig. 3. Cotton seedcotton yield 2011. LSD(0.05) = 734.

Seed Production Potential of Palmer Amaranth in Arkansas

K.L. Smith[1], R.C. Doherty[1], J.A. Bullington[1], J.R. Meier[1],
and M.V. Bagavathiannan[2]

RESEARCH PROBLEM

Glyphosate-resistant Palmer amaranth is the most troublesome pest in Arkansas cotton production. The prolific seed production, high germination rate, and rapid growth coupled with the lack of post emergence herbicide control options make this species a constant threat to cotton farmers. Sustainable control of Palmer amaranth requires careful management of seed in the soil seedbank. To emphasize the importance of managing seedbanks, it is critical to understand the number of seed produced by individual plants. This research was conducted to quantify the seed production potential of large Palmer amaranth escapes growing in Arkansas cropland.

BACKGROUND INFORMATION

Cotton producers in Arkansas are well aware of the importance of controlling Palmer amaranth and other pigweed species. These weeds compete with cotton for nutrients, moisture, and light and reduce harvest efficiency. Cotton lint yield was reduced approximately 11% for each increase of one Palmer amaranth plant per 10 m of row (Rowland et al., 1999). In 1995, *Amaranthus* species reduced cotton yields in Arkansas by 10% (Byrd, 1996). Farmers adopted the glyphosate-resistant (GR) cotton technology soon after introduction in 1999 and the first GR Palmer amaranth was confirmed in 2006. During the past four years, GR Palmer amaranth has spread rapidly, and currently greater than 90% of the cotton fields in Arkansas have some level of GR Palmer amaranth infestation. Economic thresholds (ETs) have traditionally been calculated based on cost of control compared to loss in yield during a single year. However, ETs do not consider the long-term biological and economic consequences of weed seed production. In particular, for prolific seed producers such as Palmer amaranth, even few escapes can greatly contribute to seedbank renewal, ensuring future management issues. Bensch et al. (2003) and Massinga et al. (2001) reported an addition of 33,000 to 500,000 seeds/m^2 from only 0.25 to 8 Palmer amaranth plants/m^2. Culpepper and Sos-

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noskie (2011) found that a meager escape of five female Palmer amaranth plants/acre may result in a seedbank addition of about 2 million seeds/acre. Single mature plants often exceed a square meter in size and farmers usually evaluate weed control failures by the number of weed escapes. Thus, educational programs focusing on Palmer amaranth management greatly emphasize controlling escapes, given the high seed production potential of individual plants. This research was initiated to demonstrate the reproduction potential of individual Palmer amaranth plants and to emphasize the need for preventing seed production and seedbank renewal.

RESEARCH DESCRIPTION

Two large female Palmer amaranth escapes were located growing in a soybean field in St. Francis County, Ark., in 2010. At maturity, each plant was carefully cut at ground level and placed in an enclosed trailer for transport to the laboratory. Plants were allowed to dry for 14 days after which seed were hand thrashed and separated from trash using a series of sieves big enough to allow Palmer amaranth seeds to pass through and small enough to hold the trash. Total seed weight was recorded for each plant and 20 aliquots (1 g each) removed and distributed over a 10 × 7 grid for visual counting. All seed with brown or black seed coats were considered mature. Mean number of mature seeds/g was estimated from the 20 subsamples.

RESULTS AND DISCUSSION

Total number of mature seeds/g across the 20 subsamples ranged from 968 to 1313 for plant 1 with an average of 1117 seeds/g and from 657 to 925 for plant 2 averaging 769 seeds/g (Fig. 1). The variability in number of seeds/g among the subsamples was less than 9%, which is reasonable considering the seed size. The difference in the number of seeds/g calculated between the two plants is not reflective of different individual seed size between the plants, but is rather due to the varying amounts of small trash contaminating the samples. Total thrashed seed weight for the two plants were 1.335 kg and 2.305 kg, respectively. The plant #1 produced about 1.492 million mature seeds and the plant #2 produced about 1.773 million mature seeds. Thus, our observations show that a single Palmer amaranth escape that grows under favorable conditions in a row-crop field can produce in excess of 1.5 million seeds.

PRACTICAL APPLICATION

The Palmer amaranth plants used in this study were large and may not be representative of a typical escape, yet they were selected from a production field and exemplify the magnitude of impact a single escape can have on the soil seedbank if growth conditions are ideal. This also illustrates why economic thresholds cannot be determined by comparing cost of control to price of reduced yield in a single year. Herbicide programs providing 99.5% control are considered excellent in most cropping cultures. If a single escape can produce over a million viable seed, even a sparse escape following good cultural practices and herbicide programs can still make a weed management program unsustainable. For instance, given the 10% viable proportion added to seedbank after herbivory, decay, and loss in viability (Bagavathiannan et al., 2012), and assuming a 25% germination, and 99% control with a good herbicide program, 1 million seeds produced in the fall would result in about 250 escapes in the subsequent crop. In a typical production field, achieving 99% control can often be a challenge due to a multitude of factors, resulting in control levels much less. Furthermore, the number of escapes will increase exponentially each year, meaning that more emphasis on preventing seed production and perhaps setting a zero tolerance goal for Palmer amaranth escapes is vital for sustainable management of this weed in Arkansas cotton.

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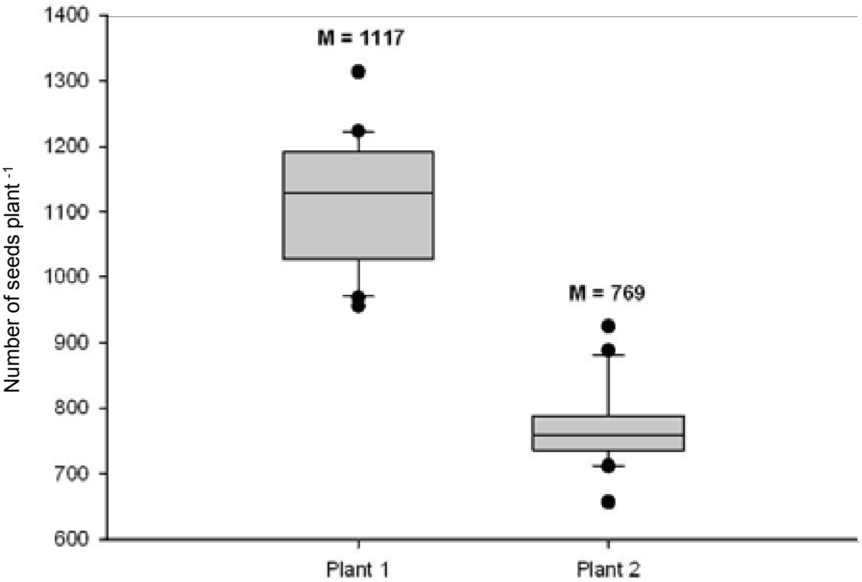

Fig. 1. Box plots showing the median and range for the number of seeds/g among the 20 subsamples for each of the two Palmer amaranth plants used in the study. The value on the top of each box corresponds to the sample mean.

High Night Temperatures Effects on Cotton During Squaring and Flowering

F.R. Echer, D.M. Oosterhuis, and D.A. Loka[1]

RESEARCH PROBLEM

Temperature is the environmental factor which most influences growth and development of the cotton crop. Cotton growing areas across the United States are experiencing variable yearly changes in temperatures and as a consequence yields are variable and unpredictable. Both night and day temperatures are important, with night temperature thought to be more important. High night temperatures increase respiration and decrease carbohydrate content (Loka and Oosterhuis, 2010). However, it is unclear which development stage is more sensitive to high night temperature.

BACKGROUND INFORMATION

The optimum temperature for growth and development is 20-30 °C (Reddy et al., 1992) and the optimum temperature for enzyme activities was estimated to be from 23.5 °C to 32 °C (Burke et al., 1988). Gipson and Joham (1969) showed that high night temperatures had a greater effect than the day temperatures on cotton flowering. Recent studies by Loka and Oosterhuis (2010) indicated that an increase in night temperature during flowering for 2 hours (short duration) from 24 °C to 27 °C and 30 °C increased respiration by 49% and 56%, respectively, compared to the control treatment. In addition Adenosine-5'-triphosphate (ATP) was decreased with increasing night temperature, although the carbohydrate content of leaves was not affected. Increasing night temperature from 20 °C to 28 °C for 4 hours each night for four weeks (long period), also increased the respiration rate and decreased the ATP, but also caused severe losses of carbohydrate content in leaves.

Additionally, Arevalo et al. (2008) showed that a short period of one week of high night temperatures of four hours during the flowering and boll development stage had little effect on respiration, whereas a longer period (four weeks) increased respiration. Night temperatures above 25 °C have been reported to increase the rates of respiration and reduce carbohydrates (Oosterhuis and Bour-

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land, 2001). Under high night temperatures, more carbohydrates are utilized by the high respiratory rates at the expense of plant growth (Reddy et al., 1996). The objective of this study was to evaluate the effect of elevated night temperatures during squaring and during flowering on plant growth and reproductive development.

RESEARCH DESCRIPTION

The experiment was conducted in growth chambers located at Altheimer Laboratory, University of Arkansas, Fayetteville, Ark. Cotton (*Gossypium hirsutum* L.) cultivar ST5288 B2R was grown in 2-L pots containing SunGro® Horticulture mix. The growth chambers were set for a 14 h photoperiod with day/night temperatures, according with treatment. Plants were watered with half-strength Hoagland's solution daily.

Treatments consisted of (1) a control (24 °C), (2) high night temperatures (HNT) (29 °C for 4 h) at squaring, and (3) high night temperatures (29 °C for 4 h) at flowering, in a randomized complete block design with 10 replications. Cotton plants were grown until the pinhead square under normal day/night temperatures (32/24 °C). Plants were then divided into 3 groups and one group (HNT at squaring) was transferred into a second growth chamber, with similar conditions of photosynthetic photon flux density, humidity, and photoperiod, but with a night temperature of 29 °C for 4 h (dark period – 20h00 until 00h00). Plants were maintained in this environment for 3 weeks, while the other group remained under normal temperatures. At the end of the third week of squaring, plants were returned to the normal temperatures growth chamber, and then the second group (HNT at flowering) was transferred to the second (high night) growth chamber for 3 weeks. Before the stress was applied, all plants were sprayed with mepiquat chloride (1.6 ml L^{-1}).

Respiration (R_p) and photosynthesis (P_n) measurements were recoded with a LI-COR 6200 infra-red gas analyzer (LI-COR Inc., Lincoln, Neb.) at 10 p.m. and 10 a.m., respectively, in each week of each growth stage. Means were compared using Student's *t*-test $P = 0.05$.

RESULTS AND DISCUSSION

Plants in the high night temperatures (29 °C) had lower respiration than control treatment (24 °C) only at the first week of squaring (Fig.1). Differences also were observed between weeks inside HNT treatment, with the lowest rate at the first week, but for the control no differences were observed (Fig.1). For HNT stress during flowering, respiration was increased during the third week of flowering. In addition, respiration rates were higher at the third week compared to the first and second week of flowering for both treatments. Photosynthesis decreased in the second week in HNT treatment during squaring, but no differences occurred for control at squaring and flowering stages (Fig. 2). Differences between treatments were observed only at the second week of the squaring period.

High night temperatures increased shedding rates in both stages, more so at flowering (Table 1). However, the boll number per plant diminished in HNT at squaring, but no effect of HNT at flowering was observed. Also, total reproductive dry matter production and the individual reproductive weight decreased under HNT during squaring, but not with HNT during flowering.

PRACTICAL APPLICATION

High night temperature increased respiration rates at the third week of flowering, however the most sensitive period apparently was squaring, due to lower photosynthesis, higher respiration, and lower reproductive dry matter production. Understanding the effect of HNT during each growth stage on the physiology and reproductive development is important for selecting for cultivar improvement and for agronomic reasons related to adjusting planting date.

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Table 1. Effects of high night temperatures (HNT) at squaring and at flowering on cotton reproductive development.

Treatment	Shedding number/plant	Boll number/plant	Total reproductive dry weight	Reproductive unit dry weight
	---------number plant^{-1}---------		----------------------g--------------------	
Control	4.77 ± 0.45	2.00 ± 0.82	2.26 a	0.23 ab
HNT at squaring	5.90 ± 1.18	1.00 ± 0	1.18 b	0.10 b
HNT at flowering	7.33 ± 1.79	2.17 ± 1.06	2.49 a	0.31 a
$LSD_{0.05}$ (*P* value)	-	-	0.94(0.01)	0.16(0.04)

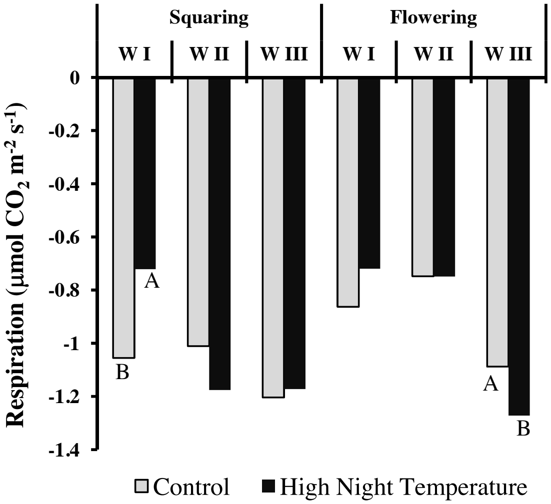

Fig. 1. Effect of high night temperature on respiration one (WI), two (WII) and three (WIII) weeks after the night temperature was raised. Control night temperature = 24 °C and high night temperature = 29 °C. Columns with different letters within a growth stage are significantly different (*P* = 0.05). $LSD_{squaring}$ 0.25 (0.02); $LSD_{flowering}$ 0.19 (0.05).

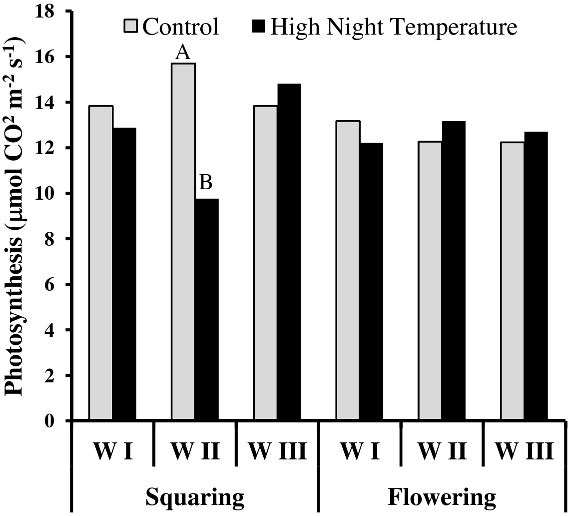

Fig. 2. Effect of high night temperature on photosynthesis one (WI), two (WII) and three (WIII) weeks after the night temperature was raised. Control night temperature = 24 °C and high night temperature = 29 °C. Columns with different letters within a growth stage are significantly different (*P* = 0.05). $\text{LSD}_{\text{squaring}}$ 2.32 (0.01); $\text{LSD}_{\text{flowering}}$ 2.04 (0.40).

Effect of High Night Temperatures at Flowering

D.A. Loka, D.M. Oosterhuis, and F.R. Echer[1]

RESEARCH PROBLEM

High temperatures are considered to be a major environmental stress contributing to variable yields. Even though extensive research has been conducted on the effects of high day temperatures on cotton, limited information exists on the effects of high night temperature on cotton growth and productivity. In this study it was hypothesized that high night temperatures would increase leaf respiration rates which would result in decreased carbohydrate content.

BACKGROUND INFORMATION

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

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RESEARCH DESCRIPTION

Growth chamber studies were conducted in 2010-2011 in the Altheimer laboratory of the University of Arkansas in Fayetteville. Cotton (*Gossypium hirsutum* L.) ST5288B2F was planted into 2-L pots containing a horticultural mix (Sun-Gro® Horticulture mix). The growth chambers were set for normal conditions of 30/20 °C (day/night), ±60% relative humidity, and 14/10 h photoperiod, while half-strength Hoagland's nutrient solution was applied daily in order to maintain adequate nutrients and water. At flowering (approximately 8 weeks after planting) plants were randomly divided in two groups: (1) Control (C) and (2) High Night Temperatures (HNT). Control plants were kept at normal day/night temperatures of 32/24 ºC while high night temperatures of 30 ºC were imposed on the second group from 18:00-24:00. Plants were arranged in a completely randomized block design with twenty replications, while the experimental design was a 2 × 2 factorial design with the main effect being high night temperatures and secondary effect being time. Photosynthetic and respiratory rates were measured weekly between 10:00-12:00 and 22:00-24:00, respectively from the fourth main-stem leaf from each plant using the LiCor 6200 gas analyzer (LI-COR Inc., Lincoln, Neb.). Glucose, sucrose, and starch content as well as glutathione reductase levels were estimated from white flowers (pistils) and their subtending leaves that were collected at the end of each week. Carbohydrate extraction was done according to Zhao et al. (2008) while antioxidant extraction was done according to Lu and Foo (2001), and the supernatants were analyzed with a Multiskan Microplate Reader (Thermo Electric Corporation, West Chester, Pa.).

RESULTS AND DISCUSSION

The results showed that high night temperatures significantly increased respiration rates while photosynthesis rates remained unaffected (Table 1). Leaf sucrose concentrations also remained unaltered, while leaf starch content was significantly decreased (Table 2). Leaf glucose levels were significantly increased and a similar pattern was observed in pistil glucose, sucrose and starch concentrations (Table 3). Leaf glutathione reductase content was increased under conditions of elevated night temperatures, while pistil glutathione reductase content was decreased, however not significantly compared to the control (Table 4).

In summary, leaf antioxidant mechanism appeared to be more efficient in protecting leaf photosynthetic machinery and carbohydrate metabolism. No reductions were observed in photosynthesis rates, while leaf glucose content increased, despite the elevated respiration rates, possibly due to the efficient starch and sucrose breakdown. On the other hand, pistil antioxidant mechanism appeared more sensitive to the high night temperatures regime resulting in accumulation of glucose, sucrose and starch concentrations indicating a perturbation in carbohydrate metabolism that could lead to inefficient use of carbohydrates

PRACTICAL APPLICATION

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

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Table 1. Effect of high night temperatures on leaf photosynthesis and respiration.

	--------Photosynthesis-------		---------Respiration---------	
μmol/m²s	**Week 1**	**Week 2**	**Week 1**	**Week 2**
Control	16.09 a[1]	15.41 a	-1.081 a	-1.135 a
HNT	16.90 a	16.41 a	-1.092 a	-1.480 b

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

Table 2. Effect of high night temperatures on leaf carbohydrate content.

Leaf	----------**Glucose**----------		----------**Fructose**----------		----------**Sucrose**----------		----------**Starch**----------	
mg/mg DW	**Week 1**	**Week 2**	**Week 1**	**Week 2**	**Week 1**	**Week 2**	**Week 1**	**Week 2**
Control	0.00913 c[1]	0.0130 b	0.005097 c	0.007404 b	0.01315 a	0.01537 a	0.000422 a	0.000386 a
HNT	0.010514 bc	0.019125 a	0.005502 c	0.009035 a	0.014298 a	0.014464 a	0.000386 a	0.000386 b

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

Table 3. Effect of high night temperatures on ovary carbohydrate content.

Ovary	------------**Glucose**------------		-----------**Fructose**-----------		------------**Sucrose**------------		------------**Starch**------------	
mg/mg DW	**Week 1**	**Week 2**	**Week 1**	**Week 2**	**Week 1**	**Week 2**	**Week 1**	**Week 2**
Control	0.016205 b[1]	0.0156268 b	0.014885 a	0.017351 a	0.020072 b	0.020416 b	0.000454 b	0.000421 b
HNT	0.019005 ab	0.0225137 a	0.018788 a	0.019296 a	0.021321 ab	0.023999 a	0.000498 b	0.000454 a

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

Table 4. Effect of high night temperatures on leaf and ovary glutathione reductase activity.

	-------------**Leaf**-------------		-------------**Ovary**-------------	
	Week 1	**Week 2**	**Week 1**	**Week 2**
Control	12.63806 c[1]	16.5307 bc	15.28603 a	8.535963 b
HNT	22.82773 ab	26.0529 a	13.28948 ab	7.188311 b

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

High Temperature Tolerance in Cotton

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

RESEARCH PROBLEM

Cotton is produced worldwide under a wide range of environmental conditions and is therefore exposed to numerous abiotic and biotic stresses. Abiotic stresses that limit crop production include water deficit, salinity and temperature extremes. Temperature is a primary controller of the rate of plant growth, development, reproduction, and fruit maturation. High temperatures can have both direct inhibitory effects on growth and yield, and indirect effects due to high evaporative demand causing more intense water stress. Therefore the overall objectives of this study were to (1) determine the best technique to screen cotton germplasm for tolerance to high temperature, and (2) use this information to evaluate contrasting cotton genotypes for temperature tolerance in a controlled environment.

BACKGROUND INFORMATION

High temperature is detrimental to metabolism and reproductive development in Upland cotton (Snider et al., 2010). The best temperature range for optimal metabolic activity is 23 °C to 32 °C with 28 °F being the best temperature for photosynthesis with growth rates declining when temperature exceeds 35 °C (Oosterhuis, 2002). High, above-average temperatures during the day can decrease photosynthesis and carbohydrate production (Bibi et al., 2008). Photosynthesis, respiration and stomatal conductivity will be affected by high temperatures, with a faster decline in photosynthesis than respiration and conductivity at high temperatures (Reddy et al., 1997). Brown and Oosterhuis (2010) stated that higher fluorescence under heat stress conditions indicated that plants were not as efficient at utilizing electrons as they move to a higher energy level in the light reactions of photosynthesis. Bibi et al. (2004) also indicated a decrease in fluorescence under high-temperature stress and stated that chlorophyll fluorescence was significantly decreased at temperatures of 35 °C compared to 30 °C. High temperature stress can adversely affect the physiology and subsequent productivity of cotton.

In previous research done by Bibi et al. (2008), chlorophyll fluorescence and membrane leakage were selected as the best indicators of plant response to high-

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temperature stress. This information was used to develop a technique for screening for high-temperature tolerance (Oosterhuis et al., 2009). No significant differences were found between cultivars tested in previous studies, which likely can be attributed to the plant stage or age of cotton plants measured, i.e., the plant material was too young and underdeveloped to show true, easily identifiable response to high temperature. These techniques have previously been successful with plants in later stages of development (Snider et al., 2010). This study was repeated with different cotton genotypes and plants were measured in later, more mature stages of development.

RESEARCH DESCRIPTION

A growth chamber study was conducted at the Altheimer laboratory in Northwest Arkansas at Fayetteville. Three heat sensitive cultivars, DP393, CG-3020B2RF and Pima St.Vincent, and three heat tolerant cultivars, VH260, Arkot 9704 and Pima 89590 were evaluated. Plants were initially grown in one large walk-in growth chamber (Model PGW36, Controlled Environments Ltd., Winnipeg, Canada) until first flower (about 6 weeks). The plants were then divided into two growth chambers, in order to have a control and a heat stress treatment. The temperature of the heat stress chamber was elevated to 40 °C and after 1 day and 1 week of high temperature, measurements were made at midday of fluorescence, membrane leakage and glutathione reductase. The temperature was then lowered to pre-stress levels (i.e. 32 °C) and measurements were made after 1 day and 1 week of recovery at midday of fluorescence, membrane leakage and glutathione reductase.

RESULTS AND DISCUSSION

At normal temperatures (30 °C), there was no significant difference between cultivars for membrane leakage or fluorescence; whereas after a week of high temperature (40 °C) only Arkot 9704 showed significant thermotolerance (less cell membrane leakage). The two Pima cultivars showed significantly more leakage indicating low tolerance or more sensitivity to heat stress. The recovery from heat stress measurements was disappointing as there were no significant differences between cultivars for fluorescence or membrane leakage. Contrary to our earlier studies, membrane leakage was a better and more sensitive indicator of plant response to stress than fluorescence.

PRACTICAL APPLICATION

Methods of quantifying high-temperature stress and its effects on cotton growth have been identified. A technique has been formulated to screen cotton genotypes for temperature tolerance. Entries from the Arkansas Cotton Variety

Tests and Advanced Breeding lines have been screened for temperature tolerance. The majority of the entries have not shown any temperature tolerance and have been susceptible to high-temperature stress. Brown and Oosterhuis stated in 2010 that current commercial cultivars do not appear to have significant tolerance to high temperatures. This is an ongoing project to screen available cotton germplasm for high-temperature tolerance, with the aim of improving the performance of cotton cultivars under conditions of high temperatures that are often experienced in the U.S. Cotton Belt.

ACKNOWLEDGMENTS

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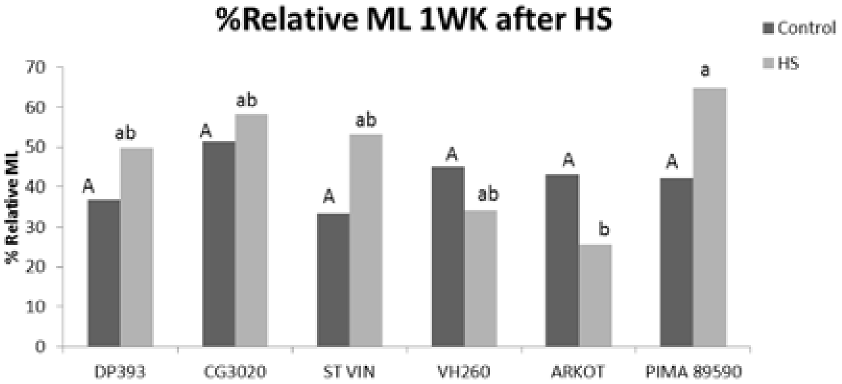

Fig. 1. Membrane leakage of six genotypes as an indication of the effect of heat stress on cell integrity. Measurements made in the control temperatures (30 °C) and in the elevated high temperature (40 °C) at one week after the start of the stress at first flower. Dark bars with the same capital letters are not significantly different (*P* = 0.05). Light bars with the same capital letters are not significantly different (*P* = 0.05).

Examining Regional Area Effects of High Temperature on the Reproductive Sensitivity for Both *Bacillus thuringiensis* (Bt) and Non-Bt Cotton Cultivars

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

RESEARCH PROBLEM

In the late 1990s Monsanto was the first company to offer a genetically modified cotton cultivar that produced a toxin from the *Bacillus thuringiensis* (Bt) bacterium. This cultivar stock, known as Bt, became the main cultivar planted in the Mississippi Delta by the year 2000. Cotton cultivars, both conventional and Bt, grown in the Mississippi Delta region of Arkansas are not immune to the negative effects that higher temperatures have upon potential yields. Cotton is most sensitive during flowering when temperatures begin to rise above 30 °C (Reddy et al., 1989; Kakani et al., 2005). Temperatures above this critical point overlap the summer season when maximums can regularly exceed 35 °C. However, research has primarily focused upon either growth chamber studies or field studies that have been extrapolated to larger areas. Information analyzing the regional effect of high temperature upon actual field cotton production in the Mississippi Delta is limited for both conventional and Bt cultivars.

BACKGROUND INFORMATION

Flowering is a sensitive reproductive development stage of cotton that can be accurately quantified from days after planting, typically beginning 60 days with the peak flowering of the crop occurring two weeks later. Increased daily temperatures can limit the fertilization efficiency of cotton limiting potential yields (Snider et al., 2009). Additionally night temperatures above 24 °C increase respiration within leaves and deplete available carbohydrate resources that would be otherwise be directed towards cotton fiber development (Loka and Oosterhuis, 2010). Measurements of high temperatures over a large regional area and its impact on actual cotton productions have been limited. Attempts have been made to use available climatic data to forecast potential yields in Alabama and Georgia. Predictions of temperatures and cotton yield were only 48% accurate for medium-range forecasts (Baigorria et al., 2010). The objective of this study was to use

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publicly available regional data for both conventional and transgenic Bt cultivars to discern the impacts that high-temperature stress may have upon yield. It was hypothesized that higher temperatures during flowering would have the greatest negative effect upon yield. Secondarily, modern genetically modified cultivars of Bt would be more sensitive during flowering than older conventional cultivars.

RESEARCH DESCRIPTION

Temperature data from 1985 through 2006 for the months of April to October were collected from the Marianna weather station in Lee County, Arkansas. Cotton yields for Lee County, were acquired from the USDA Quick Stats website (http://quickstats.nass.usda.gov/). Data collected included maximum temperature, minimum temperature, and total cotton yield in lbs/acre for both irrigated and non-irrigated cotton fields. Planting dates were provided from the Lon Mann Cotton Research Station in Marianna, Arkansas. Bt-cotton was introduced to the area in the late 1990s, but was not the dominant cultivar until the 2000 growing season.

Each daily maximum high temperature above 30 °C was assigned a value of one. T totals for the week were cataloged, with a minimum of zero and a maximum of seven values. Night temperatures above 24 °C were tallied in the same manner as the day temperatures. Growth stages used were first square, first flower, peak flower, and open boll. Each stage has an accepted growth period from planting of 35 days, 60 days, 85 days, and 120 days, respectfully. It was assumed that planting across the region would occur within one week prior and after the date planted at Lon Mann. Analysis was performed for three time periods for each growth stage, the week prior to the scheduled growth stage based upon planting date, the week of the scheduled growth stage based upon planting date, and one week after the scheduled planting date.

RESULTS AND DISCUSSION

A negative relationship was found between high temperatures and yield for the months of June, July, and August (Fig. 1). However, the strongest negative correlation of maximum temperature to cotton yield occurred in July with an R^2 of 0.363 compared to June's equivalence of 0.059, and August's R^2 of 0.026. The high R^2 value and steep negative slope of the regression line for July indicated that growth stages that occur within this month would be most affected by temperatures above optimal.

Conventional cotton did not display any significant difference across all growth stages for both irrigated and non-irrigated fields. Bt-cotton had significance for higher minimum temperatures ($P = 0.033$; Table 1) for yield loss on irrigated fields the week prior to the scheduled first squaring. Significance was also found for higher minimum temperatures on irrigated fields the week after the scheduled first squaring and the week prior to the scheduled first flower

(*P* = 0.025 and *P* = 0.002; Table 1). Irrigated Bt-cotton had no significance for any time period following the week prior the scheduled first flower. In contrast, non-irrigated Bt-cotton yields were not significant at squaring by higher minimum temperatures. But Non-irrigated fields were affected at all time periods during first flower. The week prior to the scheduled first flower, non-irrigated yields were significantly affected by high minimum temperatures (*P* = 0.001; Table 1). Non-irrigated fields were also affected by high day temperatures during both the week of the scheduled first flower and week after (*P* = 0.017 and 0.039). The strongest correlation for yield loss for both irrigated (R^2 = 0.68; Table 1) and non-irrigated (R^2 = 0.71) Bt-cotton yields was the week prior to first flower. Again, conventional cultivars did not display any significant correlations.

DISCUSSION AND PRACTICAL APPLICATION

This project demonstrated that it is possible to determine effects of temperature stress from a large regional area that corresponds to smaller growth chamber and field trials. There are critical times when a grower must be concerned about high-temperature stress and yield potential, with the most critical time period being right before flowering. This is in agreement with previous research (Reddy et al., 1989; Kakani et al., 2005). Conventional cotton is not planted to the same levels as it once was prior to 2000, however, it does indicate a greater tolerance to higher temperature stresses, both maximum and minimum, when compared to Bt cultivars.

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Table 1. Growth stage analysis for Bt-cultivars showing significance (*P* < 0.05) for susceptibility to temperature stress for both irrigated and non-irrigated cotton yields.

Time	Irrigated	Non-irrigated	R^2	P Value
First Square – Week Prior	High Minimum		0.41	0.033
First Square – Week After	High Minimum		0.44	0.025
First Flower – Week Prior	High Minimum		0.68	0.002
First Flower – Week Prior		High Minimum	0.71	0.001
First Flower – Week During		High Maximum	0.48	0.017
First Flower – Week After		High Maximum	0.39	0.039

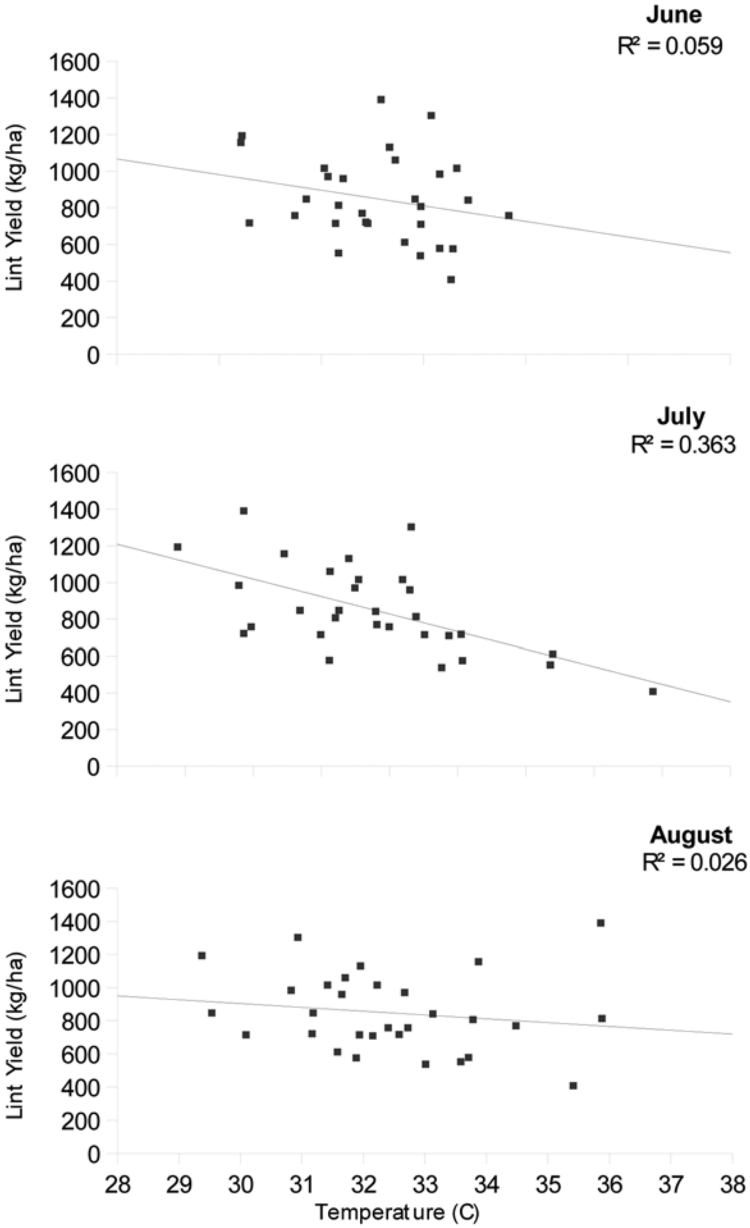

Fig. 1. Relationship between maximum high temperatures and cotton yield for June, July, and August for Lee County Arkansas. The negative correlation of June and August do not possess good coefficient R^2 values suggesting that growth stages in June and August do not have high significance. In July, the negative correlation is more pronounced, suggesting that in July cotton is more susceptible to temperature stresses.

Utilization of the Dark Green Color Index to Determine Cotton Nitrogen Status

T.B. Raper[1], D.M. Oosterhuis[1], U. Siddons[1], L.C. Purcell[1], and M. Mozaffari[2]

RESEARCH PROBLEM

Inadequate or excessive applications of fertilizer N in cotton are financially and environmentally costly. Timely in-season determination of the N nutritional status of cotton can help producers combat these negative effects; however, current methods of N determination are often time consuming and/or expensive. More instantaneous, accurate methods of determining N status, which utilize equipment already in the possession of the producer, are needed.

BACKGROUND INFORMATION

Recent work utilizing an inexpensive digital camera and image processing software to calculate the dark green color index (DGCI) has resulted in successful determination of corn and turf N status (Karcher, 2003; Rorie et al., 2011). The objective of this research was to examine the effectiveness of the DGCI derived from standard digital photographs and image-analysis software to determine the N status of cotton and to compare sensitivities of calculated DGCI from laboratory, field nadir, and field off-nadir photographs to measurements of leaf N concentrations from laboratory and chlorophyll meter determinations.

RESEARCH DESCRIPTION

The trial was planted with cotton (*Gossypium hirsutum* L.) cultivar Stoneville 4288 B2RF on 27 May 2011 at the Lon Mann Cotton Research Station near Marianna, Ark. Fertilizer N rates included 0, 30, 60, 90, 120, and 150 lb N/acre applied as urea applied in a single preplant application and incorporated to create a wide range of plant N status. Leaf sampling, chlorophyll meter readings and digital pictures were taken at the third week of flowering. Field nadir and field off-nadir (approximately 60° from nadir) pictures were taken of the canopy with an inexpensive digital camera (Canon PowerShot SD450, Lake Success, N.Y.)

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against a neutral pink color board that included yellow and green disks which served as interval color standards (Fig. 1). Two most recently matured, fully expanded leaves 4-6 nodes from the terminal were sampled and placed on ice. Chlorophyll meter (Minolta SPAD-502, Konica Minolta Sensing, Inc., Tokyo, Japan) measurements and pictures of the leaf samples were taken indoors under fluorescent lighting against a standardized color board (referred to as laboratory DGCI) within 2 hours of sampling (Fig. 2). Leaf samples were then dried and leaf N concentration of sample was determined by the Agricultural Diagnostic Laboratory at the University of Arkansas in Fayetteville, Arkansas.

Images were processed using SigmaScan Pro v. 5.0 (Systat Software, Inc., San Jose, Calif.). This software normalized each image using internal color standards prior to the calculation of DGCI. A full description of the DGCI calculation used can be found by Rorie et al. (2011). Images were manually cropped and cleaned to eliminate noise in analysis. Linear regressions of the replicate data examining the relationships between DGCI measurements (field nadir, field off-nadir, and laboratory), SPAD readings, and leaf N concentrations were performed in JMP 9 (SAS Institute Inc., Cary, N.C.).

RESULTS AND DISCUSSION

Visible differences in N status due to treatment were noted at sampling; cotton receiving 0 lb N/acre appeared stunted and yellow in color, while cotton receiving 150 lb N/acre appeared much larger and dark green in color (Fig. 1). The regressed replicate data indicated the response of leaf N concentration to fertilizer N rate was significant, positive and linear ($r^2 = 0.55$, data not shown) and measured leaf N values reached and exceeded published critical values (Bell et al., 2003).

Field nadir and off-nadir DGCI readings did not correlate as strongly to leaf N as laboratory DGCI readings (Fig. 2). The laboratory DGCI readings were also slightly more sensitive to leaf N ($r^2 = 0.603$) than SPAD readings were to leaf N ($r^2 = 0.561$, not shown). Coefficients of determination with leaf N ranged from 0.44 for the nadir DGCI readings to 0.603 for the laboratory DGCI readings. Stronger relationships between laboratory DGCI readings and leaf N than between all other methods may be due to the laboratory method's inclusion of all plant material used to determine leaf N concentration. In contrast, the SPAD meter measured only a portion of each leaf and the field nadir and off-nadir methods included upper canopy plant material which was not in the leaf N measurement.

The relationship between nadir laboratory DGCI readings and SPAD readings was strong (Fig. 2). This strong relationship is logical, as both measurements are conducted on the same tissue. Failure of the field nadir and off-nadir DGCI readings to correlate as strongly with SPAD readings is again most likely due to the inclusion of tissue in the field images that was not actually sampled by the SPAD meter. However, the relationship between SPAD readings and field off-nadir DGCI readings was also quite strong ($r^2 = 0.818$). These results suggest that field off-nadir images may be the most practical method for in-field determination of cotton N status since the relationship between laboratory DGCI readings and SPAD readings was only slightly higher but consisted of leaf sampling, storing, transportation, and more required time than other methods. The full article can be found in Raper et al. (2012).

PRACTICAL APPLICATION

Initial results indicate digital image analysis as a practical and inexpensive method sensitive to cotton N status which could possibly replace chlorophyll meters. Although laboratory images are the most sensitive to changes in leaf N and SPAD readings, field off-nadir images seem to be the most practical method of cotton N status determination for the producer since it requires no destructive sampling and much less time. Further research across years and sites is necessary to establish critical DGCI values for cotton and streamline the image processing. An effective extension program could be easily set up to allow producers to email or picture message off-nadir images of the crop of interest with a standardized color board for instantaneous determination of cotton N status.

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Fig. 1. Field off-nadir images of plots recieving 150 lb N/acre (left) and 0 lb N/acre (right) with standardized color board in the background. Standardized color board consists of a dark green and yellow color chip on a neutral pink background to allow the normalization of each image during analysis. The high N rate treatment was taller and visibly darker green than the 0 lb N/acre treatment.

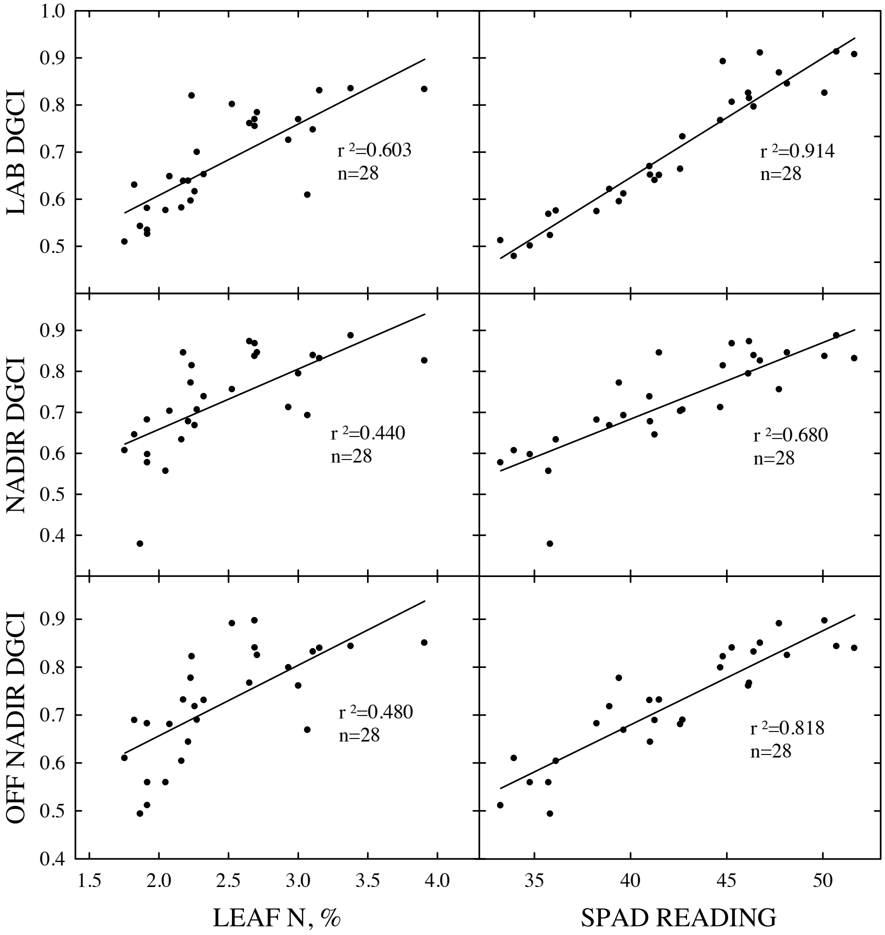

Fig. 2. Simple linear regression and coefficients of determination between laboratory DGCI, field nadir DGCI, field off-nadir DGCI and leaf N or SPAD readings during 2011 at the third week of flowering near Marianna, Arkansas.

Effect of Foliar Application of Urea with N-(n-butyl) thiophosphoric triamide (NBPT) on the Yield of Cotton

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

RESEARCH PROBLEM

Foliar fertilization with nitrogen (N) is used to supplement soil N application in order to meet the high N requirements of crops (Oosterhuis and Weir, 2010). Urea is the most common foliar N source in cotton, due to its relatively low toxicity, quick absorption, and low cost (Maples and Baker, 1993; McConnell et al., 1998; Oosterhuis and Bondada, 2001). However, in the literature reports of yield, increments with foliar urea application are not consistent. The general objective of this research was to determine the effect of addition of N-(n-butyl) thiophosphoric triamide (NBPT) to foliar urea to improve urea absorption and cotton yields.

BACKGROUND INFORMATION

Foliar application of N has the advantages of low cost and rapid plant response, and the disadvantages of possible foliar burn, incompatibility problems with other chemicals and limitations on the amount of nutrient that can be applied (Oosterhuis and Weir, 2010). Maples and Baker (1993) conducted a number of experiments with supplemental foliar N applications and reported that the results varied according to the location, due mainly to differences in soil characteristics. The studies of Oosterhuis and Bondada (2001) showed that the results of foliar fertilization in cotton may vary depending on the size of boll load, such that cotton plants with high boll loads exhibited significantly higher cotton yields in treatments that received foliar N.

Once foliar applied urea is absorbed by the leaves, it is converted to ammonia, by the enzyme urease (Sirko and Brodzik, 2000), and ammonia is incorporated into glutamate by the enzyme glutamine synthetase (Blevins, 1989). The use of a urease inhibitor with foliar urea application can be an effective method to help study the fate of urea in cotton leaves. The compound NBPT is the urease inhibitor most commonly used in agriculture. The objectives of this research were to study foliar urea assimilation in cotton and to test the effect of the urease inhibitor NBPT in cotton foliar urea application. Only the yield results are presented in this report.

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RESEARCH DESCRIPTION

Field experiments were conducted in 2009, 2010, and 2011 at the University of Arkansas Lon Mann Cotton Branch Station at Marianna, Ark. The experiment was uniformly fertilized following preseason soil tests and state recommended rates, except for N, which was applied according to the treatments. Treatments consisted of: (A) full recommended N soil rate with no foliar N application, (B) 75% of recommended N soil rate with no foliar application, (C) 75% of recommended N soil rate with two foliar urea applications (at first flower and two weeks later), and (D) 75% of recommended N soil rate with two foliar urea plus NBPT applications (at first flower and two weeks later). Each foliar urea application was calculated to supply 11.2 kg of N per hectare. The treatment with urea plus NBPT was applied using the commercial fertilizer Agrotain. The experimental unit consisted of a plot with 4 rows spaced 0.96 m apart and 15 m in length. Measurement of seedcotton yield was collected from the two middle rows using a mechanical harvester.

RESULTS AND DISCUSSION

In the 2009 there was a significant treatment effect, with the treatments 100% N Soil-No Foliar and 75% N Soil-Urea+NBPT-Foliar exhibiting the highest yields (Table 1). A significant difference was observed between the treatments 75% N Soil–Urea Foliar and 75% N Soil–Urea+NBPT-Foliar. In 2010 and 2011, the treatment effect on seedcotton yield was not significant (Table 1). Differences were expected between the treatments 100% N Soil-No Foliar and 75% N Soil-No Urea Foliar, but the comparison was not significant at $P = 0.05$.

A related growth chamber study (Kawakami, 2010) showed that the addition of NBPT to foliar urea application decreased urease activity and it showed a trend for increasing leaf urea content. In the field studies, significant seedcotton yield improvements were observed with addition of NBPT to foliar urea in 2009 but not in 2010 and 2011. The overall mean of the three years showed a trend for the addition of NBPT to foliar urea to improve cotton yield, however, the results were not conclusive and the study would need to be continued.

PRACTICAL APPLICATION

The addition of NBPT to foliar urea fertilizer was effective in inhibiting cotton leaf urease; however, in this study, we were not able to confirm the positive effect of NBPT on cotton yields. On the otherhand, no negative effect of NBPT addition to foliar urea was observed, thus the use of Agrotain (urea + NBPT) can be safely used as a source of foliar N in cotton.

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Table 1. Effect of foliar treatments on seedcotton yield of field-grown cotton in 2009, 2010, and 2011.

Treatment	2009	2010	2011	Mean
100% soil, no foliar	2010 a[1]	2390 a	1821 a	2073
75% soil, no foliar	1660 b	2700 a	1694 a	2018
75% soil, plus foliar	1776 b	2890 a	1749 a	2138
75% soil, plus foliar, plus NBPT	1997 a	2760 a	1795 a	2184

[1] Means in a column followed by the same letter are not significantly different ($P = 0.05$).

Effect of Water-Deficit Stress on Polyamine Metabolism of Cotton Flower and Their Subtending Leaf

D.A. Loka, D.M. Oosterhuis, and C. Pilon[1]

RESEARCH PROBLEM

Water-deficit stress is a major abiotic factor limiting more than a third of the arable land around the world. Polyamines are endogenous plant growth promoters that affect a variety of physiological and metabolic functions. Research in other crops has indicated a relationship between changes in polyamine metabolism and drought tolerance. However, no information exist on polyamine metabolism of cotton under conditions of limited water supply. In this study it was hypothesized that limited water supply would significantly affect cotton polyamine metabolism resulting in changes in their concentrations.

BACKGROUND INFORMATION

Polyamines (PA) are low-molecular-weight organic polycations with two or more primary amino groups $-NH_2$ and they are present in bacteria, plants and animals. In plants, the diamine putrescine (PUT) and its derivatives, the triamine spermidine (SPD) and the tetramine spermine (SPM) are the most common polyamines and they have been reported to be implicated in a variety of plant metabolic and physiological functions (Kakkar et al., 2000). Additionally, PAs play a significant role in flower induction (Bouchereau et al., 1999) along with flower initiation (Kaur-Sawhney et al., 1988), pollination (Falasca et al., 2010), fruit growth and ripening (Kakkar and Rai, 1993). Furthermore, research in other crops has indicated that changes in PA concentrations is a common plant response to a variety of abiotic stresses, including salinity, high or low temperatures, and drought, as well as biotic stresses (Boucehereau et al., 1999).

Water deficit is a major abiotic factor limiting plant growth and crop productivity around the world (Boyer, 1982). Cotton (*Gossypium hirsutum* L.) is considered to be relatively tolerant to drought, i.e. by osmotic adjustment (Oosterhuis and Wullschleger 1987). Since projections anticipate that water-stress episodes are going to intensify in the future due to increased greenhouse gas concentrations, tools to help with selection of drought-tolerant genotypes are greatly need-

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ed. Polyamine metabolism is an enticing target; however, despite the extensive research on other crops, limited information on PA metabolism exists for cotton with the only reports being on the distribution of polyamines in the cotton plant (Bibi et al., 2011), polyamine content just prior to rapid fiber elongation (Davidonis, 1995), the effect of heat stress on PAs (Bibi et al., 2010), and the occurrences of uncommon polyamines (norspermidine, norspermine, pentamine, and hexamine) (Kuehn, et al., 1990).

The purpose of this study was to investigate the changes in PA concentrations in first day flower ovaries and their subtending leaves under conditions of water-deficit stress by using two cultivars differing in drought tolerance in order to determine whether PAs are involved in drought tolerance.

RESEARCH DESCRIPTION

Growth chamber studies were conducted in 2009-2010 in the Altheimer laboratory of the University of Arkansas in Fayetteville. Cotton (*Gossypium hirsutum* L.) cultivars ST5288B2F (drought-sensitive) and Siokra L23 (drought-tolerant) were planted into 1-L pots containing a horticultural mix (Sun-Gro horticulture mix). The growth chambers were set for normal conditions of 30/20°C (day/night), ±60% relative humidity, and 14 h photoperiod, while half-strength Hoagland's nutrient solution was applied daily in order to maintain adequate nutrients and water. Irrigation was withheld at flowering (approximately 8 weeks after planting) until plants were visually wilted after which water stressed plants received 50% of their daily use of water for ten days. Plants were arranged in a completely randomized block design with 15 replications and the experimental design was a 2 × 2 factorial with the main effects being water-deficit stress and cultivar, with 15 replications in each treatment. Treatments consisted of: 1) ST5288 and Siokra L23 control, where optimum quantity of water was applied throughout the duration of experiment, and 2) ST5288 and Siokra L23 water-stressed, where 50% of daily water use was applied. Measurements of leaf stomatal conductance were taken daily between 11:00 a.m.-1:00 p.m. from the fourth main-stem leaf from each plant using a leaf porometer Decagon SC-1 (Decagon Devices, Inc., Pullman, Wash.). Photosynthetic rates were measured the first and fourth day after spraying, between 11:00 a.m.-1:00 p.m. from the fourth main-stem leaf from each plant using the LI-COR 6200 gas analyzer (LI-COR Biosciences, Lincoln, Neb.) Polyamine content was estimated from white flowers (ovaries) and their subtending leaves that were collected when available from all four treatments. Polyamine analysis was done according to Flores and Galston (1984) with modifications.

RESULTS AND DISCUSSION

Water-deficit stress significantly decreased both ST5288 B2F and Siokra L23 stomatal conductance rates compared to the control (Fig.1). Interestingly, well-watered Siokra L23 had significantly lower stomatal conductance rates compared to well-watered ST 5288. Limited supply of water had a similar effect on photosynthesis, with photosynthetic rates of water-stressed plants of both cultivars being significantly lower compared to control, while water-stressed Siokra L23 had significantly lower photosynthetic rates compared to water-stressed ST 5288 (Fig. 2). Regarding polyamine metabolism, the results of our study (Table 1) indicated that polyamines in cotton accumulate in higher concentrations in the reproductive structures compared to the vegetative tissues. Total polyamine concentrations were not shown to be affected significantly by water-deficit stress conditions however the opposite was observed when each polyamine concentration was analyzed individually. Diamine putrescine was shown to significantly affect stomatal function in cotton, with increasing concentrations inducing stomatal closure. Triamine spermidine levels on the other hand remained unaffected, suggesting that SPD does not play a significant role in cotton defense mechanism under conditions of water-deficit stress. Conversely, SPM levels significantly affected photosynthetic rates since decreases in its concentration resulted in significantly lower photosynthetic rates.

PRACTICAL APPLICATION

Polyamine metabolism of cotton reproductive ovaries and their subtending leaves appeared to be significantly affected by water-deficit stress. In addition, changes in polyamine concentrations appeared to affect physiological functions such as photosynthesis and stomatal conductance. We speculate that polyamines play an important role in cotton protection under adverse environmental conditions and changes in their concentrations, especially PUT and SPM, could be used as potential markers for selection of drought-tolerant cultivars.

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Table 1. Effect of water-deficit stress on polyamine concentrations of subtending leaf and ovary.

	LEAF				OVARY			
	ST 5288		SIOKRA L23		ST 5288		SIOKRA L23	
Treatment	**Control**	**WS**	**Control**	**WS**	**Control**	**WS**	**Control**	**WS**
	nmole/gFW							
Total PA	276.82a[1]	313.5 a	270.7 a	248.9 a	731.9 b	933.5 a	685.5 b	674.2 b
Putrescine	23.8 b	61.2 a	55.1 ab	63.2 a	146.2 a	242.5 b	107.9 a	155.9 a
Spermidine	146.6 a	141.7 a	119.2 a	125.9 a	351.4 ab	418.6 a	336.5 b	334.4 b
Spermine	106.3 a	110.7 a	96.2 a	59.71 b	234.2 ab	272.3 a	241 ab	183.9 b

[1] Numbers within a column followed by the same letter are not significantly different ($P = 0.05$).

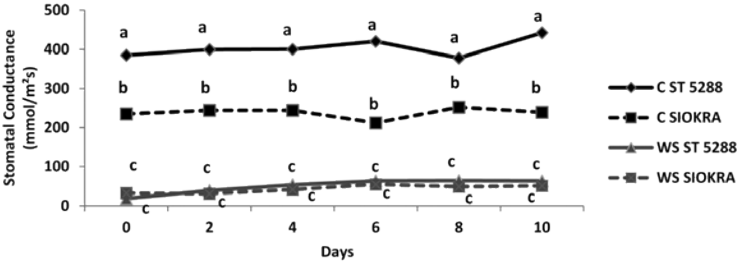

Fig. 1. Effect of water-deficit stress on stomatal conductance rates of ST 5288 and Siokra L23. Points within a sampling day with the same letter are not significantly different (P = 0.05).

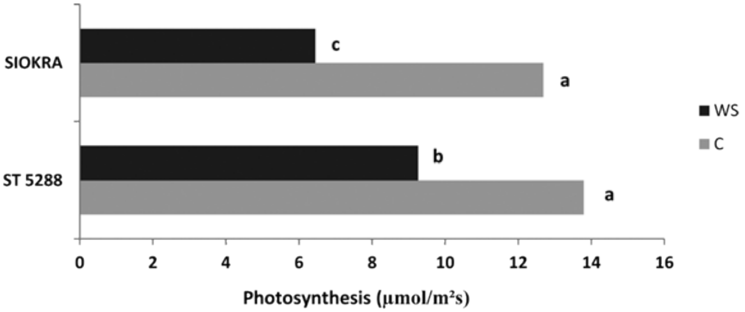

Fig. 2. Effect of water-deficit stress on photosynthetic rates of ST5288 and Siokra L23. Bars with the same letter are not significantly different (P = 0.05).

Effect of 1-Methylcyclopropene on Lint Yield of Field-Grown Cotton

J.B. Phillips, D.M. Oosterhuis, and E.M. Kawakami[1]

RESEARCH PROBLEM

One of the main problems in cotton production is the extreme year-to-year variability in yield (Lewis et al., 2000), which is a major concern to cotton farmers and the industry in general. Variability in cotton yield is associated with many factors and temperature appears to play a major role. High temperatures limit growth and development processes in much of the cotton producing areas (Reddy et al., 2002). Cotton has been shown to be particularly sensitive to high temperature stress during flowering (Snider et al., 2011). When plants are under stress they increase the production of the plant hormone ethylene, which is a stress hormone known for its role in the regulation of fruit abscission processes (Guinn, 1982). The current project was designed to evaluate the effectiveness of 1-MCP to counteract the effects of stress and maintain fruit and seed numbers for increased yield. As a result, higher and less variable yields could be achieved without undue changes in management and production costs.

BACKGROUND INFORMATION

1-Methylcyclopropene is a plant growth regulator that works by occupying the ethylene receptors of plants and thereby inhibiting ethylene from binding and initiating a response such as abscission or senescence (Sisler and Serek, 1997). The affinity of 1-MCP for the ethylene receptor sites is 10 times greater than that of ethylene. 1-MCP has been shown to prevent and delay abscission in both citrus and cherry tomatoes (Beno-Moualem et al., 2004). It has been reported that a 1-MCP application on field-grown cotton increased the yield (Kawakami et al., 2006). The objective of this study was to evaluate the effectiveness of 1-MCP to counteract the effects of high temperature stress during flowering and maintain fruit and seed numbers for increased yield on field-grown cotton.

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RESEARCH DESCRIPTION

Field studies were conducted at the University of Arkansas Lon Mann Cotton Research Station in Marianna, Ark., and also at the Arkansas Agricultural Research and Extension Center in Fayetteville, Ark. Both experiments were planted with cotton (*Gossypium hirsutum* L.) cultivar ST4288B2F. Weed and pest management were performed according to state recommendations.

The field study at the Marianna location was arranged in a completely randomized block design with five replications. The plot size was four rows, 15 m in length. The trial was furrow irrigated as needed and fertilized according to recommended practices for cotton. Treatments consisted of: (T1) Untreated control; (T2) 1-MCP at 10g ai/ha applied at first flower (FF) and again one week after first flower; (T3) 1-MCP at 10g ai/ha applied at one and two weeks after first flower; (T4) 1-MCP at 10g ai/ha applied at two and three weeks after first flower; and (T5) 1-MCP at 10g ai/ha applied when temperatures were predicted to exceed 95 ^{o}F for three consecutive days or more after first flower. All 1-MCP treatments were sprayed with a backpack CO_2 sprayer calibrated at 20 gal/acre. The lint yield per hectare was calculated from machine picked individual plots.

The field study at the Fayetteville location was arranged in a completely randomized block design with five replications. The trial consisted of two planting dates at two weeks apart to ensure higher temperatures at the same main-stem nodal position in the second planting. The plot size was four rows, 6 m in length. The trial was furrow irrigated as needed and fertilized according to recommended practices for cotton. Treatments consisted of: (T1) Untreated control; (T2) 1-MCP at 10g ai/ha applied at first flower. All 1-MCP treatments were sprayed with a backpack CO_2 sprayer calibrated to 20 gal/acre. The lint yield per hectare was calculated from a one-meter length of row hand-picked for each plot.

RESULTS AND DISCUSSION

In the Marianna field study there was no significant effect of the 1-MCP application times (Fig. 1). The lack of effect on yield was surprising as we expected positive effects with the later applications of 1-MCP or an application when temperatures exceeded 95 ^{o}F, however the results indicated no significant effect.

The Fayetteville field study was successful in achieving high temperatures during peak flowering for both the first and second planting dates and there was a significant effect of the 1-MCP application on yield for the first planting date (Fig. 2). There was a 15% to 33% yield increase with 1-MCP application applied at first flower. Average temperatures for 4 days after 1-MCP application were 99 ^{o}F and 104 ^{o}F for the first and second planting date, respectively. Previous research has shown that temperatures above 95 ^{o}F cause significant decreases in photosynthesis (Bibi et al., 2008) and reproductive success (Snider et al., 2011). The yield increases were attributed to improved pollen tube growth and successful fertilization of the ovules (Snider et al., 2009).

PRACTICAL APPLICATION

In conclusion, 1-MCP had a significant effect on the yield of field-grown cotton in Fayetteville but not in Marianna. These results indicate that 1-MCP has the potential to increase yield, and the data suggest that applications of 1-MCP applied to high-temperature stressed cotton during the flowering period has a positive effect on yield.

ACKNOWLEDGMENTS

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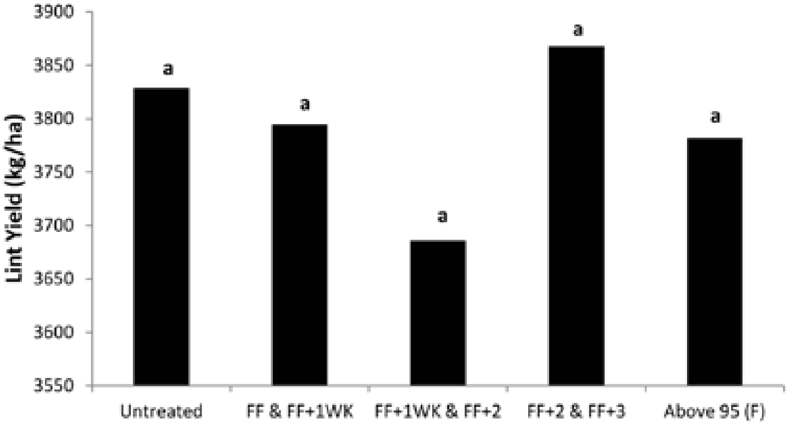

Fig. 1. Machine picked lint yield in the Marianna field study. Columns with the same letters are not significantly different at the α = 0.05 level.

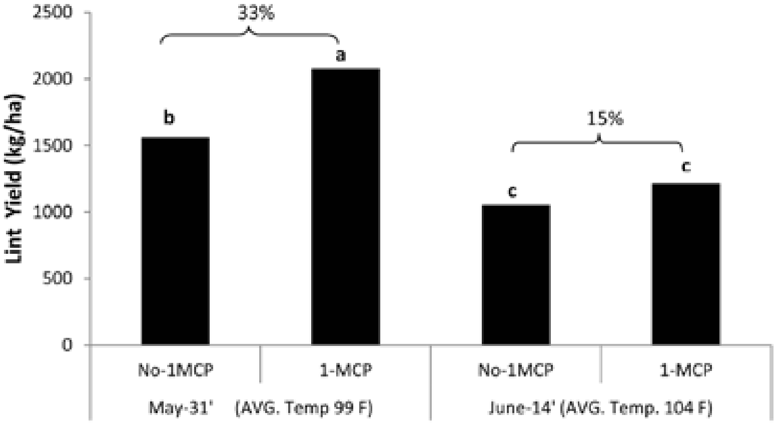

Fig. 2. Lint yield of 1-MCP treatments in Fayetteville, Ark. for two planting dates. The 1-MCP was foliar applied at first flower in each planting date. The percent increase for each treatment compared to the untreated control is shown. Average temperatures for 4 days after 1-MCP application were 99 °F for the first planting date and 104 °F for the second. Columns with the same letters are not significantly different at the α = 0.05 level.

Cotton Response to Irrigation Timing and Use of Enhanced Efficiency Nitrogen Fertilizer and Biosolids – Year II

T.G. Teague[1], C. Rothrock[2], and C. Shumway[1]

RESEARCH PROBLEM

Water-deficit stress in cotton during the critical interval between early squaring and first flower can result in late season crop delay and substantial reductions in yield and profit. Every fruiting form that will produce a harvestable boll generally is already on the plant by the time of first flower; root growth essentially is complete as well. Plant structure at first flower—total fruiting forms, nodes, leaf area, roots, etc.—are reduced if plants are subjected to significant pre-flower water-deficit stress. Water deficits also impact nutrient availability—N fertilizer is limited if soil water is limited. Good management decisions for these two important production inputs—irrigation and N fertilization—are critical to an efficient production system where the goal is early and high yields.

BACKGROUND INFORMATION

Timing irrigation initiation in cotton to avoid pre-flower water-deficit stress has been shown to improve earliness and increase cotton yields in Arkansas (Teague, 2009-11). In this second year of a planned three-year field study (see Teague and Shumway, 2011 for first year results), we compared cotton plant response to different N fertilizer types in cotton grown with no irrigation, full season irrigation, or delayed start irrigation that followed pre-flower water deficits. We evaluated crop growth and compensation capacity following stress or early irrigation and examined N fertilizer effects on crop maturity and lint quality. Additional objectives included assessments of irrigation on early season root development and utility of crop and soil moisture monitoring techniques to quantify water deficits and plant response to irrigation.

RESEARCH DESCRIPTION

The field study, carried out at the Judd Hill Research Farm near Trumann, Arkansas was designed as a 3 × 4 factorial experiment with irrigation timing (3

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[2] Professor, Department of Plant Pathology, Fayetteville.

factors) and N fertilizer (4 factors) arranged in a split plot with irrigation considered main plots. Furrow irrigation was initiated either just prior to the 1st week of squaring (early start) or was delayed 3 additional weeks until first flower (delayed start) (Table 1). A non-irrigated control (rainfed) was included. Fertilizer was applied prior to planting at 100 lb N/acre either as urea, urea + 300 lb/acre biosolids (trade name Top Choice Organic), or polymer coated urea (trade name ESN). Top Choice is a 4-3-0 biosolids soil amendment available from Top Choice Organic (Poinsett Fertilizer, Trumann, Ark.). ESN is a controlled release fertilizer from Agrium, Inc. (Denver, Colo.). An unfertilized control (0 N) also was included. Plot location was the same as in 2010 (Teague, 2011). Fertilizers were broadcast by hand and incorporated using disk bedders on 6 May. Beds were flattened at planting with a DO-All. Cruiser treated (thiamethoxam) cotton (*Gossypium hirsutum* L.) seed of cultivar Deltapine 0912 B2RF was seeded on 11 May in the Dundee silt loam soil at 3 to 4 seeds/ft on raised beds (38-inch row spacing). Production practices were similar across all treatments in-season including insect and weed control, plant growth regulator application and defoliation; only irrigation start timing and N fertilizer inputs were varied for the study. Weekly irrigation was applied using polyethylene irrigation tubing (poly pipe) for furrow irrigation. Water was delivered to every row middle in appropriate main plots. Irrigation timing dates are listed in Table 1. The late start date corresponded to the furrow irrigation start date of the commercial farmer on the surrounding Judd Hill Foundation farm and is a typical start time (= lay by) for many cotton producers in Arkansas. Soil water potential across irrigation treatments was monitored using Watermark sensors (Irrometer Co., Inc., Riverside, Calif.)). Sensors were installed in each irrigation main plot across the upper third of the experiment ca 70 ft from the irrigation source. The sensors were installed directly in the center of the crop bed between plants. There were 3 sensors at each monitoring site—two at 8 inches and one at 16 inches (Fig. 1). Sensors were attached to Hansen AM 400 data loggers (M.K. Hansen Co., Wenatchee, Wash.).

To evaluate early-season seedling root and above ground biomass, 25 plants were collected on 14 June, 34 days after planting (DAP). Plants complete with roots were selected and dug from arbitrary one-foot sections of row from plots in each tillage treatment in N treatment 1 subplots (at-planting urea). Plants were weighed for fresh weight, and the number of nodes for 5 seedlings recorded. Seedling disease pressure was assessed. Root systems also were scanned using the WinRHIZO software (Quebec, Canada). The COTMAN crop monitoring system (Oosterhuis and Bourland, 2008) was used to document differences in crop development among irrigation and fertilizer treatments from squaring until physiological cutout. Weekly insect sampling using drop cloths confirmed efficacy of insect pest control. End-of-season season plant mapping was performed using the COTMAP procedure (Bourland and Watson, 1990).

Applications of defoliants and boll openers were made 120 DAP on 8 and 16 Sept. Following defoliation, 50 handpicked boll samples were collected, ginned and submitted for HVI fiber quality determinations. Yields were determined using a 2-row research cotton picker which was used to harvest two center rows per plot.

Plots were harvested 28 Sept (140 DAP). A second picking was made 11 October to evaluate contribution of late season upper canopy bolls to total yield. Data were analyzed using ANOVA with mean separation using protected LSD.

RESULTS AND DISCUSSION

The hot and dry conditions that characterized the 2011 season provided a good opportunity to evaluate the impact of very early irrigation on plant development. Plant collections for root evaluations were made at 34 DAP on 14 June after the early start irrigation treatments had received two irrigations. Size and weight of plant tops and roots were positively affected by early start of irrigation (Table 2). Results showed that average root diameter was greater for the early irrigated plants compared to plants not receiving irrigation (Table 3). In addition, with the early irrigated plants, there was a numerical trend for greater surface area and greater root volume. Seedling disease ratings did not differ among irrigation treatments. Nitrogen fertilizer treatments did not influence early season growth, root development, or disease severity, and there was no N × irrigation interaction. Isolation of *Fusarium* spp. from cotton seedlings was increased for the urea treatment compared to the unfertilized check.

Results from plant monitoring with COTMAN showed significant differences in pace of pre-flower nodal development among plants in the different irrigation and N fertilizer treatments (Fig. 1). If a crop follows the COTMAN target development (standard curve), there should be 10.25 total main-stem sympodial nodes by the time of occurrence of first flowers (= 1 boll node + 9.25 squaring nodes). In 2011, with high temperatures in June, we observed first flowers by 55 DAP. In that first week of flowering the mean number of squaring nodes was less than the expected 9.25 target value for COTMAN in all treatments, and there were significant differences among irrigation treatments. Plants that were fertilized and that had received early irrigation produced a greater number of main stem squaring nodes by first flowers (8.3 nodes) compared to fertilized plants in delayed irrigation or rainfed treatments (7.3 and 6.1 squaring nodes, respectively) ($P = 0.007$; $\text{LSD}_{(0.05)} = 0.78$). Growth curves for unfertilized plants grown with early irrigation produced fewer mean no. squaring nodes by first flowers compared to fertilized plants. Unfertilized plants reached physiological cutout nodes above white flower (NAWF) = 5 earlier than fertilized plants. Differences in pace of pre-flower nodal development among the different N fertilizer treatments were not apparent in rainfed treatments. Soil N from fertilizer applications likely was not as available to those plants because of reduced soil moisture.

Water potential data from soil moisture sensors indicate that the weekly irrigation schedule was sufficient to keep soil water at 8 inches from reaching levels below -35kPa in early June (a common trigger for scheduling irrigation); but the schedule appeared to be insufficient by 24 June after the plants reached the third week of squaring (44 DAP)—1 wk prior to appearance of first flowers (Fig. 2). Slopes of the COTMAN growth curves were reduced relative to the standard curve in both irrigation timing treatments as soil water potential was reduced.

Significant fertilizer and irrigation effects on final plant structure were measured in final, end-of-season plant mapping using COTMAP. For N fertilizer effects, no differences in plant structure measurements were observed among treatments that received fertilizer; however, plants in the unfertilized check were shorter, produced fewer sympodia and monopodia, and had a lower value for highest sympodia with 2 positions (data not shown). Fewest total bolls per plant were noted in the untreated check; this treatment also had significantly fewer effective sympodia. For irrigation main effects, rainfed plants were shorter with fewer total main stem sympodia and bolls (Table 4). Small boll shed, documented in-season using COTMAN (data not shown), was evident in COTMAP results for boll retention categories. Highest levels of early boll retention (first and second position bolls on lower mainstem sympodia) were observed for early start irrigation. Plants with late start irrigation produced more sympodia per plant compared to rainfed plants or plants receiving early irrigation.

Irrigation and irrigation timing significantly affected lint yield ($P = 0.001$). Fertilized treatments outperformed non-fertilized checks; however, there were no significant differences in yield among fertilizer sources (Fig. 3). N fertilizer and Irrigation × N were significant at $P = 0.06$ and $P = 0.07$, respectively, if data from unfertilized checks were included in the analysis. If yield data from unfertilized checks were not included in the statistical analysis, the N and N*I were not significant ($P > 0.80$). After the first picking, mean yield from fertilized irrigation main plots were lowest for the rainfed cotton, 626 lb/acre. Mean yields were 1057 lb/acre in fertilized, delayed irrigation main plots, an increase of 41% over rainfed cotton. With an early irrigation start time, yields were 1393 lb/acre, an additional 24% increase over late start irrigation. There were upper canopy bolls produced in late season which did not mature sufficiently to open by first picking. When a second harvest was made on 11 October, mean yields were increased an additional 0, 59 and 96 lb/acre for the rainfed, early start and delayed start treatments, respectively (data not shown). Fiber quality was impacted significantly by irrigation. Length, uniformity and strength were reduced in rainfed compared to irrigated cotton (Table 5). No fiber quality differences were noted in response to N treatments.

PRACTICAL APPLICATIONS

Fertilized cotton produced significantly higher yields than the unfertilized control; however, N fertilizer type had no significant impact on lint yield or quality. Irrigation affected early-season root growth—plants that received early irrigation produced bigger more extensive roots than non-irrigated plants. Plants receiving early irrigation also produced more main stem sympodial branches by first flowers; this is an important indicator of yield potential. Early irrigated plants produced highest yields and higher quality fiber. For high and early yields, irrigation should be timed to avoid pre-flower stress *not* as a reaction to stress.

Results from this study indicate that in irrigated Midsouth cotton production, pre-flower water stress avoidance should be a crop management priority for producers aiming for high and early yields. In-season crop and soil moisture monitoring will aid in research and implementation of innovative new technologies such as slow release fertilizers and soil amendments. Ultimately, these will benefit cotton production as well as help protect the environment and lead to a more sustainable cotton system. This study will be repeated in 2012 with expanded evaluations of irrigation and fertilizer effects on farm profit and measures of environmental impact.

ACKNOWLEDGMENTS

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Table 1. Irrigation timing dates for early start and delayed start irrigation timing for 2011 Judd Hill irrigation timing.*N source field trial.

Irrigation Timing	Date of irrigation	Days after planting (DAP)
Early Start	3, 10, 16, 24 June; 1, 8, 13, 20, 27 July; 3, 11 Aug	23, 30, 36, 44
Delayed Start	1, 8, 13, 20, 27 July; 3, 11 Aug	51, 58, 63, 70, 77, 84, 92, 100

Table 2. Effect of irrigation and N fertilizer on early season cotton seedling growth and diseases, Judd Hill 2011.

					----------Percent isolation----------				
Treatment	**Shoot wt.(g)**	**Root wt (g)**	**Hypotcotyl disease rating**	**Root disease rating**	***Rhizoctonia solani***	***Binucleate Rhizoctonia spp.***	***Pythium* spp.**	***Fusarium spp.***	***Thielaviopsis basicola***
Irrigation									
Early start	13.18 a[1]	1.39 a	2.0 a	13.4 a	22.0 a	18.0 a	37.3 a	85.3 a	0.0 a
Delayed/Rainfed	7.43 b	0.82 b	2.0 a	13.4 a	5.3 a	6.0 b	31.3 a	91.3 a	0.7 a
N Fertilizer									
Urea	10.88 a	1.16 a	2.0 a	16.4 a	19.3 a	6.7 a	28.0 a	94.7 a	0.0 a
Untreated	9.73 a	1.05 a	2.0 a	10.4 a	8.0 a	17.3 a	40.7 a	82.0 b	0.7 a
Pr > F									
Irrigation	*0.01*	*0.01*	*0.67*	*0.98*	*0.14*	*<.0001*	*0.62*	*0.36*	*0.42*
N Fertilizer	*0.24*	*0.28*	*0.10*	*0.12*	*0.12*	*0.08*	*0.26*	*0.02*	*0.37*
*Irrigation * N Fert.*	*0.51*	*0.46*	*0.52*	*0.98*	*0.21*	*0.21*	*0.66*	*0.37*	*0.37*

[1] Numbers in a column followed by the same letter are not significantly different ($P = 0.05$).

Table 3. Effect of irrigation and N fertilizer on early season cotton root development, Judd Hill 2011.

Treatment	Root length (cm)	Root surface area (cm^2)	Average root diameter (mm)	Root volume (cm^3)	Root tips	Root links	Altitude	External path length
Irrigation								
Early start	46.1 a[1]	18.6 a	1.34 a	0.62 a	38.1 a	101.9 a	15.6 a	163.8 a
Delayed/Rainfed	40.5 a	13.4 a	1.13 b	0.38 a	54.2 a	86.2 a	13.5 a	125.4 a
N Fertilizer								
Urea	45.3 a	16.6 a	1.22 a	0.51 a	46.8 a	115.0 a	15.7 a	162.4 a
Untreated	41.3 a	15.5 a	1.25 a	0.49 a	45.5 a	73.1 a	13.4 a	126.7 a
Pr > F								
Irrigation	*0.10*	*0.09*	*0.05*	*0.08*	*0.12*	*0.67*	*0.45*	*0.38*
N Fertilizer	*0.26*	*0.18*	*0.78*	*0.84*	*0.84*	*0.14*	*0.21*	*0.29*
*Irrigation * N Fert.*	*0.56*	*0.99*	*0.61*	*0. 70*	*0.63*	*0.57*	*0.51*	*0.47*

[1] Numbers in a column followed by the same letter are not significantly different ($P = 0.05$).

Table 4. Results from final end-of-season plant mapping using COTMAP for irrigation timing main plot effects, Judd Hill 2011[1].

Category	Mean per plant for irrigation treatment				
	Early Start	Delayed Start	Rainfed	*P > F*	*LSD_{05}*
1st Sympodial Node	6.8	6.6	6.8	*0.16*	
No. Monopodia	2.1	2.0	2.1	*0.82*	
Highest Sympodia with 2 nodes	10.0	12.7	8.1	*0.0004*	*0.89*
Plant Height (inches)	36.9	37.3	23.7	*0.0006*	*3.37*
No. Effective Sympodia	8.0	8.5	3.7	*0.0004*	*1.05*
No. Sympodia	14.1	17.4	12.3	*0.0005*	*1.09*
No. Symp. with 1st Position Bolls	4.8	3.7	2.8	*0.002*	*0.58*
No. Symp. with 2nd Position Bolls	0.9	1.3	0.2	*0.01*	*0.50*
No. Symp. with 1st & 2nd Bolls	0.5	0.7	0.2	*0.03*	*0.29*
Total Bolls/Plant	7.1	7.0	4.0	*0.004*	*1.27*
% Total Bolls in 1st Position	74.8	62.3	79.5	*0.03*	*10.89*
% Total Bolls in 2nd Position	18.4	27.3	10.8	*0.01*	*0.81*
% Total Bolls in Outer Position	0.2	0.0	0.0	*0.44*	
% Total Bolls on Monopodia	6.6	10.0	9.7	*0.20*	
% Total Bolls on Extra – Axillary	0.0	0.5	0.0	*0.27*	
% Boll Retention - 1st Position	37.2	25.3	24.7	*0.003*	*4.51*
% Boll Retention - 2nd Position	13.2	15.4	5.7	*0.03*	*6.50*
% Early Boll Retention	45.3	38.9	34.1	*0.04*	*7.94*
Total Nodes/Plant	19.9	23.0	18.2	*0.002*	*0.80*
Internode Length (inches)	1.9	1.6	1.3	*0.007*	*0.12*

[1] Means of 10 plants per plot.

Table 5. Means for N fertilizer and irrigation timing effects for High Volume Instrument (HVI) classing data for 50 boll samples collected throughout consecutive plants on consecutive fruiting sites, Judd Hill 2011[1].

Treatment	Micronaire	Length	Uniformity	Strength	Elongation
Irrigation timing					
Early start	5.14	1.10	83.6	29.7	7.8
Delayed start	5.20	1.12	83.9	30.9	7.6
Rainfed	5.20	1.01	81.3	27.4	7.6
Nitrogen					
Urea	5.04	1.08	83.1	29.5	7.6
Urea - Slow Release	5.15	1.07	82.7	29.2	7.9
Urea + Biosolids	5.23	1.08	83.1	29.7	7.7
Untreated	5.31	1.07	82.8	28.94	7.5
P > F					
Irrigation (I)	*0.95*	*0.0003*	*0.0002*	*0.0005*	*0.54*
Nitrogen (N)	*0.58*	*0.58*	*0.77*	*0.72*	*0.17*
*I*N*	*0.32*	*0.28*	*0.23*	*0.24*	*0.38*

[1] Determinations made at Fiber and Biopolymer Research Institute, Texas Tech University, Lubbock, Texas.

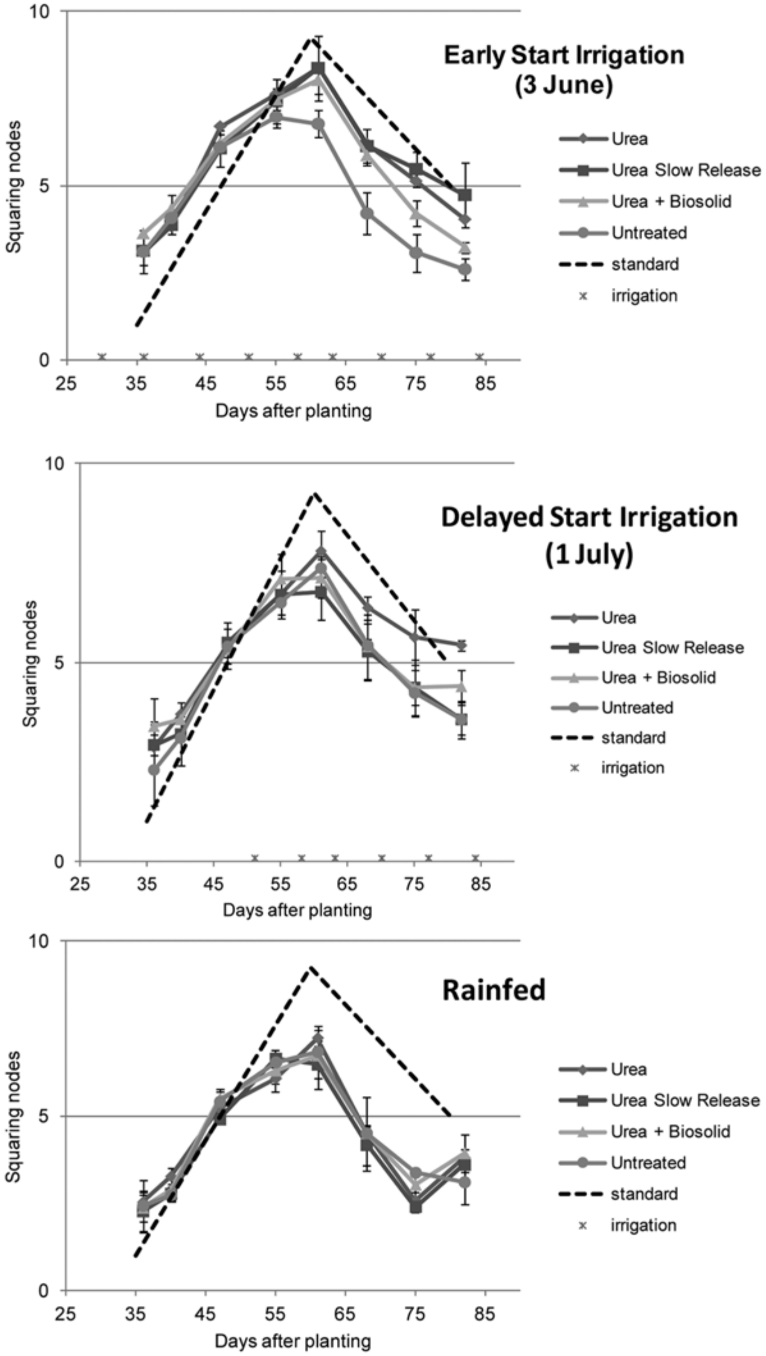

Fig. 1. COTMAN growth curves for N fertilizer treatments for each irrigation timing main plot, 2011.

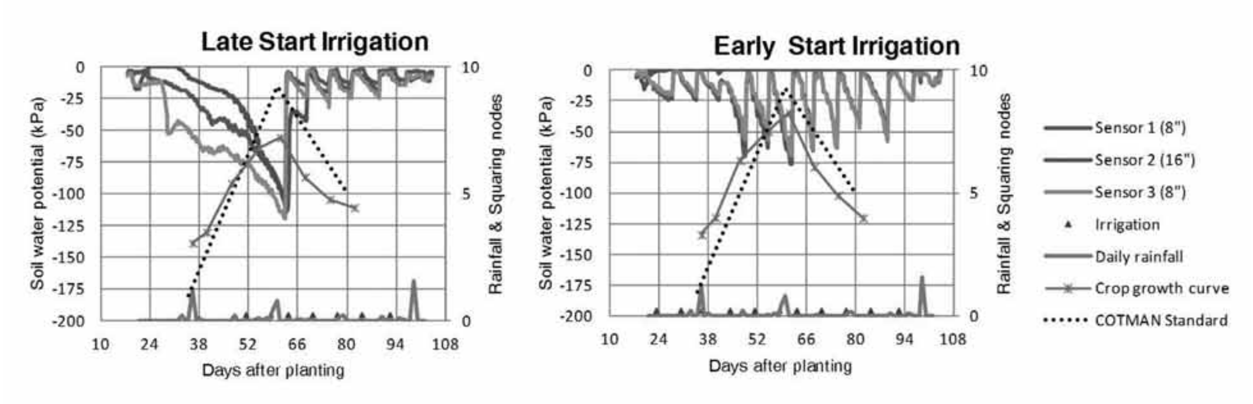

Fig. 2. Soil water potential at 8-, 16- and 8-inch depths in delayed and early start irrigation treatments in the 2011 Judd Hill Irrigation XNitrogen trial as measured by Watermark sensors recorded by a Hansen data logger. Soil water potential (rep 3), daily rainfall (inches), irrigation events, are shown along with COTMAN growth curves and the standard COTMAN target development curve. The moisture sensor at the 16-inch depth for early start malfunctioned at 24 DAP.

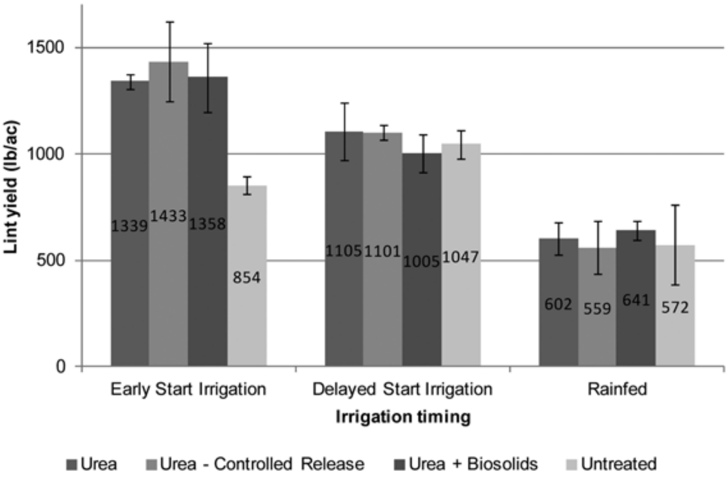

Fig. 3. Mean (± SEM) lint yields for four fertilizer treatments when grown with the irrigation start time at early square, at first flowers, or with no supplemental irrigation. Irrigation ($P < 0.01$) significantly affected yields; N and Irrigation XN were significant at $P = 0.06$ and $P = 0.07$, respectively.

Yield Response of Cotton to Timing of Potassium Fertilization Under Deficient Soil Test Levels

L. Espinoza[1], M. Ismanov[2], and P. Ballantyne[1]

RESEARCH PROBLEM AND BACKGROUND INFORMATION

Potassium (K) plays an important role in fiber development and fiber quality. Deficient amounts of this nutrient will result in reduced yields and short fibers since K provides turgor pressure inside the fiber cell walls, which is necessary for elongation (Ruan et al., 2001). The decrease in root activity after flowering, and the use of high-yielding, faster-fruiting cotton (*Gossypium hirsutum* L.) cultivars requiring a greater demand during boll filling makes the correction of a nutrient deficiency in cotton difficult. Understanding when soil-applied fertilizers are no longer effective is critical for optimizing cotton yield. The objective of this experiment was to assess the yield response of cotton to K fertilizer applied at different growth stages, under deficient soil K level, and to determine at what growth stage granular K is no longer an option.

RESEARCH DESCRIPTION

An experiment was established at the Lon Mann Cotton Research Station, near Marianna, Ark. during the 2010 and 2011 season. The soil has been mapped as a Memphis silt loam (fine silty-mixed, thermic, Typic Hapludalfs). Treatments consisted of 0 and 60 lb K_2O/acre, as muriate of potash, applied once at first square, first bloom, and 200, 400, 600, and 800 heat units after first bloom in 2010, and in 2011 at emergence, first square, first bloom, 200, 400, and 600 heat units after first bloom. The K-fertilizer was hand broadcast to designated plots and later incorporated with irrigation. Plants began squaring on 15 June, with the K-fertilizer applied on 17 June (first square treatment). The remaining treatments were applied on 7, 15, 21 July and 8 August, 2010. During 2011, plants began squaring on 16 June, with K-fertilizer applied on 17 June (first square treatment). The remaining treatments were applied on 11, 18, 26 July and 2 August, 2011. Each plot consisted of 4 rows (38-in wide) by 45-ft long. Treatments were arranged as a randomized complete block design, and were replicated four times. The cotton cultivar Phytogen 375 WRF was planted at the rate of 40,000 seeds per acre on

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6 May 2010, with cotton cultivar Stoneville 5458 B2F planted during 2011 at 40,000 seeds per acre. Nitrogen was applied at the rate of 100 lb N/acre, with 40 lb N/acre applied at emergence and 60 lb N/acre applied at first square. Irrigation (furrow) and weed and insect control were performed according to Cooperative Extension Service recommendations.

Soil samples (0-6 in deep) were collected prior to planting and analyzed according to Mehlich-3 standard procedure, with soil pH measured in a 1:2 (volume) soil-water mixture. Petiole samples were collected throughout the season, beginning two weeks prior to bloom and were analyzed for K. The COTMAN crop monitoring program (Oosterhuis and Bourland, 2008) was used to assess differences in crop development among treatments from squaring to physiological cutout. Prior to harvest, ten whole plants were collected from three of the replicates, with cotton manually harvested according to position. At harvest, the two middle rows from each plot were harvested with a plot picker equipped with a weighing system. Average yields were calculated and analyzed using ANOVA with mean separation using LSD at the 0.10 level.

RESULTS AND DISCUSSION

Average soil pH for the surface soil samples was 6.6 in 2010 and 7.2 in 2011. The soil test P and K were considered “Optimum” and “Medium”, respectively, according to University of Arkansas’ guidelines. The study site had not received K fertilizer since 2005. Typical K-deficiency symptoms (interveinal chlorosis initially that changes to a bronze-orange color) were obvious in plants receiving no K fertilizer. Potassium deficiency symptoms first appeared on the first week of bloom (7-14 July in 2010 and 11-15 July in 2011).

COTMAN graphs show earlier squaring initiation in plants that received no K or 60 lb K_2O per acre by first square (Fig. 1). Plants growing under both, deficient and sufficient-K, conditions developed similar numbers of fruiting structures, with the effect of deficient K-levels becoming obvious after the plants had bloomed. It is commonly accepted that the onset of K deficiency symptoms in cotton occurs relatively late in the season as most of the demand for K occurs during the boll filling period.

These preliminary results show that applications of granular K-fertilizer after flowering were effective in recovering some of the potential yield losses due to suboptimal soil test-K levels (Table 1). However, earlier applications resulted in larger yield gains. When the fertilizer was applied by first square, 721 and 413 lb/acre seed cotton, above the control, were obtained in 2010 and 2011 respectively. As applications were delayed beyond 400 heat units past bloom, yield gains were significantly reduced. The 2010 and 2011 growing seasons were characterized by low rainfall and high temperatures, resulting in heat units accumulating significantly faster than in previous years. The yield response of cotton to applications of K-fertilizer during a year that follows historical weather trends could be drastically different to the response observed during 2010 and 2011. This study will be repeated in the coming years to validate the results obtained so far.

Figures 2 and 3 show the yield distribution of cotton plants growing under K-sufficient and -deficient conditions. As stated before, the number of fruiting nodes, and associated plant height, were similar for plants growing under both conditions. The detrimental effects of K deficiency in cotton are not typically obvious before the 1st or 2nd week of bloom. In this study, plants growing under K-deficient conditions had similar numbers of first-position bolls, when compared to plants growing with sufficient K. When yields were separated by boll position on a sympodial node (Fig. 3) it was obvious that a significant percentage of the yield differences among plants growing under deficient and sufficient K, could be attributed to reduced 2nd and 3rd positions bolls.

PRACTICAL APPLICATIONS

The objective of this study was to determine when granular K fertilizer is no longer effective for ameliorating K deficiency of cotton. Results of this preliminary study show that granular K fertilizer applied 600 heat units beyond first bloom was effective in reducing the yield loss associated with deficient soil-K levels. However, earlier applications resulted in larger yield gains. Growing cotton at suboptimal soil test-K levels (less than 130 ppm) during two seasons resulted in the combined loss of more than 1,100 lb/acre seed cotton compared to the untreated. These results underscore the importance of soil testing and proper fertilization.

ACKNOWLEDGMENTS

This research was made possible by the financial support of The AgSpectrum Company and Cotton Incorporated.

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Table 1. Average seed cotton yield response to K treatments. Potassium was applied at a single rate of 60 lb K_20/acre. The numbers in parentheses following date of fertilization are the actual heat units the day the fertilizer was applied.

	------------Mean Yield------------	
Treatment	2010	2011
	lb/acre	lb/acre
Untreated control	2224 c[1]	2845 c
Emergence	---	3280 a
First Square	2945 a	3258 a
First Bloom	2897 a	3250 a
First Bloom + 200 Heat units	2811 a	3231 a
First Bloom + 400 heat units	2697 ba	3144 ba
First Bloom + 600 Heat unit	2551 b	2953 b
First Bloom + 800 Heat units	2514 b	---
LSD (0.10)	249	199
CV (%)	8.8	6.1
p-value	0.0004	0.0001

[1] Numbers within a column with the same letter are not significantly different (*P* = 0.10).

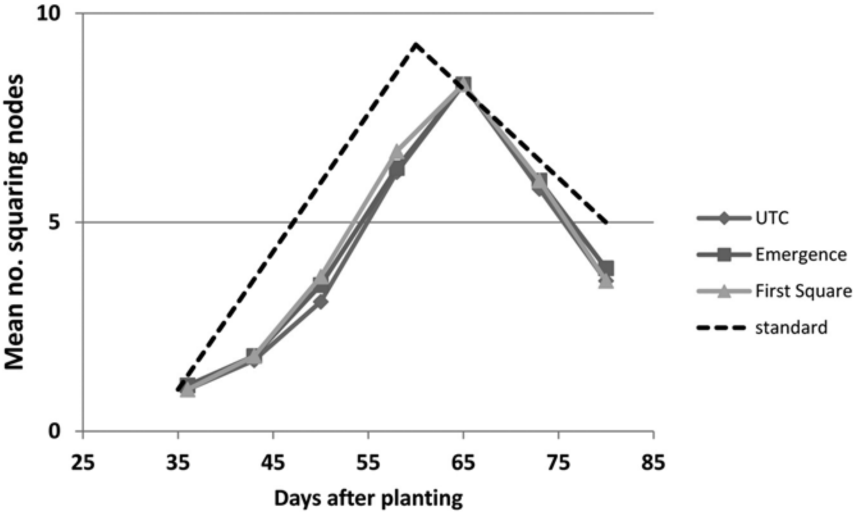

Fig. 1. Average nodes above first square (NAFS) and nodes above white flower (NAWF) development for the control treatment and for the treatment consisting of 60 lb K_2O/acre given at emergence or first square. Each point in the graph represents the average of 30 plants. The dotted line represents the typical development curve for cotton growing under optimum conditions.

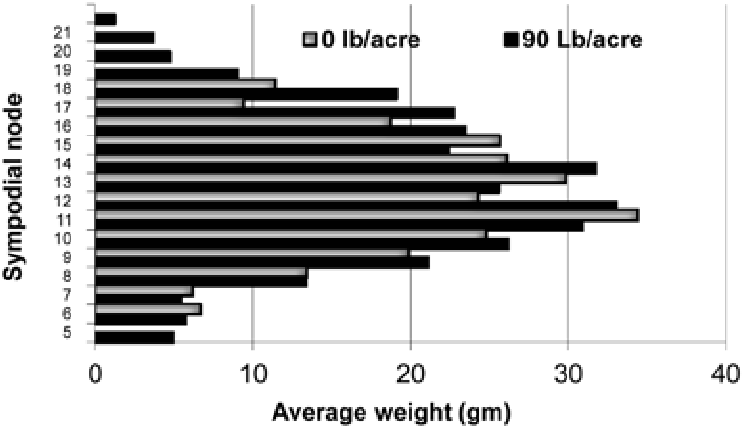

Fig. 2. Yield distribution for first fruiting positions of cotton plants that received 90 lb K_2O/acre potassium, compared to plants from the untreated control (n = 30).

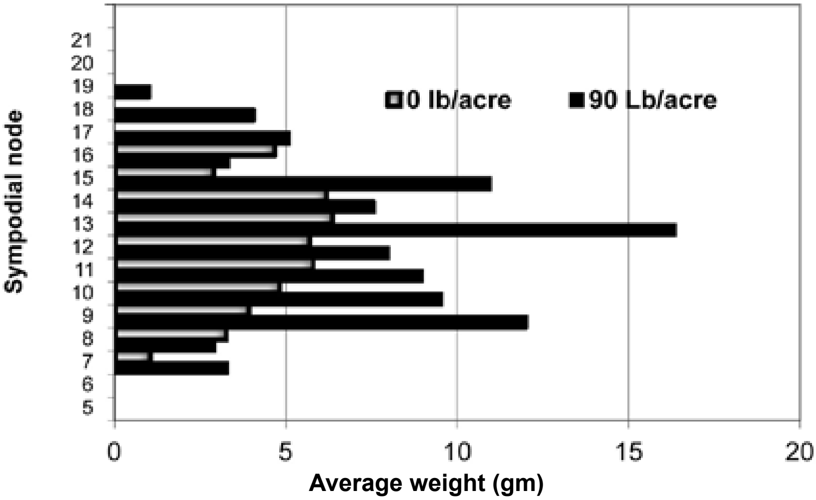

Fig. 3. Yield distribution for second and third positions of cotton plants that received 90 lb K_2O/acre potassium, compared to plants from the untreated control (n = 30).

Effect of Urea ESN on Cotton Yield in a Marvel Silt Loam in Arkansas

M. Mozaffari[1], N.A. Slaton[2], C.G. Herron[1], and S.D. Carroll[1]

RESEARCH PROBLEM

Cotton (*Gossypium hirsutumn* L.) yield in Arkansas is usually increased by application of nitrogen (N) fertilizer. Improving N use efficiency will increase the growers' profit margin and reduce potential environmental risks of excessive N application. This scenario will improve the long-term economical and environmental sustainability of cotton production in Arkansas.

BACKGROUND INFORMATION

Polymer coated controlled release (slow release) N fertilizers may provide the growers with the opportunity to increase their N use efficiency. A polymer-coated urea (44% N, Agrium Advanced Technologies, Loveland, Colo.) is currently being marketed in Arkansas under the trade name of Environmentally Smart Nitrogen or ESN[3]. The objective of this study was to evaluate furrow irrigated cotton response to ESN and urea fertilizers in a Marvel silt loam, a typical Arkansas soil used for cotton production.

RESEARCH DESCRIPTION

A replicated (n = 6) N fertilization experiment was conducted at the Lon Mann Cotton Research Station in Marianna, Ark. in 2011. The experimental design was a randomized complete block design with a factorial arrangement of four urea-ESN combinations each applied at five rates ranging from 30 to 150 lb N/acre and a no N control. The four urea- and ESN-N combinations were: 100% urea-N; 50% urea-N plus 50% ESN-N; 25% urea-N plus 75% ESN-N, and 100% ESN-N. Before adding any fertilizer, composite soil samples were collected from the 0-6 inch depth of each replication. The entire experimental area was fertilized with 60

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

lb K_2O and 30 lb P_2O_5/acre. All fertilizers were hand applied onto the soil surface and incorporated immediately with a Do-all cultivator. The beds were re-hipped and cotton was planted in 38-inch wide rows. Cotton cultivar Stoneville 4288BRF was planted on 26 May and harvested on 11 October 2011. Crop management practices closely followed the University of Arkansas Cooperative Extension Service recommendations for irrigated cotton production. At harvest the two center rows of each plot were harvested with a spindle type cotton picker.

Analysis of variance was performed using the GLM procedure of SAS (SAS Institute Inc., Cary, N.C.). When appropriate, means were separated by the least significant difference (LSD) method and interpreted as significant when $P \leq 0.10$.

RESULTS AND DISCUSSION

Analysis of the pre-treatment soil samples indicated that the soil was typical of those used for irrigated cotton production in Arkansas (Table 1). The 2011 growing season was slightly drier than normal. At Lon Mann Cotton Research Station in Marianna, total precipitation during the growing season was 16.3 inches relative to long-term average (1960 to 2007) of 19.7 inches. The monthly rainfall was consistently lower than long-term average. Thus the weather conditions were not conducive for very significant N loss by leaching and denitrification.

Neither N source nor the N source by rate interaction significantly influenced seedcotton yield ($P \geq 0.37$). Seedcotton yield was significantly ($P < 0.0001$) increased by N fertilization rate (Table 2). Seedcotton yield of cotton that did not receive any N fertilizer was 1731 lb/acre and application of 30 lb N/acre resulted in the lowest yield of the N-fertilized cotton. The seedcotton yield was maximized by application of 90 to 150 lb N/acre. The yield means for various N urea-ESN combinations and rates are listed in Table 2. The 2011 results suggest that ESN provided equal or slightly better N availability than urea.

PRACTICAL APPLICATION

Nitrogen loss from urea was less than wet years because the summer of 2011 was drier than normal. Averaged across N sources, cotton yields were not different among the various combinations of urea and ESN. These results suggest that ESN can be preplant incorporated in irrigated cotton production in Arkansas.

ACKNOWLEDGMENTS

This research was funded by a grant from USDA Regional Water Quality grant. We appreciate the donation of enhanced efficiency fertilizer by Agrium Advanced Technologies and the assistance of the University of Arkansas Soil Testing and Research Laboratory staff with soil and plant analyses.

Table 1. Selected soil property means (0-to 6-inch depth) of samples taken before applying fertilizers to a cotton N fertility test established in Marianna Ark. in 2011.

		----------Mehlich-3-extractable nutrients----------						--------Soil physical properties--------			
Soil pH [1]	Soil NO_3-N [2]	P	K	Ca	Mg	Cu	Zn	Sand	Silt	Clay	Texture
		--------------------(ppm) --------------------						---------------(%)---------------			
6.6	25	25	95	1183	205	1.0	1.0	20	60	20	silt loam

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

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

Table 2. Seedcotton yield as affected by the non-significant (*P* > 0.10 N) N source and N source by rate interaction and significant (*P* < 0.0001) N rate effect, averaged across N sources, for a cotton N fertility experiments conducted at the Lon Mann Cotton Research Station in 2011.

	----------------------------- Seedcotton yield (lb/acre) --------------------------------				
N rate	100% Urea-N	50% Urea-N 50% ESN-N[1]	25% Urea-N 75% ESN-N	100% ESN-N	Mean
lb N/acre					
0			1731		
30	2175	2187	2024	2059	2118
60	2774	2529	2824	2283	2602
90	3094	2990	2999	2974	3014
120	2906	3050	3008	2993	2989
150	2558	2846	2943	3221	2907
LSD 0.10	---------------------------------- NS[2] --------------------------------				172[3]
P value			0.3760		< 0.0001

[1] ESN is the trade name for Environmentally Smart Nitrogen. Urea-N and ESN-N indicate N supplied by urea and ESN respectively.

[2] NS means not significant at *P* ≤ 0.1.

[3] LSD for comparison of any two N rates as averaged across all N sources.

Nitrogen Fertilizer Timing and Tillage—Focusing Management to Build Sustainable Cotton Systems

T.G. Teague[1], L. Espinoza[2], C.S. Rothrock[3], A. Flanders[4], and L.A. Fowler[4]

RESEARCH PROBLEM

This study looks at practices that are helpful in improving efficient use of nitrogen (N) fertilizers in different conservation tillage systems—the goal being to get more N into the crop with less lost to the environment. A long-term cotton systems study to assess agronomic, economic and environmental impacts of conservation tillage systems was initiated in northeast Arkansas at the Judd Hill Foundation in fall 2007 (Teague et al., 2011). Our work in 2011 was focused on N fertility. In this report, we summarize results from component studies to evaluate N fertilizer applied at planting or in split applications either at planting with sidedress and at first squares or after first flowers. We also examined the agronomic benefit of Agrotain-amended urea compared to non-amended urea. Fertilizer treatments were evaluated in conventional, no-till and no-till with a terminated winter cover crop of wheat.

BACKGROUND INFORMATION

Conservation tillage has become standard practice for most Arkansas cotton producers. Winter cover crops of wheat or rye often are included in the system in northeast Arkansas directed at reducing damage associated with wind and blowing sand. Cover crops also can enhance weed management, irrigation water infiltration, and early- season root health. One concern among producers and their crop advisors with long-term management in conservation tillage systems is whether N fertility should be modified across systems.

The three ways that N is lost from soils to the environment are leaching, denitrification and volatilization. In conservation tillage production systems, ammonia volatilization losses can occur when urea fertilizer is surface-applied in the presence of residues or where limited or no soil incorporation occurs. Without a timely rain, the urea fertilizer laying on the soil surface will convert to ammonia gas and much of its value will be lost to the atmosphere. Volatilization is magni-

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fied when urea is put on wet compared to dry soil. Other environmental factors that contribute to higher N volatility are low humidity, higher temperatures and higher amounts of crop residue which have higher levels of the urease enzyme. Urea fertilizer may be stabilized on the soil surface by the use of a urease inhibitor which can temporarily block the function of the urease enzyme. Urease inhibitors decrease the rate of conversion of urea to ammonia and carbon dioxide, thereby reducing the potential for ammonia volatilization until that time when a rain event or irrigation moves the fertilizer into the soil to be available for the crop. Agrotain® and Arborite® currently are the only urease inhibitors recommended by the University of Arkansas System Division of Agriculture. Use of these urease inhibitors is now included as a nutrient management conservation practice standard by USDA-NRCS in Arkansas.

RESEARCH DESCRIPTION

The study was located on the Judd Hill Foundation Research Farm in Poinsett County, Ark. The experiment was arranged as a split-plot design with 3 tillage systems, 1) conventional, 2) no till, or 3) wheat winter cover crop (cover crop), considered main plots. The tillage strips have been maintained since 2007. In 2011, subplot treatments were N fertilizer (as urea) application timing and Agrotain amended urea. Application timing treatments were 1) 100lb N/acre at emergence, 2) 50 lb N/acre at emergence + 50 lb N sidedress at first square, and 3) 50 lb N/acre at emergence + 50 lb N sidedressed at 1week after first flowers (Table 1). Urea and Urea + Agrotain treatments were paired within timing treatments. Main plots were 16 rows wide and 450 ft long. Sub-plot application timing treatments and N source treatments were randomized within main plots; each was 8 rows wide, 120 ft long with 10-ft alleys. Fertilizer was broadcast using a 2 row Gandy spreader on 19 May, 8 days after planting (DAP).

For the 2011 cover crop, wheat was broadcast seeded 4 November 2010 at 10 lb wheat seed/acre. In the spring, the cover crop was terminated with glyphosate ca. 30 days before planting. Cruiser treated (thiamethoxam) DPL 0912 B2RF was planted on 11 May 2011 in a soil mapped as Dundee silt loam soil at 3 to 4 seeds/ft. Production practices were similar across all tillage treatments in-season with the following exceptions used only in conventional tillage main plots: disk bedders (hippers) used to re-form beds in early spring, tops of beds flattened just prior to planting with a DO-ALL fitted with incorporation baskets. No cultivations were made in any treatments. Furrow irrigation was applied weekly depending on rainfall. Irrigation dates were 3, 10, 24 June, 1, 7, 14, 20, 27 July, and 3, 11 August.

Plant stand density was sampled on 20, 26 May and 2 June (9, 15 and 22 DAP) by counting emerged plants per 3 ft in two transects across the center 4 rows of each subplot (=144 measures/main plot per sample date). Counts were made using a COTMAN-style T-stick sampler.

Crop monitoring was used to document differences in crop development among tillage and fertility treatments from squaring until physiological cutout.

On 13 June, during the first week of squaring, the number of plants with visible squares (% plants squaring) was determined by inspecting four sets of 25 consecutive plants across four rows per plot (=100 total plants). First fruiting node also was evaluated on this sample date. Subsequent plant monitoring was done using the COTMAN crop monitoring system (Oosterhuis and Bourland, 2008). To evaluate early-season seedling growth, 25 plants were collected on 14 June, 34 DAP. Plants complete with roots were selected and dug from arbitrary one-foot sections of row from plots in each tillage treatment in N treatment 1 subplots (at-planting urea). Plants were weighed for fresh weight, and the number of main-stem nodes for 5 seedlings recorded. Seedling disease pressure also was assessed. Root systems were scanned using the WinRHIZO software (Regent Instruments, Inc., Quebec, Canada). End-of-season season plant mapping was performed using the COTMAP procedure (Bourland and Watson, 1990). Plots were harvested with a two-row research cotton picker on 4 October. Grab samples from the picker basket were collected for each treatment plot; samples were ginned with a laboratory gin and submitted to the Fiber and Biopolymer Research Institute, Texas Tech University, Lubbock. All plant monitoring, yield and fiber quality data were analyzed using ANOVA with mean separation using Fisher's protected LSD test.

RESULTS AND DISCUSSION

Weather conditions during much of the production season were hot and dry (Table 2). Spring temperatures were warm up until planting, but in the first week after planting, temperatures were less than ideal for stand establishment. On 5, 6 and 7 DAP, weather station measures of daily low air temperatures were 47, 45 and 46 °F, respectively.

Weather conditions at the time of the first N applications at 8 DAP were ideal for fertilizer incorporation. On the evening following application, there was a gentle, 0.66 inch rain. Volatilization was not directly measured in this study; however, under such conditions, loss of N through volatilization likely was minimal. Results from other studies have shown that 0.5 inches of rain is sufficient to properly incorporate urea fertilizer.

Plant stand density was higher in the conventional compared to no-till and cover crop treatments by 9 DAP ($P = 0.06$) (Fig. 1); however, by 22 DAP, 2 June, fewer plants per 3 ft were observed in the conventional system compared to the no-till and cover crop treatments ($P = 0.05$). Neither N fertilizer timing nor source had a measurable effect on plant stand density.

For the root and plant growth assessments of seedlings collected at 34 DAP, there was a trend for conventional tillage to have larger seedlings than the no-tillage treatments ($P = 0.07$); however, there were no significant differences among treatments for other measures of plant size and root architecture (Table 3). No differences were found between tillage treatments for seedling disease ratings or isolation of selected genera containing seedling disease pathogens (Table 4).

COTMAN growth curves for main plot tillage treatments in 2011 show that pace of crop development followed the standard COTMAN reference curve with squaring initiated just prior to 35 DAP (Fig. 2). Production of main stem squaring nodes was similar among tillage treatments season-long. There were differences among N timing treatments. First flowers were observed during the week of the 57 DAP COTMAN sample. On this sample date, plants that had received 100 lbs N fertilizer at emergence had a mean 9.4 squaring nodes per plant compared to 9.0 nodes for N timing with a sidedress at first square application compared to 8.7 nodes per plant where the sidedress was delayed until after first flowers (P = 0.02, LSD_{05} = 0.53). There were no differences among tillage, N type or interactions on the sample date. At 62 DAP, the first flower sidedress was applied, and plants in that treatment had a mean of 8.5 squaring nodes compared to 9.4 and 9.3 squaring nodes for plants that had already received 100 N either at emergence or emergence + first square (P = 0.01; LSD_{05} = 0.37).

Final end-of-season plant mapping results from COTMAP sampling showed few significant or notable plant differences associated with fertilizer treatments (data not shown). Among tillage systems, cotton plants in conventional tillage had fewer first position bolls but highest percentage bolls occurring in second position and higher numbers of main-stem sympodia with both first and second position bolls (Table 5). Early boll retention (sum of first and second position on lowest five main stem sympodia) was highest in conventional tillage cotton.

Yields were significantly impacted by tillage practices in 2011 (Fig. 3). Neither N application timing nor type significantly affected yield in 2011. There were no significant N fertility × tillage interactions. The greatest probability of obtaining a meaningful response to the use of Agrotain is in no-tillage situations where the fertilizer is surface-applied and when little or no rainfall occurs for more than 4 days following application. Timely rain and irrigation following application of urea in 2011 appeared to negate any benefits from Agrotain in this 2011 trial. Fiber quality (HVI) analyses showed no differences among tillage system for lint quality parameters including % lint, micronaire, length, uniformity, strength, or elongation (Table 6).

In economic comparisons of each system, cost estimates indicate inputs in the conventional and cover crop systems to be $11.75 to $14.00 more per acre than no-till. Additional costs (machinery, labor) for a sidedress application was calculated at $2.00 per acre. The Agrotain increased the N fertilizer cost by $6.41 per acre compared to straight urea. This cotton systems study at the Judd Hill Foundation will be repeated in 2012 with expanded evaluations of agronomic, economic and environmental impacts of soil conservation practices.

ACKNOWLEDGMENTS

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Table 1. Urea fertilizer rate, and timing for subplot fertility treatments in 2011.

N fertilizer (lb N/acre) timing treatment	Application date	Days after planting
1) 100 lb @ crop emergence	19 May	8
2) 50 lb @ emergence + 50 lb @ first square	19 May + 8 June	8 + 28
3) 50 lb @ emergence + 50 lb @ first flowers	19 May + 12 July	8 + 62

[1] Applications were made following plant emergence, 8 days after planting just as cotyledons were emerging.

Table 2. Average monthly heat unit (DD60s) and precipitation accumulation, 1960-2007 for Northeast Arkansas[1] summer months compared to 2011 on-farm measurements at Judd Hill.

	---Heat Units (DD60s)[2]---		------Rain (inches)------		2011 Deviation from Average	
Month	Average[1]	2011	Average[1]	2011	Heat Units	Rainfall
June	532	758	3.89	1.84	200	-2.05
July	644	936	3.67	0.75	77	-2.92
August	583	722	2.85	0.13	147	-2.72
September	363	312	3.73	1.45	91	-2.28
				Total	606	-9.97

[1] Source: NOAA National Climatic Data Center, daily surface data for Keiser, Ark.
[2] DD60 calculations based on average daily temperature (°F) (Daily Heat Units = ((High + Low)/2)-60).

Table 3. Effect of tillage system on cotton root development in early season[1], 2011 Judd Hill.

Treatment	Nodes	Top wt (g)	Root wt (g)	Root length (cm)	Root surface area (cm^2)	Average root diameter (mm)	Root volume (cm^3)	Root tips	Root links	Altitude	External path length
Conventional	7.5 a[2]	10.94 a	1.25 a	39.7 a	14.3 a	1.21 a	0.43 a	41.2 a	95.2 a	13.2 a	105.4 a
Wheat cc	7.3 a	9.57 a	1.09 a	42.1 a	14.6 a	1.16 a	0.42 a	34.5 a	72.4 a	12.9 a	103.7 a
No till	7.0 a	9.07 a	1.00 a	35.0 a	12.7 a	1.22 a	038 a	30.5 a	60.2 a	12.1 a	101.4 a
P > F	*0.07*	*0.57*	*0.55*	*0.67*	*0.71*	*0.78*	*0.77*	*0.66*	*0.62*	*0.84*	*0.99*

[1] Plant samples were collected 34 DAP.
[2] Numbers in a column followed by the same letter are not significantly different (*P* = 0.05).

Table 4. Effect of tillage system on cotton seedling diseases in early season[1], 2011 Judd Hill.

			---Percent isolation---				
Treatment	Hypotcotyl disease rating	Root disease rating	*Rhizoctonia solani*	Binucleate *Rhizcotonia* spp.	*Pythium* spp.	*Fusarium* spp.	*Thielaviopsis basicola*
Conventional	2.1 a[2]	38.8 a	13.3 a	4.0 a	48.0 a	88.0 a	0.00
Wheat cc	2.1 a	33.2 a	13.3 a	5.3 a	22.7 a	98.7 a	0.00
No till	2.1 a	32.5 a	2.7 a	0.0 a	28.0 a	96.0 a	0.00
P > F	*0.92*	*0.87*	*0.29*	*0.68*	*0.07*	*0.18*	

[1] Plant samples were collected 34 DAP.
[2] Numbers in a column followed by the same letter are not significantly different (*P* = 0.05).

Table 5. Results from final end-of-season plant mapping using COTMAP for tillage main plot effects, 2011[1].

	--------Mean per plant for tillage treatment-------				
Category	**Conventional**	**Cover Crop**	**No-till**	***P > F***	***LSD$_{05}$***
1st Sympodial Node	7.3	7.3	7.2	*0.45*	
No. Monopodia	2.3	2.1	2.3	*0.27*	
Highest Sympodia with 2 nodes	13.5	12.6	13.3	*0.51*	
Plant Height (inches)	43.5	45.6	49.9	*0.31*	
No. Effective Sympodia	10.3	9.8	10.4	*0.76*	
No. Sympodia	17.4	16.6	17.3	*0.57*	
No. Symp. with 1st Position Bolls	4.4	4.8	5.0	*0.20*	
No. Symp. with 2nd Position Bolls	2.0	1.4	1.3	*0.20*	
No. Symp. with 1st & 2nd Bolls	1.3	0.7	0.7	*0.06*	
Total Bolls/Plant	10.3	8.2	8.4	*0.19*	
% Total Bolls in 1st Position	56.3	68.8	67.7	*0.07*	
% Total Bolls in 2nd Position	31.6	23.2	24.5	*0.05*	*6.6*
% Total Bolls on Monopodia	10.5	7.3	6.7	*0.40*	
% Total Bolls on Extra – Axillary	1.6	0.7	1.1	*0.09*	
% Boll Retention - 1st Position	33.3	32.9	32.7	*0.96*	
% Boll Retention - 2nd Position	24.4	15.6	15.6	*0.05*	*7.7*
% Early Boll Retention	48.8	39.7	41.3	*0.07*	
Total Nodes/Plant	23.8	22.9	23.5	*0.65*	
Internode Length (inches)	1.8	2.0	2.1	*0.09*	

[1] Means of 10 plants per plot.

Table 6. Means for high volume instrument (HVI) classing data[1] from grab samples collected in picker basket during harvest. No significant differences were observed among N fertilizer or tillage treatments. Means for tillage treatments are shown, Judd Hill 2011.

Tillage	Micronaire	Length	Uniformity	Strength	Elongation
Conventional	4.83	1.15	83.90	32.13	6.67
Wheat CC	4.47	1.14	83.57	32.13	6.43
No-Till	4.47	1.15	83.87	30.87	6.50
$P > F$	*0.19*	*0.62*	*0.82*	*0.18*	*0.06*

[1] HVI evaluations made at Fiber and Biopolymer Research Institute at Texas Tech University.

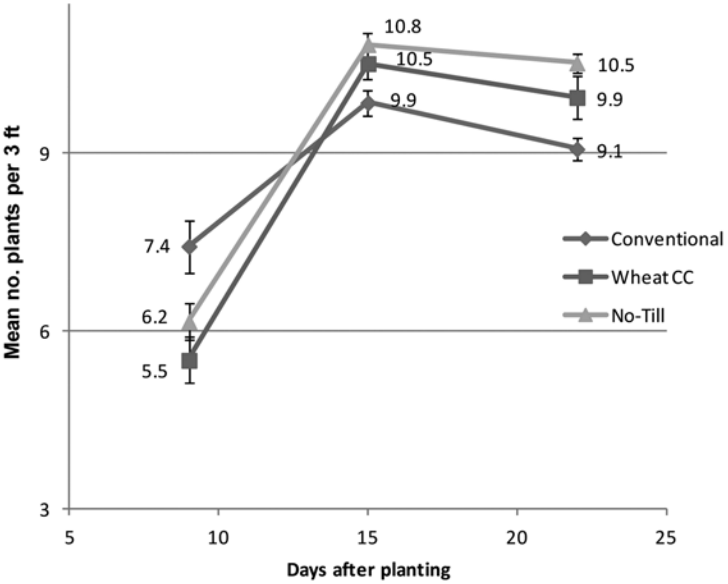
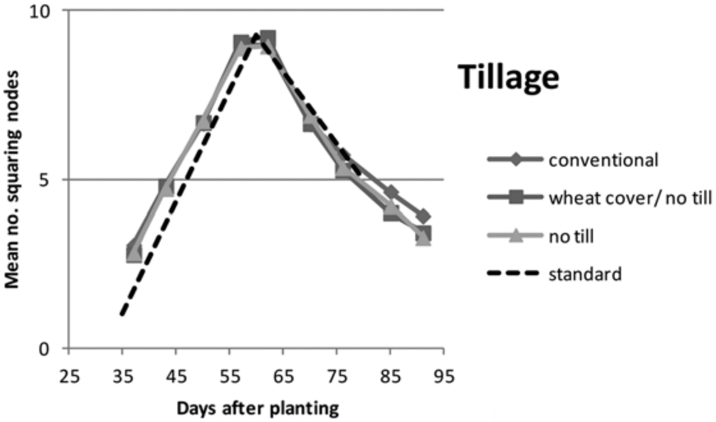


Fig. 1. Mean no. (±SEM) of plants/3 ft for 3 sample dates: 20, 26 May and 2 June (9, 15 and 22 DAP). Plant stand density was reduced by 22 DAP in the conventional compared to no-till and cover crop treatments.



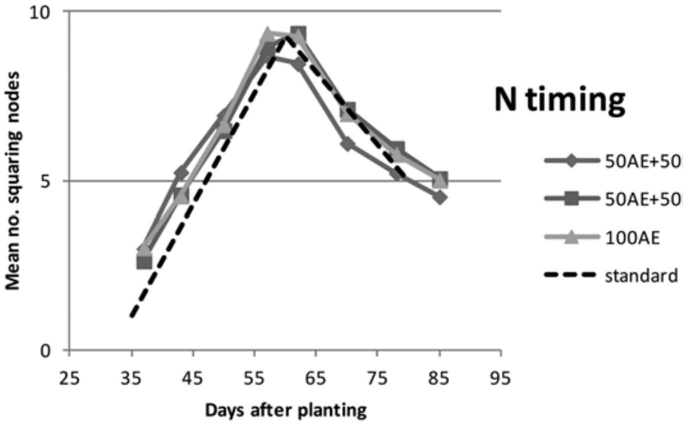


Fig. 2. COTMAN growth curves for main plot tillage treatments for tillage main effects (top) and for subplot N fertilizer timing effects (below) Date of planting was 3 May. COTMAN growth curves show that pace of crop development generally followed the standard curve (COTMAN target development curve) with squaring initiated just prior to 35 DAP. Nodal development was similar among tillage systems season-long; however, for N treatments, when N sidedress application was delayed until after first flowers, squaring node production was reduced compared to plants receiving the 100 N application rate at emergence or sidedress at first square. Physiological cutout was 5 days earlier for plants that did not receive the sidedress application until first flowers.

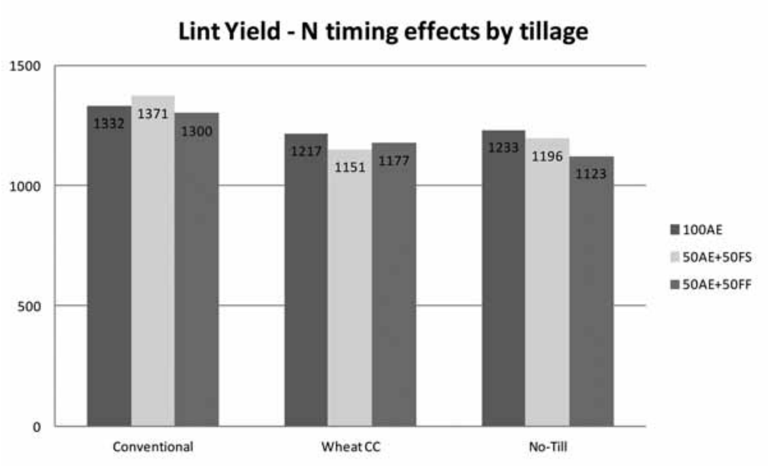


Fig. 3. Mean lint yield for N fertilizer timing across each tillage system (above) and for main plot tillage effects (below). Neither timing nor N type affected yield, but significantly higher yields were observed for the cotton in the conventional compared to no-till and wheat cover crop systems (*P* = 0.002).

Control of Tarnished Plant Bug, *Lygus Lineolaris*, in Cotton with Transform in Arkansas, 2009-2011

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RESEARCH PROBLEM

The tarnished plant bug (TPB), *Lygus lineolaris,* has become a more difficult pest to control in the last several years. Multiple applications are needed to achieve control which makes it one of the most expensive pests in Arkansas cotton production. Transform (sulfoxaflor) a new insecticide, was evaluated across several trials in the past three years for control of this pest in cotton.

BACKGROUND INFORMATION

Tarnished plant bug, is an important insect pest of Mid-south cotton (Layton, 2000). Plant bug damage causes square shedding and abnormal growth of bolls and terminals. The amount of damage this pest can cause varies depending on population density from year to year. Growers and consultants have relied on repeated foliar applications to minimize TPB damage. In 2011 growers averaged 6.4 applications (Williams, 2011). The reliance of insecticides for control of plant bugs has led to resistance of some commonly used insecticides, particularly pyrethroids, and new chemistries are needed (Snodgrass, 2000). Transform is the first insecticide from the sulfoximine chemical class. The purpose of this study was to compare Transform to current standards.

RESEARCH DESCRIPTION

Trials were conducted from 2009-2011. All trials were conducted at the Lon Mann Cotton Branch Experiment Station in Lee County, Ark. Plot size was 12.5 ft (4 rows) by 50 ft, in a randomized complete block design with 4 replications. Insecticide treatments were applied with a Mud Master (Bowman Manufacturing, Newport, Ark.) fitted with TX6 cone jet nozzles at 19-in nozzle spacing and 10 gal/acre, at 40 psi. Plant bug numbers were determined by taking 2 shakes per plot with a 2.5-ft drop cloth, for a total 10-row ft. Treatments were evaluated based

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on the current University of Arkansas Extension Cooperative Service threshold of 6 plant bugs per 10-row ft. The data was processed using Agriculture Research Manager V. 8 (Gylling Data Management, Inc., Bookings, S.D.) and Duncan's New Multiple Range Test (*P* = 0.10) to separate means._

RESULTS AND DISCUSSION

In the Plant Bug 2009 trial, at 3 days after the first treatment (3DAT1), all treatments had fewer plant bugs than the untreated control (UTC) (Fig. 1). Transform (0.067 lb ai/acre) was the only treatment lowering plant bug numbers below the Cooperative Extension Service established threshold of 6 per 10 row ft. At 6DAT, Transform (0.045 lb ai/acre) was the only treatment to reduce plant bug numbers compared to the UTC (untreated control) although numbers were not below threshold. At 3DAT2, all treatments had lower numbers than the UTC (Fig. 2). However, only Transform (0.034, 0.045, and 0.067 lb ai/acre) reduced plant bug numbers below threshold. Transform (0.067 lb ai/acre) was the only treatment that kept plant bug numbers below threshold at 6 days after treatment. At 14 and 20 days after the second application, no treatments kept plant bug numbers below threshold, although all treatments were lower than the UTC. All treatments increased yields compared to the UTC. Transform (0.067 lb ai/acre) had the highest yield of all treatments but did not differ from Orthene (1 lb ai/acre) or two of the lower rates of Transform (0.034 and 0.045 lb ai/acre).

In the Plant Bug 4-2010 trial at 3 and 9 DAT1, no treatments reduced numbers below threshold; although, all treatments had fewer plant bugs than the UTC (Table 1). At 4 DAT2, all treatments reduced plant bug numbers compared to the UTC. Transform (0.066 lb ai/acre), Transform (0.022 and 0.045) + Diamond (6 oz/acre), Transform (0.022 and 0.045) + Karate Z (0.04 lb ai/acre), Transform (0.045 lb ai/acre) + Orthene (0.5 lb/acre) and Orthene (0.5 lb/acre) + Diamond (6 oz/acre) all provided control below the Cooperataive Extension Service recommended threshold. At 11DAT2, all treatments reduced plant bug numbers below the UTC. Transform (0.045 lb ai/acre), Transform (0.045 lb ai/acre) + Karate Z (0.04 lb ai/acre), Transform (0.045 lb ai/acre) + Orthene (0.5 lb/acre) and Orthene (0.5 lb/acre) all remained below threshold. Harvest totals across all treatments were higher than the UTC with at least an 88% yield increase above the UTC.

In the 2011 trial at 3DAT1, all treatments reduced plant bug numbers compared to the UTC *(*Table 2). All treatments reduced plant bug numbers below threshold except Endigo (0.0805 lb ai/acre) and Lorsban Advanced (24 and 32 fl oz/acre). At 7DAT1, Transform (0.047 and 0.0703 lb ai/acre), Bidrin 8 (0.5 lb ai/acre), Endigo (0.0805 lb ai/acre) and Lorsban Advanced (32 fl oz/acre) had fewer plant bugs than the UTC. The only treatments that did not provide control below threshold were Lorsban Advanced (24 fl oz/acre), and Acephate (1 lb ai/acre). At 10DAT1 Transform (0.047 and 0.0703 lb ai/acre), Endigo (0.0805 lb ai/acre), and Lorsban Advanced (24 fl oz/acre) + Karate (2 fl oz/acre) all remained below threshold. At 5DAT2, all treatments had fewer plant bugs than the UTC and all but Lorsban Advanced (24 and 32 fl oz/acre) were below threshold. At 11DAT2, Transform (0.047 and 0.0703 lb ai/acre) were the only treatments that kept populations below threshold and had fewer plant bugs than all other treatments except Bidrin 8 (0.5 lb ai/acre), Acephate (1 lb ai/acre) and Endigo 0.0805 lb ai/acre. Transform (0.0703 lb ai/acre) and Acephate (1 lb ai/acre) were the only treatments to provide higher yields than the UTC.

PRACTICAL APPLICATION

Control of tarnish plant bugs can be achieved with Transform at several different rates and in tank mixes. It provided better control and longer residual than many of the standards in use today. Transform has the potential to be a useful tool in combating tarnished plant bug.

ACKNOWLEDGMENTS

Appreciation is expressed to the Lon Mann Cotton Branch Experiment Station, as well as Dow for their support.

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Table. 1. Efficacy of Transform for control of Tarnished Plant Bugs. Plant Bug 4 2010.

	Average Plant Bugs/10 row feet and Yield					
Treatment	**7/9/2010**	**7/15/2010**	**7/19/2010**	**7/26/2010**	**Yield lint lbs/acre**	**Yield % above UTC**
	3 DAT-1	9 DAT-1	4 DAT-2	11 DAT-2		
UTC	95.3 a[1]	71.8 a	74.3 a	32.5 a	518 c	
Transform 0.022 lb ai/acre	30.5 c	22.8 bc	13.5 bc	10.8 bc	1104 ab	113
Transform 0.045 lb ai/acre	22.8 c	12.8 c	7.5 bcd	3.8 c	1098 ab	112
Transform 0.066 lb ai/acre	17.5 c	6.8 c	1.3 d	8.8 bc	1143 ab	121
Transform 0.022 lb ai/a + Diamond 6 oz/acre	21.8 c	18.8 c	3.8 cd	8.5 bc	1176 ab	127
Transform 0.045 lb ai/a + Diamond 6 oz/acre	21.0 c	12.0 c	2.3 cd	6.0 bc	1136 ab	119
Transform 0.022 lb ai/acre + Karate Z 0.04 lb ai/acre	17.5 c	21.8 bc	2.8 cd	6.0 bc	1071 ab	107
Transform 0.045 lb ai/acre + Karate Z 0.04 lb ai/acre	20.3 c	12.3 c	1.5 d	4.8 c	1022 ab	97
Transform 0.022 lb ai/acre + Orthene 0.5 lb/acre	17.3 c	17.5 c	6.0 bcd	14.3 b	1041 ab	101
Transform 0.045 lb ai/a + Orthene 0.5 lb/acre	20.8 c	16.8 c	2.3 cd	3.8 c	1243 a	140
Orthene 0.5 lb/acre	30.8 c	39.5 b	15.3 b	5.8 bc	1058 ab	104
Diamond 6 oz/acre	52.5 b	25.8 bc	8.5 bcd	10.3 bc	1096 ab	112
Orthene 0.5 lb/acre + Diamond 6 oz/acre	17.0 c	15.5 c	2.5 cd	7.0 bc	976 b	88

[1] Numbers in columns followed by the same letter are not significantly different ($P = 0.10$).

Table. 2. Efficacy of Transform for control of Tarnished Plant Bugs. Plant Bug 2011.

	Average Plant Bugs/10 row feet and Yield											
Treatment Name	**7/15**		**7/19**		**7/22**		**7/27**		**8/2**		**Yield lint lbs/acre**	
	3 DAT-1		7 DAT-1		10 DAT-1		5 DAT-2		11 DAT-2			
UTC	12.0	a[1]	11.0	a	14.3	a	18.5	a	29.5	b	1247.8	b
Transform 0.047 lb ai/acre	3.3	bc	2.8	bc	3.3	de	1.8	e	4.3	d	1288.3	b
Transform 0.0703 lb ai/acre	1.8	c	1.5	c	1.5	e	1.3	e	5.3	d	1530.1	a
Bidrin 8 0.5 lb ai/acre	1.3	c	3.0	bc	7.3	bcd	3.0	de	15.5	cd	1349.8	ab
Acephate 1 lb ai/acre	1.5	c	8.8	ab	8.3	bcd	4.0	de	15.5	cd	1510.5	a
Endigo 0.0805 lb ai/acre	6.5	b	2.8	bc	4.8	cde	2.0	de	7.3	d	1413.8	ab
Cobalt Advanced 25 fl oz/acre	3.3	bc	5.8	abc	8.8	bcd	5.0	cd	26.3	bc	1339.3	ab
Cobalt Advanced 40 fl oz/acre	5.3	bc	5.3	abc	9.3	abc	2.0	de	24.3	bc	1420.3	ab
Lorsban Advanced 24 fl oz/acre	6.5	b	8.3	ab	10.8	ab	8.0	b	34.5	b	1364.1	ab
Lorsban Advanced 32 fl oz/acre	6.3	b	3.8	bc	7.0	bcd	7.0	bc	51.3	a	1409.9	ab
Lorsban Advanced 24 fl oz/acre + Karate 2 fl oz/acre	3.8	bc	6.0	abc	4.5	cde	1.3	e	24.3	bc	1372.0	ab

[1] Numbers in columns followed by the same letter are not significantly different ($P = 0.10$).

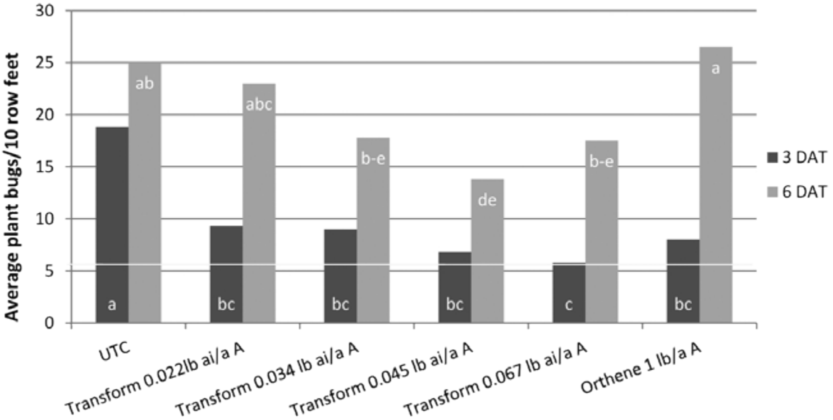

Fig. 1. Efficacy of Transform for control of Tarnished Plant Bugs 3 and 6 DAT1. Plant Bug 2009 Trial. Threshold 6 plant bugs per 10 row feet is shown.

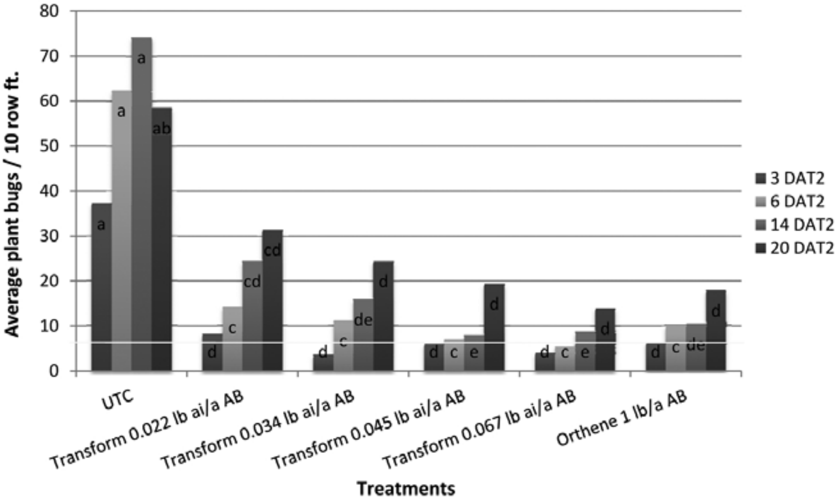

Fig. 2. Efficacy of Transform for control of Tarnished Plant Bugs 3, 6, 14, and 20 DAT2. Plant Bug 2009 Trial. Threshold 6 plant bugs per 10 row feet is shown.

Control of Tarnished Plant Bug with Tank Mixes and Premix Insecticides

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J.W. Fortner[2], and R. Goodson[3]

RESEARCH PROBLEM

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

BACKGROUND INFORMATION

From 2003 to 2009 the tarnished plant bug caused more yield loss than any other pest, averaging a loss of over 50,000 bales in Arkansas (Williams, 2009). Plant bug populations in 2009 and 2010 were extremely high and currently labeled insecticides did not provide the level of control that is needed to reduce plant bug numbers below economic thresholds with one application (Colwell et al., 2010). Use of insecticide premixes and tank mixes are the most effective way to increase control. A total of 23 trials from the 2009-11 growing seasons were compiled to evaluate the level of control these mixes provide compared to a single product.

RESEARCH DESCRIPTION

Trials were conducted during the 2009-11 growing seasons. Treatments were applied with a Mud Master (Bowman Manufacturing, Newport, Ark.) fitted with TXVS-6 hollow cone nozzles. Spray volume was 10 GPA at 40 psi. Plot sizes were 12.5 ft (4 rows) by 50 ft. Insect numbers were determined by using a 2.5-ft drop cloth and taking 2 samples per plot for a total of 10 row ft per plot. Data were processed using Agriculture Research Manager V. 8 (Gylling Data Management, Inc., Brookings, S.D.) Analysis of Variance, and Duncan's New Multiple Range Test (*P* = 0.10) to separate means. Data was compared between tests by

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[1] Program technician, Department of Entomology, Fayetteville.

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[3] County extension agent, Helena.

converting each treatments' season total plant bug numbers to their respective untreated checks season total to provide a percent control. All identical treatments were averaged together to provide a more accurate data set. The number of data sets used for each individual treatments' average is designated by n = #.

RESULTS AND DISCUSSION

Tank mixes and premixes on average showed increased TPB control when compared to individual compounds. All treatments showed an increase in efficacy when a single product was mixed with bifenthrin (Table 1). When the rate of Belay was doubled from 2 oz/acre to 4 oz/acre, control was still not as effective as the low rate of Belay (2 oz/acre) + Bifenthrin (6 oz/acre). An average efficacy increase of 16.6% was observed when the selected insecticides were combined with bifenthrin (Table 2). All selected insecticides showed an increase in efficacy when Diamond (6 oz/acre) was mixed with a single product (Table 3). Another instance of the higher rate of an insecticide not providing the level of control a tank mix provided can be seen here with Centric (3 oz/acre) compared to Centric (2.5 oz/acre) + Diamond (6 oz/acre). Tank mixes with Diamond (6 oz/acre) showed an average increase of 17% when compared to a single product application (Table 4). Results in Diamond Tank Mix 2009 and 2010 showed the improved efficacy a tank mix of Diamond provides over a single product application (Tables 5 and 6). Tank mixes that included bifenthrin and Diamond provided the best control of all treatments. Transform alone provided exceptional control when compared to other single products. The results of these studies show insecticide mixes are an effective way to increase control of tarnished plant bug with existing products.

ACKNOWLEDGMENTS

We thank the Cotton State Support Committee and Cotton Incorporated for their support.

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Table 1. Tarnished plant bug control with tank mixes and premixes of bifenthrin.

Treatment	% Control Above Untreated Check with Bifenthrin
Bifenthrin 6 oz/acre + Diamond 6 oz/acre n = 3	83
Bidrin XP	82
Bif + Nov Premix 2010 25.6 oz/acre n = 2	80
Belay 2 oz/acre + Brigade 2.6 oz/acre	79
Brigade 6.4 oz/acre + Bidrin 6.4 oz/acre	77
Bif + Nov Premix 2010 16 oz/acre n = 2	77
Belay 2 oz/acre + Bifenthrin 5.12 oz/acre	76
Fanfare 6.4 oz/acre + Diamond 9.6 oz/acre	73
Brigadier 10.24 oz/acre	73
Dimethoate 8 oz/acre + Bifenthrin 6.4 oz/acre	71
Bifenthrin 6.4 oz/acre n = 4	65

Table 2. Average increase in control when selected insecticides are combined with bifenthrin.

Treatment	Average Increase in Control for Bifenthrin Mixes (%)
Diamond 6 oz/acre	14
Dimethoate 8 oz/acre	9
Belay 2 oz/acre	15
Bidrin 8 0.5 lb ai/acre	18
Imidacloprid 4F 2 oz/acre	27
Average increase in control	16.6

Table 3. Tarnished plant bug control with tank mixes and pre-mixes of Diamond.

Treatment	% Control above Untreated Check with Diamond
Bifenthrin 6 oz/acre + Diamond 6 oz/acre	83
Diamond 6 oz/acre + Centric 2.5 oz/acre	83
Diamond 6 oz/acre + Bidrin 6 oz/acre	82
Bif + Nov Premix 2010 25.6 oz/acre	80
Diamond 6 oz/acre + Acephate 0.75 oz/acre	80
Diamond 6 oz/acre + Alias 4F 1.0 oz/acre	80
Bif + Nov Premix 2010 16 oz/acre	77
Orthene 0.5 lb/acre + Diamond 6 oz/acre	75
Transform 0.045 lb ai/acre + Diamond 6 oz/acre	75
Fanfare 6.4 oz/acre + Diamond 9.6 oz/acre	73
Diamond 9.6 oz/acre	72
Diamond 6 oz/acre	70

Table 4. Average increase in control when selected insecticides are combined with Diamond.

Treatment	Average Increase in Control for Diamond Mixes %
Centric 2.5 oz/acre	11
Bifenthrin 6.4 oz/acre	18
Acephate 0.75 lb/acre	7
Bidrin 8 0.5 lb ai/acre	18
Carbine 1.7 oz/acre	31
Average increase in control	17

Table 5. Efficacy of Diamond tank mixes 2009.

Treatment	Season Total
UTC	275.3 a[1]
Carbine 1.7 oz	207.3 b
Diamond 9 oz/acre	106.5 cd
Centric 2.5 oz/acre	120.3 c
Bidrin 6 oz/acre	91.3 cde
Diamond 6 oz/acre	88.5 cde
Diamond 6 oz/acre + Centric 2.5 oz/acre	72.3 def
Diamond 6 oz/acre + Carbine 1.7 oz/acre	71.5 def
Diamond 6 oz/acre + Bidrin 6 oz/acre	67.8 def
Acephate 0.75 lb/acre	61.3 ef
Diamond 6 oz/acre + Acephate 0.75 lb/acre	43.0 f

[1] Numbers within a column with the same letters are not significantly different (*P* = 0.05).

Table 6. Efficacy of Diamond tank mixes 2010.

Treatment	Season Total
UTC	269.5 a[1]
Diamond 6 oz/acre	97.8 b
Diamond 9 oz/acre	99.8 b
Diamond 6 oz/acre + Centric 2.5 oz/acre	46.3 d
Diamond 6 oz/acre + Bidrin 6 oz/acre	49.5 d
Diamond 6 oz/acre + Acephate 0.75 lb/acre	52.3 d
Diamond 6 oz/acre + Carbine 1.7 oz/acre	71.3 cd
Centric 2.5 oz/acre	62.8 cd
Bidrin 6 oz/acre	86.0 bc
Acephate 0.75 lb/acre	69.8 cd
Carbine 1.7 oz/acre	106.3 b

[1] Numbers within a column with the same letters are not significantly different (*P* = 0.05).

Efficacy of Selected Insecticides for Control of Plant Bugs in Arkansas

N.M. Taillon[1], G.M. Lorenz III[1], W.A. Plummer[1], B.C. Thrash[2], J.W. Fortner[1], C.K. Colwell[1], and G. Wilson[3]

RESEARCH PROBLEM

The tarnished plant bug, has become the most destructive pest in cotton. Multiple applications are required to achieve control of this pest, making it very expensive to control as well. Due to the difficulty in achieving adequate control, efficacy trials are essential in determining which insecticides provide adequate control.

BACKGROUND INFORMATION

The tarnished plant bug (TPB), *Lygus lineolaris,* has become the most destructive pest in cotton since the eradication of the boll weevil and the development of *Bacillus thuringiensis* (Bt) technologies. Before 1995, TPB were controlled with insecticides targeting other insect pests such as the tobacco budworm/cotton bollworm and boll weevil. Reduced applications for these pests have established the TPB as the primary insect pest of cotton in the Mid-south. Recently, TPB has become resistant to several classes of insecticides, further compounding the problem (Catchot et. al., 2009). In 2010, Arkansas growers treated 92% of the cotton acreage planted at a cost of $18.06/acre. In spite of the aggressive attempts to control this pest, a total of 38,946 bales of cotton were lost to the TPB, 48% of the total bales lost for the year. These studies were conducted to evaluate the efficacy of insecticides currently recommended, as well as some new products and tank-mixes, for control of TPB in Arkansas and the Mid-south.

RESEARCH DESCRIPTION

Trials were located at the Lon Mann Cotton Branch Experiment Station in Lee County, Ark. 2011. Plot size was 12.5 feet (4 rows) by 50 feet in a randomized

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[2] Program technician, Department of Entomology, Fayetteville.

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complete block design with 4 replications. DPL 0912, BGII RRG was planted on 15 May (PB3), and 27 May (PB12, PB13) 2011. Insecticide treatments were applied with a Mud Master fitted with TX6 hollow cone nozzles at 19 in nozzle spacing; spray volume was 10 gal/acre, at 40 psi. Insect numbers were determined by using a 2.5-ft drop cloth. Two drop cloth samples were taken per plot for a total of 10 row ft per plot. Treatments were evaluated based on the current University of Arkansas Cooperative Extension Service threshold of 6 plant bugs per 10 row ft. Data were processed using Agriculture Research Manager V. 8 (Gylling Data Management, Inc., Brookings, S.D.) and Duncan's New Multiple Range Test (*P* = 0.10) to separate means.

RESULTS AND DISCUSSION

In PB3-2011 at 3 days after the first application (3 DAT-1), all treatments reduced plant bug numbers compared to the untreated check (UTC) (Table 1). Lorsban Advanced (24 and 32 oz/acre), and Endigo (0.0805 lb ai/acre) did not reduce numbers below that of the Cooperative Extension Service threshold. Plant bug numbers at 7 DAT-1 were above threshold in all treatments except for Transform (0.047 and 0.0703 lb ai/acre), Bidrin 8 (0.5 lb ai/acre), Endigo (0.0805 lb ai/acre), Cobalt Advanced (25 and 40 oz/acre), and Lorsban Advanced (32 oz/acre). While populations continued to increase in the UTC, Transform (0.047 and 0.0703 lb ai/acre), Endigo (0.0805 lb ai/acre), and Lorsban Advanced (24 oz/acre) + Karate (2 oz/acre) continued to control plant bug numbers 10 DAT-1. All treatments reduced plant bug numbers compared to the UTC at 5 DAT-2. All treatments reduced TPB below threshold except for Lorsban Advanced (24 and 32 oz/acre). Transform (0.047 and 0.0703 lb ai/acre), and Endigo (0.0805 lb ai/acre) controlled plant bug numbers better than all other treatments at 11 DAT-2. However, Transform (0.047 and 0.0703 lb ai/acre) were the only treatments below the Cooperative Extension Service threshold. Transform (0.0703 lb ai/acre) and Acephate (1 lb ai/acre) had a higher yield than the UTC and Transform at a lower rate (0.047 lb ai/acre). Yield ranged from 40.5 to 282.3 lint lbs/acre above the UTC.

In PB12-2011, 3 DAT-1, Diamond (6 oz/ a), Endigo (4.5 oz/acre), CMT 4586 (8 oz/acre), and Leverage (2.8 oz/acre) + Non-ionic Surfactant (NIS) (0.25% v/v) reduced plant bug numbers lower than the UTC, while CMT 4586 and Leverage (8 and 2.8 oz/acre, respectively) reduced plant bug numbers below the Cooperative Extension Service threshold (Table 2). At 7 days after the first application, Diamond + Alias 4F (6 and 1 oz/acre, respectively) and Diamond + Alias 4F (6 and 2 oz/acre, respectively), Diamond (6 oz/acre), Alias 4F (2 oz/acre), Endigo (4.5 oz/acre), and CMT 4586 (8 oz/acre) reduced plant bug numbers lower than the UTC; all of which were below the Cooperative Extension Service threshold except for Diamond (6 oz/acre). At 4 DAT-2, all treatments reduced plant bug numbers below the UTC. At 7 DAT-2, all treatments had fewer plant bugs than the UTC. Diamond + Alias F (6 and 0.5 oz/acre, 6 and 1 oz/acre, 6 and 2 oz/acre, respectively), Diamond (6 oz/acre), Endigo (4.5 oz/acre), CMT 4586 (8 oz/

acre), and Leverage (2.8 oz/acre) + NIS (0.25% v/v) reduced plant bug numbers below the Cooperative Extension Service threshold. At 11 DAT-2, all treatments reduced plant bugs below the UTC. No treatments reduced plant bug numbers below threshold. Diamond + Alias 4F (6 and 0.5 oz/acre, 6 and 1 oz/acre, 6 and 2 oz/acre, respectively) had a higher yield than the UTC. Yield ranged from 143.4 to 470.4 lint lbs/acre above the UTC.

In PB13-2011, 3 DAT, plant bug numbers in all treatments were lower than the UTC, while Athena (8 and 12 oz/acre), Brigade (6.4 oz/acre), Brigade + Bidrin (6.4 oz/acre each), Brigade + Diamond (6.4 oz/acre each), Carbine (2.3 oz/acre), Centric (2 oz/acre), and Orthene (0.75 lb/acre) were all below the Cooperative Extension Service threshold (Table 3). At 8 DAT, all treatments remained lower than the UTC. Only Brigade + Bidrin (6.4 oz/acre each), Brigade + Diamond (6.4 oz/acre each), Carbine (2.3 oz/acre), and Orthene (0.75 lb/acre) remained below the Cooperative Extension Service threshold. Brigade (6.4 oz/acre) had a higher yield than the UTC. Yield ranged from -86.6 to 244.7 lint lbs/acre in relation to yield in the UTC.

PRACTICAL APPLICATION

These trials indicate the difficulty in controlling plant bug numbers with existing insecticides and emphasize the need for new classes of insecticides to achieve acceptable control levels of this pest.

ACKNOWLEDGMENTS

We would like to thank the Cotton State Support Committee and Cotton Inc. for their support.

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Table 1. PB3-2011 Tarnished plant bug data per 10 row feet at 3,7,10 days after first application, and 5, 11 days after second application, yield data.

Treatment Name	7/15 3 DAT-1	7/19 7 DAT-1	7/22 10 DAT-1	7/27 5 DAT-2	8/2 11 DAT-2	Season Total	Yield lint lb/acre
UTC	12.0 a[1]	11.0 a	14.3 a	18.5 a	29.5b	85.3 a	1247.8 b
Transform 0.047 lb ai/acre	3.3 bc	2.8 bc	3.3 de	1.8 e	4.3d	15.3 d	1288.3 b
Transform 0.0703 lb ai/acre	1.8 c	1.5 c	1.5 e	1.3 e	5.3d	11.3 d	1530.1 a
Bidrin 8 0.5 lb ai/acre	1.3 c	3.0 bc	7.3 bcd	3.0 de	15.5cd	30.0 bcd	1349.8 ab
Acephate 1 lb ai/acre	1.5 c	8.8 ab	8.3 bcd	4.0 de	15.5cd	38.0 bc	1510.5 a
Endigo 0.0805 lb ai/acre	6.5 b	2.8 bc	4.8 cde	2.0 de	7.3d	23.3 cd	1413.8 ab
Cobalt Advanced 25 fl oz/acre	3.3 bc	5.8 abc	8.8 bcd	5.0 cd	26.3bc	49.0 b	1339.3 ab
Cobalt Advanced 40 fl oz/acre	5.3 bc	5.3 abc	9.3 abc	2.0 de	24.3bc	46.0 b	1420.3 ab
Lorsban Advanced 24 fl oz/acre	6.5 b	8.3 ab	10.8 ab	8.0 b	34.5b	68.0 a	1364.1 ab
Lorsban Advanced 32 fl oz/acre	6.3 b	3.8 bc	7.0 bcd	7.0 bc	51.3a	75.3 a	1409.9 ab
Lorsban Advanced 24 fl oz/acre + Karate 2 fl oz/acre	3.8 bc	6.0 abc	4.5 cde	1.3 e	24.3bc	39.8 bc	1372.0 ab

[1] Means in a column followed by the same letter are not significantly different ($P = 0.05$).

Table 2. PB12-2011 Tarnished plant bug data per 10 row feet 3, 7 days after first application and 4, 7, 11 days after second application; yield data.

Treatment Name	7/28 3 DAT-1	8/1 7 DAT-1	8/5 4 DAT-2	8/8 7 DAT-2	8/12 11 DAT-2	Season Total	Yield lint lb/acre
UTC	15.8 a[1]	11.3	30.0 a	30.0 a	54.0 a	141.0 a	1071.4 b
Diamond 6 oz/acre + Alias 4F 0.5 oz/acre	11.0 ab	8.3 ab	5.5 b	3.5 bcd	9.0 c	37.3 bcd	1427.5 a
Diamond 6 oz/acre + Alias 4F 1.0 oz/acre	8.8 ab	4.5 b	2.8 b	3.0 cd	9.5 c	28.5 d	1437.3 a
Diamond 6 oz/acre + Alias 4F 2 oz/acre	8.0 ab	5.0 b	4.3 b	4.3 bcd	13.0 c	34.5 cd	1541.8 a
Diamond 6 oz/acre	7.5 b	6.0 b	2.8 b	1.8 d	8.0 c	26.0 d	1291.9 ab
Alias 4F 2.0 oz/acre	10.0 ab	3.8 b	7.5 b	6.3 bc	27.5 b	55.0 b	1251.1 ab
Endigo 4.5 oz/acre	6.0 b	5.5 b	3.3 b	4.8 bcd	10.0 c	29.5 d	1404.6 ab
CMT 4586 8 oz/acre	5.8 b	5.5 b	4.0 b	6.8 bc	28.5 b	50.5 bc	1327.9 ab
Leverage 2.8 oz/acre + COC 1% v/v	8.3 ab	7.8 ab	6.8 b	7.5 b	14.0 c	44.3 bcd	1215.2 ab
Leverage 2.8 oz/acre + NIS 0.25% v/v	5.0 b	8.5 ab	4.0 b	4.8 bcd	21.0 bc	43.3 bcd	1296.8 ab

[1] Means in a column followed by the same letter are not significantly different (*P* = 0.05).

Table 3. PB13-2011 Tarnished plant bug data per 10 row feet 3, 8 days after application; yield data.

Treatment Name	7/27 3 DAT	8/1 8 DAT	Season Total	Yield lint lb/acre
UTC	12.0 a[1]	22.5 a	34.5 a	1440.6 ab
Athena 8 oz/acre	5.0 bc	13.0 bc	18.0 bc	1577.8 ab
Athena12 oz/acre	5.8 bc	9.0 bcd	14.8 bcd	1478.1 ab
Brigadier 2 6.4 oz/acre	8.3 b	6.8 cd	15.0 bcd	1470.0 ab
Brigade 6.4 oz/acre	3.0 c	7.5 bcd	10.5 cd	1354.0 b
Brigade 6.4 oz/acre + Bidrin 6.4 oz/acre	3.8 c	4.0 d	7.8 d	1602.3 ab
Brigade 6.4 oz/acre + Diamond 6.4 oz/acre	3.0 c	2.5 d	5.5 d	1685.3 a
Carbine 2.3 oz/acre	5.8 bc	5.8 cd	11.5 bcd	1523.9 ab
Tri-Max Pro 1.5 oz/acre	6.8 bc	14.5 b	21.3 b	1412.8 ab
CENTRIC 2 oz/acre	5.0 bc	7.8 bcd	12.8 bcd	1554.9 ab
Orthene 0.75 lb/acre	5.3 bc	5.8 cd	11.0 cd	1528.8 ab

[1] Means in a column followed by the same letter are not significantly different (*P* = 0.05).

Effect of Spray Volume on the Efficacy of Insecticides Recommended for Tarnished Plant Bugs

G.E. Studebaker and S. Lancaster[1]

RESEARCH PROBLEM

The tarnished plant bug (TPB) is a major pest of cotton in Arkansas (Williams, 2010), often requiring multiple applications of insecticide to maintain control. Insecticide efficacy for this pest has been decreasing in recent years. Spray volume can have an effect on insecticide efficacy, particularly in crops with a full canopy during high daytime temperatures. It is important to know what spray volumes give the best performance in order for growers to get the best control from the products they apply.

BACKGROUND INFORMATION

Insecticides are an integral part of any Integrated Pest management (IPM) program to manage insect pests. However, there are a number of factors that can affect the efficacy of an insecticide. Insecticide resistance, insect pest, canopy density, time of day, temperature, spray nozzle selection and spray volume are some of the factors that can have a significant effect on efficacy. Spray volume is one factor that can be easily manipulated by the applicator. Growers are often tempted to lower spray volume in order to cover larger acreages with one tank load of product, thereby saving time. However, reducing spray volume by too much can have an adverse effect on the efficacy of the products being applied.

RESEARCH DESCRIPTION

Cotton (*Gossypium hirsutum* L.) cultivar UA48 was planted at the University of Arkansas Northeast Research and Extension Center in May of 2011 in plots 8-rows wide by 45-ft long. Insecticides from each of the major chemistry groups were chosen to be evaluated at two spray volumes. Insecticides and chemistries were: dicrotophos 8EC (organophosphate), acephate (organophosphate), thiamethoxam 40WG (neonicotinoid) and bifenthrin 2EC (synthetic pyrethroid). Each insecticide was evaluated at a spray volume of 5 and 10 gallons per acre

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(gpa). Insecticides were applied with a high clearance sprayer equipped with two TX-6 hollowcone nozzles per row. Tarnished plant bugs were counted 4-days after treatment using a black shake cloth from the center two rows of each plot. Data were analyzed by ANOVA using Agriculture Research Manager Software V. 8 (Gylling Data Management, Inc., Brookings, S.D.).

RESULTS

Tarnished plant bugs per 10 row-ft for each treatment are reported in Table 1. All insecticides did significantly reduce TPB below the untreated control at both volumes ($P = 0.0031$). However, spray volume only had a significant effect on dicrotophos with the higher volume giving better control. When only spray volume was analyzed, there was a significant overall effect with 10 gpa giving significantly better control than 5 gpa ($P = 0.0186$, Fig. 1).

CONCLUSIONS

Spray volume does have an overall effect on the efficacy of insecticides used to control TPB in cotton. A spray volume of 10 gpa is what is generally recommended for most pests and appears to be the correct volume for controlling TPB. However, using a volume of 5 gpa may not give adequate control. Further research is needed to determine what minimal spray volume is necessary to maintain the most efficacious control of this important cotton pest.

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Table 1. Tarnished plant bug per 10 row-ft at 5 and 10 gpa final spray volume.

Insecticide	Rate lb ai/acre	Spray Volume gal/acre	TPB/10 row-ft
Untreated		---	7.5 a[1]
Acephate 90S	0.6	5	3.0 bc
		10	1.0 bc
Dicrotophos 8EC	0.4	5	3.5 b
		10	0.8 c
Thiamethoxam 40WG	0.0375	5	3.0 bc
		10	1.0 bc
Bifenthrin 2EC	0.067	5	3.3 bc
		10	1.0 bc

[1] Means within a column followed by same letter do not significantly differ ($P = 0.1$).

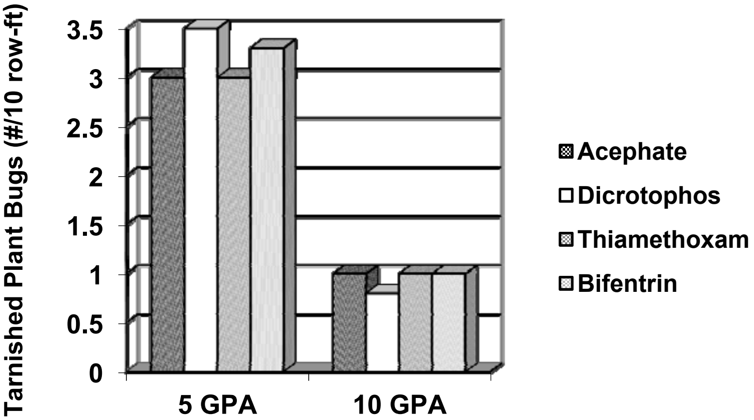

Fig. 1. Comparison of overall efficacy at 5 and 10 GPA.

Economical Alternatives for Applying Residual Herbicides in an Effort to Control Glyphosate Resistant Palmer Amaranth

K.J. Bryant, K.L. Smith, J.A. Bullington, R.C. Doherty and J.R. Meier[1]

RESEARCH PROBLEM

The incidence of glyphosate-resistant (GR) pigweeds in Arkansas has grown rapidly in the last two years. In 2010, fields with widespread GR pigweeds ranged from Northernmost Arkansas southward to Chicot County. Weeds that are resistant to glyphosate threaten the progress of no-till adoption by Arkansas' cotton farmers. Glyphosate-resistant pigweed is believed to be the greatest obstacle cotton farmers have faced thus far in the war on glyphosate resistance.

BACKGROUND INFORMATION

Weed scientists with the University of Arkansas System Division of Agriculture have developed recommendations for controlling glyphosate-resistant pigweed without incorporating tillage. This is possible by including residual herbicides at pre-emergence, in-season and at lay-by. Residual herbicides require timely rainfall for activation. Arkansas cotton farms face a 20% chance that their pre-plant residual herbicides will not receive sufficient rainfall soon enough to be activated (unpublished data, 2010). If the residual herbicides are not activated, some pigweeds escape. The only solution for escapes that are glyphosate resistant is cultivation or hand hoeing.

To reduce the risk of inactive residuals, cotton farmers can incorporate herbicides such as trifluralin or Prowl. Dickey Machine Works in Pine Bluff, Ark. manufactures a bedder/roller/incorporator which they call the Dickey-vator. This piece of equipment differs from a typical bedder/roller in that it is equipped with spray nozzles and hoses to apply herbicide and has a set of rolling baskets that follow the bedding, rolling and spraying operations to incorporate herbicide. The purpose of this study is to compare the cost of multiple pre-emergence weed control strategies using the Dickey-vator to a base approach of not incorporating a residual herbicide.

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[1] Director, weed specialist/professor, program technician, program technician, and program technician, respectively, Southeast Research and Extension Center, Monticello.

RESEARCH DESCRIPTION

Research plots were established at the Rohwer Research Station by Ken Smith using two application methods and multiple materials and rates for obtaining residual control of glyphosate-resistant pigweed. One such approach involves a new piece of equipment that should allow cotton farmers to hip and incorporate a yellow herbicide on the top of the bed in one pass. This approach is compared to other methods of gaining control of pigweeds in cotton with minimal tillage. Enterprise budgets are constructed for each of the treatments using the Mississippi State Budget Generator (Laughlin and Spurlock, 2003). A net change in profit is calculated for each alternative when compared to the base treatment.

A total of 16 combinations of incorporated and PRE herbicides applied using the Dickey-vator were compared to a traditional approach of bedding, then conditioning, followed by planting with Cotoran sprayed behind the planter. Suggested retail price of the Dickey-vator was obtained from the manufacturer and machinery cost parameters were developed for the budget generator. Machinery coefficients are displayed in the appendix table.

RESULTS AND DISCUSSION

The research plots established at the Rohwer Research Station failed in 2011. Due to untimely rainfall there was no difference in weed control among treatments. The plots will be established again in 2012, and the weed control results will be added to the cost analysis presented here.

The treatments and their associated net change in profit are displayed in Table 1. The net change in profit is strictly the result of cost differences. To date we have no lint yield or efficacy data to include in the analysis. Most of the treatments are less expensive than the base approach resulting in a positive change in net profit. Only three of the 16 alternatives reduce net profit compared to the base. Thus, an economical method of incorporating yellow herbicides into a cotton weed control program has been identified. If these treatments result in superior weed control to the base treatment then some economically feasible alternatives to controlling GR pigweed in cotton do exist.

An example partial budget comparing treatment 8 to the base is displayed in Table 2. The cost associated with bedding, spraying, incorporating and planting is almost identical for the two scenarios. The alternative scenario has the advantage of not requiring a row conditioner, thus reducing cost by $5.15 per acre. This means that up to $5.00 per acre above the cost of the herbicide in the base scenario can be spent on additional herbicide in the alternative scenario.

PRACTICAL APPLICATION

The ability to control GR pigweed is imperative if cotton production is to remain economically viable in Arkansas. Current recommendations call for the use of residual herbicides which must be activated by rain. This study estimated the cost of each of 16 strategies which incorporate residual herbicides to some degree, thereby reducing dependence on rain. Thirteen of the treatments were less expensive than the base treatment.

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Table 1. Weed control treatments and their associated net change in profit.

Treatment #	Herbicides	Quantity	Units	Net Change in Profit ($/acre)
Base	Cotoran 4L Pre-emerge	1.6	pts/acre	Base
2	Trifluralin 4EC	1.0	pts/acre	9.85
3	Trifluralin 4EC	2.0	pts/acre	6.58
4	Prowl H2O	1.05	pts/acre	7.60
5	Prowl H2O	2.1	pts/acre	2.03
6	Trifluralin 4EC	2.0	pts/acre	6.58
7	Trifluralin 4EC	3.0	pts/acre	3.31
8	Trifluralin 4EC	4.0	pts/acre	0.04
9	Prowl H2O	2.1	pts/acre	2.03
10	Prowl H2O	3.15	pts/acre	(3.49)
11	Prowl H2O	4.2	pts/acre	(9.02)
12	Trifluralin 4EC	3.0	pts/acre	3.31
13	Trifluralin 4EC Direx 4L	1.0 2.0	pts/acre pts/acre	3.70
14	Trifluralin 4EC Valor SX	1.0 1.0	pts/acre oz/acre	5.16
15	Prowl H2O	3.15	pts/acre	(3.49)
16	Prowl H2O Direx 4L	1.05 2.0	pts/acre pts/acre	1.45
17	Prowl H2O Valor SX	1.05 1.0	pts/acre oz/acre	2.91

Table 2. The partial budget comparing alternative 8 to the present recommendation.

Alternative 8		Base scenario	
Additional Cost:		**Additional Revenue:**	
Bed-Roll & Inc. – Fold	$ 6.78		
Trifuralin 4EC	13.08		
Plant – Folding	8.44		
Reduced Revenue:		**Reduced Costs:**	
		Bed-Disk (Hipper)	$ 6.02
		Row Cond Folding	5.15
		Plant & Pre – Folding	9.48
		Cotoran 4L	7.69
A. Total additional costs and reduced revenue	$28.30	**B. Total additional revenue and reduced costs**	$28.34
		Net change in Profit (B minus A)	$ 0.04

Efficacy of Foliar Insecticides for Control of Heliothines in Conventional Cotton in Arkansas

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RESEARCH PROBLEM

While plant bugs are considered the number one pest in Arkansas cotton, caterpillar pests can be equally or even more devastating to the bottom line for producers. Insecticide resistance in key arthropod pests has been a major concern for producers and crop consultants in the cotton industry because of the heavy reliance on chemical control strategies. There has been a continuing need for new insecticides in cotton due to target pests' ability to develop resistance. (French-Constant and Roush, 1990).

BACKGROUND INFORMATION

The bollworm, *Helicoverpa zea* (Boddie), and tobacco budworm, *Heliothis virescens* (F.), have historically been significant economic pests of cotton across the U.S. Cotton Belt due to the cost of control strategies and associated yield loss (Williams, 2006).The introduction of new chemistries such as chlorantraniliprole and flubendiamide give producers more options for control of heliothines. The objective of this study was to evaluate new products to establish standards for control of tobacco budworm and corn earworm in conventional cotton.

RESEARCH DESCRIPTION

This trial was located in Jefferson County, Ark. 2011. Plot size was 25.3 feet (8 rows) by 50 feet in a randomized complete block design with 4 replications. Conventional variety PHY 315 was selected and planted on 15 May 2011. Insecticide treatments were applied with a John Deere Spray Tractor. The boom was fitted with TX6 hollow cone nozzles at 19-in nozzle spacing. Spray volume was 10 gal/a, at 40 psi. Insecticide applications were applied on 12 and 23 July 2011. Insect density was determined by sampling 25 terminals, squares, blooms

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[3] County extension agent staff chair, Lake Village.

and bolls per plot. Plots were sampled on 3 and 9 days after first application and 3, 6 and 10 days after second application. Data were processed using Agriculture Research Manager V. 8 (Gylling Data Management, Inc., Brookings, S.D.) and Duncan's New Multiple Range Test (*P* = 0.10) to separate means.

RESULTS AND DISCUSSION

Producers encountered an extremely high population of heliothines in the 2011 growing season with trap count numbers increasing up to the 8th of July, and the majority of the population being bollworms (Fig. 1). Control of heliothines was established 3 days after treatment 1 (3DAT1), with all treatments significantly better than the untreated control (UTC) (Table 1). At 9DAT1, all treatments were better than Cobalt Advanced (25 oz/acre) and the UTC. At 3DAT2, all treatments had less damage than the UTC while all other treatments were significantly better than Cobalt Advance (25 oz/acre) except Brigade (6.4 oz/acre) and HGW86 (6.75 oz/ace) (Table 2). At 6DAT2, all treatments had less damage than the UTC; however, Beseige (9 and 12/5 oz/acre), Prevathon (20 oz/acre), HGW86 (13.5 oz/acre), Belt (2 and 3 oz/acre), and Belt (1.5 oz/acre) + Brigade (6.4 oz/acre) had less damage than all other treatments. At 10DAT2, all treatments had less damage than the UTC, all other treatments had less damage than Cobalt Advance (25 oz/acre) with the exception of Brigade (6.4 oz/acre). Season total damage showed that all treatments had less damage than the UTC, all other treatments had less damage than Cobalt Advanced (25 oz/acre), and all other treatments had less damage than Brigade (6.4 oz/acre) and HGW86 (6.75 oz/acre) (Fig. 2). Yield in all treatments was above the UTC. Increases ranged from 362 lint lb/acre to 854 lint lb/acre (Table 3). The results of this study indicate that growers have several options for control of the heliothine complex in conventional cotton.

ACKNOWLEDGMENTS

We thank Chuck Hooker, Bayer CropScience, FMC Corporation, DuPont, Syngenta and Dow Agro Sciences, for their cooperation with this study.

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Table 1. Efficacy of foliar insecticides for control of heliothines in conventional cotton in Arkansas (damage 3 and 9 days after first application).

Treatment	**Total Damage**			
Application 12 July	3 DAT 1		9 DAT 1	
UTC	32.50	a[1]	25.63	a
Cobalt Advance 25 oz/acre	18.38	b	30.63	a
Belt 1.5 oz/acre + Brigade 6.4 oz/acre	4.75	b	5.75	b
Belt 2 oz/acre	7.00	b	10.25	b
Belt 3 oz/acre	5.13	b	5.25	b
Brigade 6.4 oz/acre	7.38	b	14.13	b
HGW86 6.75 oz/acre	12.00	b	13.13	b
HGW86 10.1 oz/acre	10.75	b	9.13	b
HGW86 13.5 oz/acre	4.63	b	6.75	b
Prevathon 20 oz/acre	5.50	b	4.88	b
Beseige 1.25 ZC 9 oz/acre	5.00	b	4.63	b
Beseige 1.25 ZC 12.5 oz/acre	11.38	b	3.63	b

[1] Numbers in a column followed by the same letter are not significantly different (*P* = 0.10).

Table 2. Efficacy of foliar insecticides for control of heliothines in conventional cotton in Arkansas (3, 6, 10 days after 2nd application).

Treatment	**----------------Total Damage-----------------**					
Application 23 July	3 DAT 2		6 DAT 2		10 DAT 2	
UTC	52.5	a[1]	61.5	a	72.4	a
Cobalt Advance 25 oz/a	34.5	b	28.0	b	29.3	b
Belt 1.5 oz/a + Brigade 6.4 oz/a	10.5	cd	5.3	de	4.3	c
Belt 2 oz/a	18.3	cd	11.0	cde	10.0	c
Belt 3 oz/a	12.8	cd	7.8	de	5.3	c
Brigade 6.4 oz/a	23.0	bc	21.8	bc	18.0	bc
HGW86 6.75 oz/a	25.0	bc	19.0	bcd	11.5	c
HGW86 10.1 oz/a	17.5	cd	17.3	b-e	10.8	c
HGW86 13.5 oz/a	15.3	cd	10.8	cde	11.5	c
Prevathon 20 oz/a	5.8	d	4.8	de	12.3	c
Beseige 1.25 ZC 9 oz/a	5.3	d	3.0	e	5.3	c
Beseige 1.25 ZC 12.5 oz/a	4.8	d	4.8	de	3.0	c

[1] Numbers in a column followed by the same letter are not significantly different (*P* = 0.10).

Table 3. Efficacy of foliar insecticides for control of heliothines in conventional cotton in Arkansas (harvest lint lbs/acre).

Efficacy of Foliar Insecticides for Control of Heliothines in Conventional Cotton in Arkansas			
Treatments	**Yield Lint lbs/acre**		**Yield above UTC**
Prevathon 20 oz/a	1049.20	a[1]	854.45
Beseige 12.5 fl oz/a	971.73	ab	776.98
Belt 3 fl oz/a	966.93	abc	772.18
Beseige 9 fl oz/a	938.15	abc	743.40
Belt 1.5 fl oz/a+ Brigade 6.4 fl oz/a	896.68	a-d	701.93
Belt 2 fl oz/a	899.28	a-d	704.53
Brigade 6.4 fl oz/a	857.80	bcd	663.05
HGW86 10.1 oz/a	867.05	bcd	672.30
HGW86 13.5 oz/a	787.88	cd	593.13
HGW86 6.75 oz/a	735.63	de	540.88
Cobalt Adv 25 fl oz/a	556.30	e	361.55
UTC	194.75	f	

[1] Numbers in a column followed by the same letter are not significantly different ($P = 0.10$).

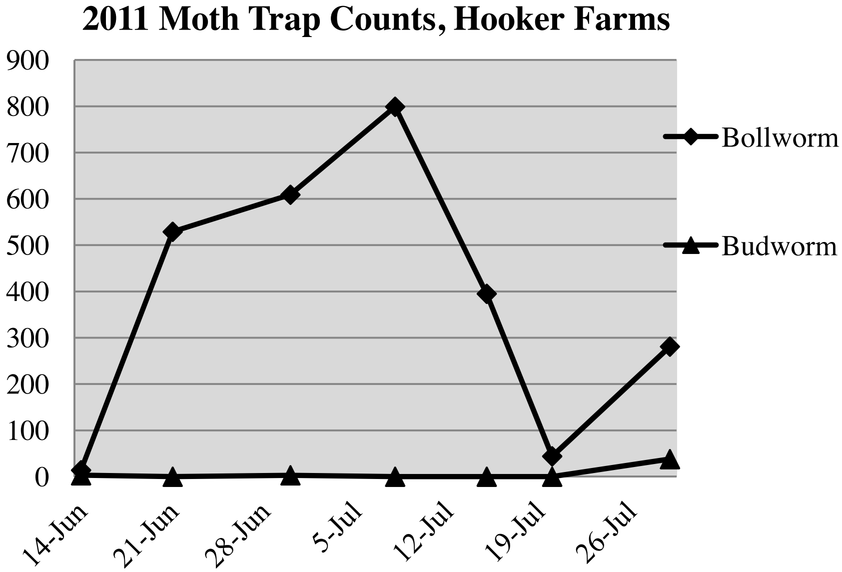

Fig.1. Efficacy of foliar Insecticides for control of heliothines in conventional cotton in Arkansas (pheromone moth trap counts) Hooker Farms.

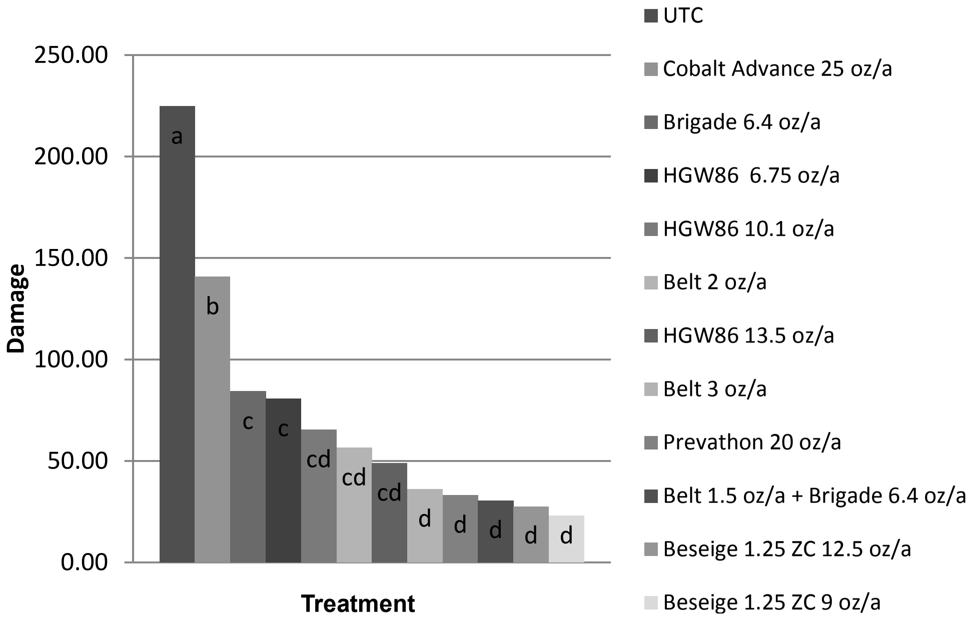

Fig. 2. Efficacy of foliar insecticides for control of heliothines in conventional cotton in Arkansas (season total damage); includes damage from all structures across all rating dates. Columns with the same letter are not significantly different (*P* = 0.05).

Structural Change in Rotation Response for Arkansas Cotton Acreage

A. Flanders[1] *and K.C. Dunn*[2]

RESEARCH PROBLEM

Arkansas cotton acreage has followed declining trends in U.S. acreage during the latter years of the previous decade. Potential acreage shifts to competing crops varies by state and is dependent on localized agronomic conditions. Increasing commodity prices for competing crops relative to cotton prices is a determinant of acreage shifts. In Arkansas, the primary crops competing for cotton acreage are corn, soybeans, and rice. Cotton and corn production are most suitable on soil types that make these crops almost completely interchangeable. Soybean and rice production are optimal on soil types that limit the interchangeability of cotton acreage with these crops.

Factors that lead to changes in U.S. field crop prices have impacts on trends for Arkansas prices. Figure 1 presents indexes of Arkansas crop prices for 2002-2010. The 2002-2006 period has similar trends for cotton, corn, and soybeans. Rice price increases greatly outpace prices for all other field crops throughout 2002-2010. After 2006, price increases for corn and soybeans are greater than cotton price increases. In 2010, the price indexes for rice, soybeans, and corn are 2.72, 1.93, and 1.87, respectively. This compares to a price index of 1.65 for cotton.

BACKGROUND INFORMATION

The major field crops in Arkansas consist of cotton, corn, soybeans, and rice. Typically, 3.5 million acres of soybeans are planted with approximately 100,000 acres devoted to seed production (Coats and Ashlock, 2011). Soybeans are most commonly produced in the eastern part of Arkansas, with some production in the Arkansas River Valley and the southwestern corner of the state. Over 35 of the 75 Arkansas counties produced soybeans in 2011. Approximately 50% of soybean acreage is on silt loam soil, 30% produced on heavier textured clay soil types, and 10% produced on sand loams/loams. In 2010, approximately 74% of planted soybean acreage was irrigated (USDA, NASS, 2012).

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[2] Economist, Agricultural Economics and Agricultural Business Extension, Little Rock.

The Arkansas River Delta region in the eastern part of the state leads in rice production. Some acreage is in the Arkansas River Valley, as well as in southwestern Arkansas. Rice and soybeans are typical rotation crops on irrigated acreage, and 68% of rice acreage follows soybeans. Approximately 28% of rice acreage follows rice, and the remaining 4% follow other crops such as corn, grain sorghum, cotton, wheat, oats, and fallow. The majority of rice is produced on silt loam soils (48% of total acreage), with an increasing amount produced on clay (27%) and clay loam (21%) soils. Arkansas primarily produces the long and medium grain varieties, but a small amount of short grain rice is also produced in the state (Wilson Jr. et al., 2010).

Arkansas corn and cotton production are focused in the eastern part of the state. Although producers have successfully cultivated corn on a wide range of soil types, corn performs best on deep, well-drained, medium to coarse textured soils. One of the most important considerations for land selection is drainage, and corn performs best on well drained soils. Characteristics of optimal soil types for cotton are similar to corn (Barber and McClelland, 2012; Ross et al., 2011).

Fig. 2 presents the state acreage planted to each crop for 1995-2010. In addition to recent trends, Fig. 2 shows long-term acreages for each of the crops. Soybeans have a historical average of between 3.0 and 3.5 million acres. Rice has a historical average of 1.5 million acres. Until 2007, cotton had a historical average of 1.0 million acres, and corn had a historical average of less than 0.5 million acres. There are approximately 6.0 million annual acres of cotton, corn, soybeans, and rice in Arkansas. Of this total, Fig. 3 indicates than only 0.5 million to 1.0 million acres per year are reasonably subject to reallocation due to price.

Arkansas cotton acreage can be categorized with a period of stable or increasing cotton acreage during 2002-2006, followed by a period of declining acreage during 2007-2010 in Fig. 3. These distinct periods of cotton acreage correspond to changes in relative prices received presented in Fig. 1. All crop prices are increasing after 2006, but cotton price increases lag behind increases for other crops. Although the price index for rice is much greater than all other crops, rotation considerations with soybeans and compatibility of soil types with cotton is a limiting factor for the impacts that increased rice prices can have on cotton acreage. The objective of this analysis is to quantify any structural changes in acreage response among cotton and competing crops for the 2002-2006 and 2007-2010 time periods.

RESEARCH DESCRIPTION

County level acreage data was applied to investigate acreage response among cotton and competing crops during 2002-2010 (USDA, NASS, 2012). Data was collected for 18 counties producing the major field crops for a total of 162 observations. The panel data structure allows for repeated annual observations on counties producing cotton and competing crops. A fixed effects model for panel data captures all unobserved, time constant factors that affect a dependent variable. Changes in cotton acreage among competing crops can be represented by a first-differenced equation as:

Eq. (1) $$\Delta Cotton_{it} = \beta_0 + \beta_1 \Delta Corn_{it} + B_2 \Delta Soybean_{it} + B_3 \Delta Rice_{it} + \Delta\mu_{it},$$

where *i* represents a county as a cross-sectional unit and *t* represents an annual observation of the change in crop acreage from the previous year. β_0, β_1, B_2, and B_3 are parameters to be estimated, and $\Delta\mu_{it}$ is an error term for the first-differenced equation. Assuming that the explanatory variables are strictly exogenous and not correlated with the error term, the first-difference method gives unbiased parameter estimates.

Potential structural change due to higher commodity crops for competing crops after 2006 can be quantified by restating Eq. (1) as

Eq. (2) $$\Delta Cotton_{it} = \beta_0 + \beta_1 \Delta Corn0306_{it} + \beta_2 \Delta Corn0710_{it} + B_3 \Delta Soybean0306_{it} + B_4 \Delta Soybean0710_{it} + \Delta Rice0306_{it} + B_6 \Delta Rice0710_{it} + \Delta\mu_{it},$$

where each explanatory variable in Eq. (1) is dichotomized to represent acreage changes for 2003-2006 and for 2007-2010.

RESULTS AND DISCUSSION

Data was pooled, and OLS was applied for heteroscedasticity-consistent covariance matrix estimation of the model represented by Eq. (1). Table 1 presents the parameter estimates for Eq. (2). Negative signs indicate that corn, soybeans, and rice are substitutes as competing crop for cotton acreage during both time periods. Producers continued similar rotation practices in both time periods, but cotton acreage declined relative to other crops in rotation programs. A coefficient greater than 1.0 for corn during 2007-2010 indicates that higher corn prices induced new corn acreage in addition to acreage that was exiting cotton for corn. Comparing estimates between the 2003-2006 and 2007-2010 time periods indicates that substitution increased for all competing crops after 2006. Increases in relative coefficient values for the later time period were 146% for corn, 151% for soybeans, and 131% for rice. Soybeans and rice are expected to substitute for cotton as rotation crops. The average coefficient change in the later period for soybeans and rice was 141%.

PRACTICAL APPLICATION

Results in Table 1 indicate structural shifts in acreage allocations among cotton and rotation crops. The structural shifts are attributable to relative relationships among commodity prices that were less favorable to cotton for the period beginning in 2007. Arkansas cotton acreage can be categorized with a period of stable or increasing cotton acreage during 2002-2006, followed by a period of declining acreage during 2007-2010. These distinct periods of cotton acreage correspond to changes in relative prices received that favor alternative crops over cotton. Results of this analysis indicate structural shifts in acreage allocations among cotton and rotation crops. Producers continued similar rotation practices in both time periods, but cotton acreage declined relative to other crops in rotation programs.

As cotton acreage declines can be attributed to decreasing relative price levels, cotton acreage increases would follow any increases in relative cotton prices. However, another consideration for producers shifting acreage out of cotton is the extensive management requirements when compared to alternative crops. Crop enterprise budgets include total labor hours required for production of each crop with surface irrigation (Dunn et al., 2011). Total labor requirements for cotton are 1.68 hours per acre. This compares to 0.66 hours for soybeans, 0.79 hours for corn, and 0.98 hours for hybrid rice. As relative prices increase for alternative crops, the greater management requirements further reduce incentives for planting cotton.

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Table 1. Regression coefficients for acreage change, cotton and major field crops, Arkansas, 2003-2011.

Variable[1]	Coefficient[2]	Std. Error	t Statistic	Prob. > |t|
Intercept	481.997	528.100	0.910	0.3630
Corn0306	-0.804*	0.172	-4.680	<0.0001
Corn0710	-1.172*	0.126	-9.300	<0.0001
Soybean0306	-0.464*	0.075	-6.210	<0.0001
Soybean0710	-0.702*	0.076	-9.270	<0.0001
Rice0306	-0.448*	0.088	-5.090	<0.0001
Rice0710306	-0.587*	0.177	-3.320	0.0012
R-Square	0.6997			

[1]Numbers following crop designate four-year time period.
[2]Values followed by * are significant at $P < 0.01$.

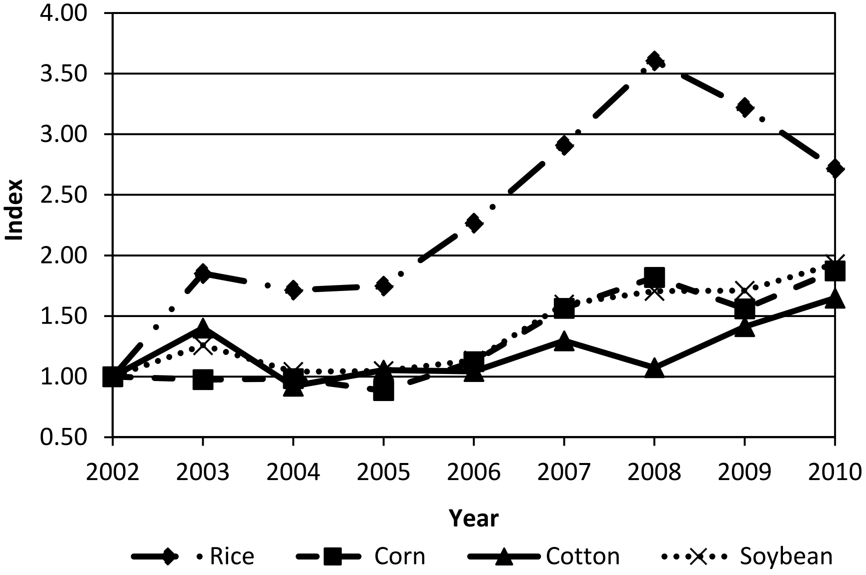

Fig. 1. Index of Arkansas price received, 2002-2010 (Source: USDA, NASS 2012).

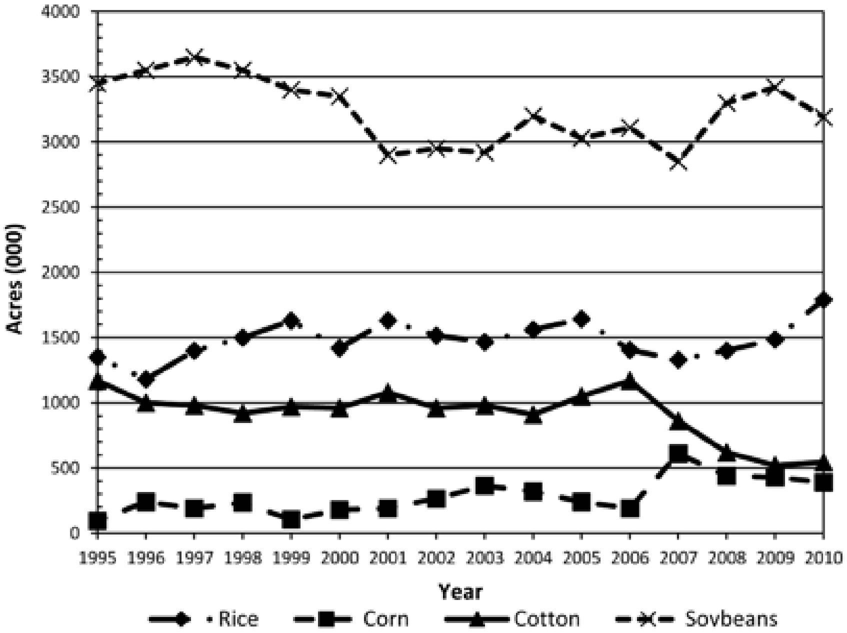

Fig. 2. Arkansas acreage for major field crops, 1995-2010 (Source: USDA, NASS 2012).

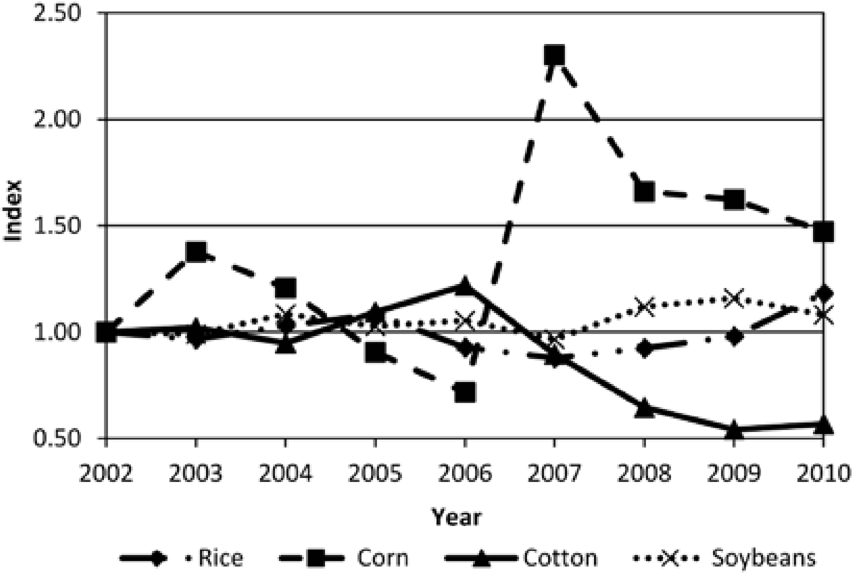

Fig. 3. Index of Arkansas acreage planted, 2002-2010 (Source: USDA, NASS 2012).

2011 Cotton Research Verification Annual Summary

B.A. McClelland[1], L.T. Barber[2], and A. Flanders[1]

INTRODUCTION

The University of Arkansas System Division of Agriculture has been conducting the Cotton Research Verification Program (CRVP) since 1980. This is an interdisciplinary effort in which recommended Best Management Practices and production technologies are applied in a timely manner to a specific farm field. Since the inception of the CRVP in 1980, there have been 241 irrigated fields entered into the program. Producers are asked what they would like to improve in their current operation then a field is chosen that fits a standard model of the producers operation and requires the necessary recommendations to improve the farm.

All of the recommendations made to the producers in the program are based on proven research by University of Arkansas System Division of Agriculture researchers in their respective disciplines. The producer agrees to apply the necessary recommendations in a timely manner

BACKGROUND INFORMATION

There were seven fields in the 2011 Cotton Research Verification Program. Locations included: Clay, Craighead, Jefferson, Lee, Lincoln, Mississippi, and Phillips counties. All of the fields were furrow irrigated. Every week the producer, the agent, and the verification coordinator met, scouted the field, and discussed the recommendations. The average field size was 51 acres and the average yield was 988 lb/acre. This was 53 lb/acre higher than the projected state yield of 935 lb/acre.

RESULTS AND DISCUSSION

The Clay County field was entered for the second year of the verification program. This field's producer wanted to work specifically on irrigation and in-

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

secticide terminations. In order to accomplish this, the producer was taught the node-above-white-flower technique for measuring maturity. Heat units were calculated and termination intervals were explained to the producer. The producer was satisfied with the inputs that he saved by not over spraying. Overall the field produced 1,347 lb/acre.

The Craighead County field is in the first year of the verification program. The producer had a desire to improve his irrigation management practices to achieve high yields and lower costs. The producer was introduced to the PHAUCET program for irrigation management. He was very pleased with the way that the field watered evenly and he was able to reduce the amount of time he had to pump in order to water the whole field. He estimated that he saved enough time to equal one irrigation. The field yielded 1248 lb/acre.

The producer of the Jefferson County Verification was in incorporating the University of Arkansas Cooperative Extension Service recommendations into his farming operation. Each week the producer listened to the recommendations and applied them in a timely manner. The field yielded 915 lb/acre. The producer stated that this was the highest yield on his farm this year.

The Lee County field incorporated a new concept of cotton management and production with double crop cotton following wheat scenario. The key to making this field work economically was careful input management. In this scenario, herbicide inputs costs were reduced due to the cover that was provided by the wheat stubble. Due to the later planting date, a lower yield was expected. However due to the lower amount of inputs and the higher price received for the crop, yield was not as big a factor. The field yielded 697 lb/acre.

The Lincoln County field was in the second year of the verification program. The producer wanted to compare his current management practices to the cotton production recommendations of the University of Arkansas Cooperative Extension Service. Due to high root-knot nematode levels one of the main recommendations was to plant nematode tolerant variety. The field looked very good toward the end of the season However, wet weather in the early fall introduced boll rot into the field reducing the yield. The field produced 935 lb lint/acre. The producer did state that this yield was consistent with the yields in that area this year.

The Mississippi County field was the third field to be in its second year of the program this year. The producer wanted to work on glyphosate pigweed management. Weeds were managed by using a combination of residual and contact herbicides under row hoods as well as contact and residual herbicides over the row. Hand weeding was utilized after lay-by to remove the few escapes. The field was clean and the cotton looked good going into the month of September. It yielded well with an average yield of 1,248 lint lb/acre.

The Phillips County cotton verification field was a unique test. The field was planted in a new conventional variety that had previously been released by the University of Arkansas called UA48. The producer wanted to try this variety to determine if conventional varieties would work on his farm. Unfortunately glyphosate drift reduced the yield and proved that variety placement was crucial when using a conventional variety in an area dominated by RoundUp Ready crops. The field yielded 543 lb lint/acre. The producer stated he was interested in the Cooperative Extension Service recommendations that were made and he would like to continue the program next year with a different variety.

PRACTICAL APPLICATION

The cotton verification program provides the only real-world data and information on cotton production profitability based on non-biased extension recommendations. There are many other sources of information for cotton management available but this program is the only one that provides non-biased university based research data to backup management decisions. The program has been very successful over the last 30 years and will remain a constant source for questions and recommendations for cotton producers in the state of Arkansas.

APPENDIX I

STUDENT THESES AND DISSERTATIONS RELATED TO COTTON RESEARCH IN PROGRESS IN 2011

Acuña, Andrea. Identification of *Gossypium* species cytoplasm with molecular markers. (M.S., advisor: Stewart)

Alcober, Ed Allan L. Genetic diversity and evolution of glyphosate-resistant palmer amaranth. (Ph.D., advisor: Burgos)

Clarkson, Derek. Insecticide/Herbicide interactions of tankmixes on cotton. (M.S., advisor: Lorenz)

DeVore, Justin. Use of deep tillage and cover crops for improved weed management in cotton and soybean. (M.S., advisor: Norsworthy)

FitzSimons, Toby. Cotton plant response to high temperature stress during reproductive development, remote sensing, and amelioration. (Ph.D., advisor: Oosterhuis)

Greer, Amanda. Relationship between Telone II and nitrogen fertility in cotton in the presence of reniform nematodes. (M.S., advisor: Kirkpatrick)

Griffith, Griff. Glyphosate-resistant Palmer amaranth in Arkansas: Resistance mechanisms and management strategies. (Ph.D., advisor: Norsworthy)

Hannam, Josh. Pathogens of the Tarnished Plant Bug, *Lygus lineolaris*, in Arkansas (M.S., advisor: Steinkraus)

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

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

Ma, Jainbing. Influence of soil physical parameters, *Thielaviopsis basicola*, and *Meloidogyne incognita* on cotton root architecture and plant growth. (Ph.D., advisors: Kirkpatrick and Rothrock)

Navas, Juan Jaraba. The influence of the soil environment and spatial and temporal relationship on *Meloidogyne incognita* and *Thielaviopsis basicola* and their interaction on cotton. (Ph.D., advisor: Rothrock)

Phillips, Justin. Effects of 1-Methylcyclopene on cotton reproductive development under heat stress. (M.S., advisor: Oosterhuis)

Pretorius, Mathilda. High temperature tolerance in cotton. (Ph.D., advisor: Oosterhuis)

Raper, Tyson. Potassium deficiency during reproductive development: Effect on reproductive development, remote sensing and amelioration. (Ph.D., advisor: Oosterhuis)

Von Kanel, Michael B. Fruit injury and developing injury thresholds in transgenic cotton. (M.S., advisor: Lorenz)

Zhang, Jin. Identification of heat stress genes related to heat tolerance in *Gossypium hirsutum* L. (M.S., advisor: Stewart)

APPENDIX II

RESEARCH AND EXTENSION 2011
COTTON PUBLICATIONS

BOOKS

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