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Cover photo: Instead of using a drone to take aerial, remote-sensing measurements of soybean experiments, Larry Purcell, Professor, Department of Crop, Soil, and Environmental Sciences, University of Arkansas System Division of Agriculture, Fayetteville, is pictured using large kites to lift cameras and sensors over his experiments; credit: Fred Miller, University of Arkansas System Division of Agriculture, Fayetteville, Ark.

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Arkansas Agricultural Experiment Station, University of Arkansas System Division of Agriculture, Fayetteville. Mark J. Cochran, Vice President for Agriculture; Clarence E. Watson, AAES Director and Associate Vice-President for Agriculture–Research. WWW/MSWord 2013.

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FOREWARD

The 2014 Arkansas Soybean Research Series include research reports on topics pertaining to soybean across several disciplines from breeding to post-harvest processing. Research reports contained in this publication may represent preliminary or only a single year of result; therefore, these results should not be used as a basis for long-term recommendations.

Several research reports in this publication will appear in other Arkansas Agricultural Experiment Station publications. This duplication is the result of the overlap in research coverage between disciplines and our effort to inform Arkansas soybean producers of all the research being conducted with funds from the soybean check-off program. This publication also contains research funded by industry, federal, and state agencies.

Use of products and trade names in any of the research reports does not constitute a guarantee or warranty of the products named and does not signify that these products are approved to the exclusion of comparable products.

Extended thanks are given to the staff at the state and county extension offices, as well as at research centers and stations; producers and cooperators; and industry personnel who assisted with the planning and execution of the programs.

ACKNOWLEDGMENTS

We would like to thank Larry Purcell, Trent Roberts, Nick Seiter, and Terry Spurlock for reviewing the articles in this publication.

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The Arkansas Soybean Promotion Board

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OVERVIEW AND VERIFICATION

Soybean Verification Program Report

C.L. Grimes[1], M.C. Norton[2], W.J. Ross[3], and C.R. Stark, Jr.[2]

ABSTRACT

The 2014 Soybean Research Verification Program (SRVP) was conducted on sixteen commercial soybean fields across the state. Counties participating in the program included Arkansas, Clark, Clay, Cross, Desha, Jefferson, Lawrence (2 fields), Lafayette, Lee, Phillips (2 fields), Prairie, Randolph, St. Francis, and White Counties for a total of 618 acres. Grain yield in the 2014 SRVP averaged 59 bu/acre ranging from 27 to 80 bu/acre. The 2014 SRVP average yield was 9 bu/acre greater than the estimated Arkansas state average of 50 bu/acre. The highest yielding field was in Desha County with a grain yield of 80 bu/acre. The lowest yielding field was in Randolph County and produced 27 bu/acre.

INTRODUCTION

In 1983, the University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) established an interdisciplinary soybean educational program that stresses management intensity and integrated pest management to maximize returns. The purpose of the Soybean Research Verification Program (SRVP) was to verify the profitability of CES recommendations in fields with less than optimum yields or returns.

The goals of the SRVP are to: 1) educate producers on the benefits of utilizing CES recommendations to improve yields and/or net returns, 2) conduct on-farm field trials to verify research-based recommendations, 3) aid researchers in identifying areas of production that require further study, 4) improve or refine existing recommendations which contribute to more profitable production, and 5) incorporate data from SRVP into Extension educational programs at the county and state level. Since 1983, the SRVP has been conducted on 550 commercial soybean fields in 33 soybean-producing counties in Arkansas. The program has typically averaged about 10 bu/acre better than the state average yield. This increase in yield over the state average can be attributed mainly to intensive cultural management and integrated pest management.

PROCEDURES

The SRVP fields and cooperators are selected prior to the beginning of the growing season. Cooperators agree to pay production expenses, provide expense data, and implement university recommendations in a timely manner from planting to harvest. A designated county agent from each county assists the SRVP coordinator in collecting data, scouting the field, and maintaining regular contact with the producer. Weekly visits by the coordinator and county agents were made to monitor the growth and development of the crop, determine what cultural practices needed to be implemented and to monitor type and level of weed, disease and insect infestation for possible pesticide applications.

An advisory committee consisting of Extension specialists and university researchers with soybean responsibility assists in decision-making, development of recommendations and program direction. Field inspections by committee members were utilized to assist in fine-tuning recommendations.

In 2014, the following counties participated in the program: Arkansas, Clark, Clay, Cross, Desha, Jefferson, Lawrence (2 fields), Lafayette, Lee, Phillips (2 fields), Prairie, Randolph, St. Francis and White counties. The sixteen soybean fields totaled 618 acres enrolled in the program. Eight Roundup Ready (RR) varieties were planted (AG 5233, NK S49-F8, PRG 4211, Armor 4744, AG 4632, PIO 94Y80, PIO 95Y40, AG 4533), three LibertyLink varieties (Halo 5:26, Delta Grow 4990 LL, Terral TV 49L29) and two conventional varieties (Leland & Osage) in the sixteen fields and CES recommendations were used to manage the SRVP fields. Agronomic and pest management decisions were based on field history, soil test results, variety, and data collected from individual fields during the growing season. An integrated pest-management philosophy is utilized based on CES recommendations. Data collected included components such as stand density, weed populations, disease infestation levels, insect populations, rainfall, irrigation amounts, and dates for specific growth stages.

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RESULTS AND DISCUSSION

Yield

The average SRVP yield was 59 bu/acre with a range of 27 to 80 bu/acre. The SRVP average yield was 9 bu/acre more than the estimated state yield of 50 bu/acre. This difference has been observed many times since the program began, and can be attributed in part to intensive management practices and utilization of CES recommendations. The highest yielding field yielded 80 bu/acre and was seeded with Armor 4744 RR in Desha County.

Planting and Emergence

Planting began with St. Francis County on 12 April and ending with Lee County planted 21 June. The majority of the verification fields were planted in May. An average of 58 lbs/acre of seed was used for planting. An average of 7 days was required for emergence. Refer to Table 1 for agronomic information.

Fertilization

Fields enrolled in the Soybean Research Verification Program were fertilized according to University of Arkansas Soil Test Laboratory results. Refer to Table 2 for detailed fertility information.

Weed Control

Fields were scouted on a weekly basis and extension recommendations were utilized for weed control programs. Refer to Table 3 for herbicide rates and timings.

Disease Control

Fields were scouted on a weekly basis and extension recommendations were utilized for disease control programs. Refer to Table 4 for fungicide applications.

Insect Control

Fields were scouted on a weekly basis and extension recommendations were utilized for insect control programs. Refer to Table 4 for insecticide applications.

Irrigation

All the fields that were irrigated were enrolled in the University of Arkansas Irrigation Scheduler Computer Program. Irrigations were recommended-based information generated from the Scheduler program. Twelve of the 16 fields in the 2014 SRVP were furrow-irrigated and 2 were center pivot. Two fields enrolled in the program were dry land. Flow meters were used in four of the fields to record water usage throughout the growing season.

PRACTICAL APPLICATIONS

Data collected from the 2014 SRVP reflect the general trend of increasing soybean yields and above average returns in the 2014 growing season. Analysis of this data showed that the average yield was higher in the SRVP compared to the state average and the cost of production was equal to or less than the Cooperative Extension Service-estimated soybean production costs.

ACKNOWLEDGMENTS

We appreciate the cooperation of all participating soybean producers and thank all Arkansas soybean growers for financial support through the soybean check-off funds administered by the Arkansas Soybean Research and Promotion Board. We appreciate the cooperation of all participating County Extension Agents. We also thank the professors, specialists and program associates of the University of Arkansas System Division of Agriculture's Agricultural Experiment Station and Cooperative Extension Service and the district administration for their support.

Table 1. Agronomic information for the 2014 Soybean Research Verification Fields.

County	Variety	Field size (ac)	Previous crop	Production system	Seeding rate (lb/ac)	Stand density (plants/ac)	Planting date	Emergence date	Harvest date	Yield† adj. to 13% moisture(bu/ac)
Arkansas	Asgrow 5233	33	Rice	FSI	54	90K	5/26	6/2	10-21	69
Clark	NK S49-F8	33	Soybean Grain	FSNI	58	128K	5/22	6/2	10-19	56
Clay	Halo 5:26	39	Sorghum	FSI	57	167K	5/22	5/28	10/24	52
Cross	Progeny 4211	43	Rice	ESI	60	140K	4/19	4/29	9/10	71
Desha	Armor 4744	51	Corn	ESI	54	128K	4/19	4/25	8/28	80
Jefferson	Delta Grow 4990 LL	64	Soybean Grain	FSI	60	147K	5/24	5/31	10-20	61
Lawrence-1	Asgrow 4632	27	Sorghum	FSI	60	148K	5/25	5/31	10/27	65
Lawrence-2	Leland	42	Soybean	FSI	60	153K	5/21	5/28	11/10	59
Lafayette	Pioneer 94Y80	50	Corn	ESI	58	125K	5/2	5/2	9/2	77
Lee	Asgrow 4632	12	Corn	FSI	58	70K	6/21	6/28	10/1	34
Phillips-1	Osage	27	Soybean	ESI	60	125K	4/25	5/2	8-29	52
Phillips-2	Asgrow 4632	34	Rice	ESI	58	106K	5/4	5/10	9-29	73
Prairie	PIO 95Y40	16	Corn	FSI	58	95K	5/26	5/31	10/24	56
Randolph	Asgrow 4533	40	Soybean	FSNI	67	85K	6/19	6/23	11/4	27
St. Francis	Terrel TV 49L29	46	Soybean	ESI	54	160K	4/12	4/22	9/25	59
White	NK S49-F8	61	Corn	FSI	58	125K	6/17	6/22	10/30	60
Average		**39**			**58**	**125K**	**5/17**	**5/23**	**10/7**	**59**

†State Avg. Yield – 50 bu/ac.

Table 2. Soil tests results, applied fertilize and soil classification for the 2014 Soybean Research Verification Fields

		Soil Test (lb/ac)			Applied Fertilize N-P-K (lb/ac)	
County	**pH**	**P**	**K**	**Zn**	**Pre-plant**	**Soil Classification**
Arkansas	6.8	84	218	8.6	0-0-60	Dewitt silt loam
Clark	6.2	21	130	7.2	0-80-130	Gurdon, Ouachita silt loam
Clay	6.3	86	240	14.0	0-0-60	Bosket fine sandy loam
Cross	7.7	106	244	10.0	0-60-90	Silt loam
Desha	6.9	94	220	9.0	0-0-60	McGehee, Rilla silt loam
Jefferson	5.9	70	182	5.6	0-23-90	McGehee silt loam, Perry clay
Lawrence-1	6.3	35	105	6.0	0-40-60	Bosket fine sandy loam
Lawrence-2	6.5	59	220	6.3	0-40-90	Patterson fine sandy loam
Lafayette	6.0	94	368	7.6	0-0-0	Billyhaw, Perry clay
Lee	6.4	96	374	6.2	0-0-0	Alligator clay
Phillips-1	6.6	54	188	3.8	0-40-60	Memphis, Foley silt loam
Phillips-2	7.1	78	216	4.8	0-0-60	Henry silt loam, LaGrange sandy loam
Prairie	7.6	29	253	11.5	0-40-60	Stuttgart silt loam
Randolph	7.0	32	68	6.8	0-60-90	Silt loam
St. Francis	6.4	118	502	9.8	0-0-0	Alligator, Sharkey & Earl clay
White	6.3	86	234	8.1	2 ton/A Chicken Litter	Calhoun silt loam

Table 3. Herbicide rates and timings for 2014 Soybean Research Verification Program fields by county.

	Herbicide	
County	Burndown/Pre-emergence herbicide application	Post-emergence herbicide application
Arkansas	3 oz/ac Fierce	22 oz/ac Roundup PowerMax
Clark	1 qt/ac Glyphosate plus 1.3 pt/ac Metolachlor	1 qt/ac Glyphosate plus 1.5 pts/ac Flexstar
Clay	----------	1st: 29 oz/ac Liberty plus 32 oz/a Prefix 2nd: 32 oz/ac Liberty
Cross	4 oz/ac Envive	32 oz/ac Roundup PowerMax plus 48 oz/a Warrant
Desha	1 pt/ac Dual Magnum	22 oz/ac Roundup PowerMax plus 1.3 pts/ac Metolachlor
Jefferson	1 qt/ac Glyphosate plus 0.5 oz/ac FirstShot (burndown) fb 2 oz/ac Zidua (pre)	30 oz/ac Liberty plus 1 pt/ac Flexstar
Lawrence-1	32 oz/ac Treflan	32 oz/ac Roundup PowerMax plus 32oz/ac Prefix
Lawrence-2	24 oz/ac Metolachlor	1st: 24 oz/ac Storm plus 40oz/ac Warrant 2nd: 16 oz/ac Select plus 13oz/ac COC
Lafayette	22 oz/ac Roundup PowerMax plus 1 pt/ac Dual Magnum	22 oz/ac Roundup PowerMax
Lee	2 oz/ac Valor	1 qt/ac Glyphosate plus 1 pt/ac Dual Magnum
Phillips-1	----------	1st 0.5 oz/ac Classic plus 1.4 oz/ac Pursuit plus 1 pt/ac Dual Magnum 2nd 0.3 oz/ac FirstRate
Phillips-2	1.5 pt/ac Boundary	22 oz/ac Roundup PowerMax plus 1 pt Dual Magnum
Prairie	----------	1st: 32 oz/ac Roundup PowerMax plus 32 oz/ac Prefix 2nd: 32 oz/ac Roundup PowerMax
Randolph	----------	1st: 32 oz/ac Glyphosate 2nd: 32 oz/ac Glyphosate
St. Francis	32 oz/ac Glyphosate plus 5 oz/a Verdict	1st: 29 oz/ac Liberty plus 32 oz/ac Prefix 2nd: 32 oz/ac Liberty
White	----------	1st: 24 oz/ac Ultra Blazer plus 24oz/ac Dual Magnum 2nd: 32 oz/ac Roundup PowerMax plus 16 oz/ac Dual Magnum

Table 4. Fungicide and insecticides applications in 2014 Soybean Research Verification fields by county.

County	Aerial Web Blight	Frogeye	Bollworm/Defoliators	Stink Bug
Arkansas	----------	----------	----------	4.27 oz/ac Brigade
Clark	----------	----------	2 oz/ac Belt	3.65 oz/ac Ravage
Clay	----------	----------	----------	----------
Cross	----------	14 oz/ac Quadris Top	---------	1.83 oz/ac Karate Z
Desha	----------	4.5 oz/ac Stratego YLD	----------	6.4 oz/ac Brigade
Jefferson	----------	----------	2 oz/ac Belt	4 oz/ac Brigade
Lawrence-1	----------	----------	----------	----------
Lawrence-2	----------	----------	----------	3.2 oz/ac Sniper
Lafayette	----------	----------	----------	----------
Lee	----------	----------	0.5 lbs/ac acephate plus 5.12 oz/ac Brigade	----------
Phillips-1	----------	10 oz/ac Quadris Top	----------	----------
Phillips-2	----------	----------	----------	----------
Prairie	----------	12 oz/ac Quadris Top	----------	4.3 oz/ac Lambda Cy
Randolph	----------	----------	2 oz/ac Ravage	----------
St. Francis	----------	----------	----------	----------
White	----------	8 oz/ac Quadris Top	----------	3.2 oz/ac Sniper

Breeding New Soybean Cultivars with High Yield and Disease Resistance

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ABSTRACT

The University of Arkansas System Division of Agriculture's Soybean Breeding and Genetics Program has been developing maturity group (MG) 4 and 5 soybean varieties with high yield, pest resistance, and specialty traits. Many of the conventional lines developed in the soybean breeding program are grown in Arkansas and other southern states. To develop new and improved soybean cultivars, every year we make hundreds of crosses to combine high yield, good disease package, and wide adaptability using diverse high-yielding varieties/lines. Lines are initially tested in preliminary tests in two Arkansas locations and further evaluated in five Arkansas locations. Subsequently, the best lines with high yield and traits of interest are selected and tested in other southern states in USDA Uniform Preliminary Test, USDA Uniform Test, or Regional Quality Traits Test. In 2014, four lines were released as cultivars: 1 conventional (UA 5014C), 1 Roundup Ready-1 (UA 5414RR), 1 large-seeded tofu/soymilk type (R08-4004), and 1 high protein conventional (UA 5814HP).

INTRODUCTION

Use of new and improved soybean cultivars with high yield, pest resistance, stress tolerance, and good adaptation is a key to improve soybean production. The University of Arkansas System Division of Agriculture's Soybean Breeding and Genetics program has been continuously working on developing new and improved conventional and herbicide resistant soybean cultivars with broad adaptation in Arkansas and other southern states. New lines are usually checked for soybean cyst nematode (SCN), root-knot nematode (RKN), sudden death syndrome (SDS), stem canker (SC), frogeye leaf spot (FLS), and soybean mosaic virus (SMV). The ultimate goal is to combine high yield with good disease package and broad adaptation. Our target maturity group ranges from late 4 to early 6. Most of our released cultivars such as Osage, Ozark, UA 5612, and UA 5213C have been used in commercial production and cultivar development in other breeding programs. Osage has been used as a yield check in the USDA uniform tests. Our breeding program is a continuous and cyclic process to keep improving soybean yield and quality.

PROCEDURES

A series of well established procedures of conventional breeding and selection for important agronomic traits were implemented in this project. The critical strategy for achieving the breeding objective is to combine the best traits from different varieties and/or lines. The breeding scheme can be summarized in three basic steps: 1) selection of parents with desired complementary characteristics and intercrossing them, 2) growing resulting populations for 4-5 generations to allow genetic segregation/recombination and then reaching genetic homozygosity (true-breeding), and 3) selecting and evaluating pure lines from each cross.

We make 200-250 different crosses using University of Arkansas developed high-yielding lines, other southern varieties/lines, or disease resistant germplasm as parents. The plant populations at early generations are advanced using a bulk pod descent method, and 12,000 to 15,000 $F_{4:5}$ families are evaluated for adaptation and agronomic performance. Selection for the Roundup Ready (RR) trait starts early in the breeding process using the combination of bulk pod descent and mass selection methods. Off-season nursery facilities are used to speed up the breeding process. For the preliminary yield trial, we test 1,500 to 2,000 new lines each year. Approximately 150-200 lines are selected and evaluated in advanced trials in Arkansas and the southern region. Typically, selected lines are tested at 2 locations with 2 replications and further evaluated at 5 locations to ensure the stability and adaptability in Arkansas. The best lines selected are evaluated in the USDA Southern Uniform Test and the Arkansas Soybean Performance Test. Promising lines are increased for foundation seed in preparation for cultivar release.

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All advanced lines tested for diseases resistance (SCN, RKN, SDS, SC, SMV, and FLS) in the greenhouse and/or field. For SCN screening, prevalent races (1, 2, 3, 5, 6, 9, and 14) are used. Two prevalent races are used for RKN screening in the greenhouse. SDS, SC, SMV, and FLS screening are conducted in the greenhouse with artificial inoculation and re-evaluated in the field under natural infection conditions. Selected lines are also included in a cooperative test for SCN, RKN, SDS, SC, SMV, and FLS in other southern state programs.

RESULTS AND DISCUSSION

Following the successful release of UA 5612 (Chen et al., 2014a) and UA 5213C (Chen et al., 2014b), additional two new high-yielding conventional lines (R05-3239 and R09-4571) were proposed to be released. Variety R05-3239, released as UA 5014C, is a maturity group (MG) 5.0 line, with determinate growth habit and tawny pubescence; while R09-4571 (release pending) is a MG 4.8 line with indeterminate growth habit and tawny pubescence. Both lines are competitive with commercial late 4 and early 5 cultivars available in southern states. Foundation seed were produced for R05-3239 and R09-4571 along with other conventional varieties. In 2014, foundation seed were produced for Hutcheson (255 units), Osage (1070 units), UA 5612 (1101 units), UA 5213C (1037 units), R05-3239 (1032 units), and R09-4571 (809 units). In addition, 1800 units of foundation seed for a new Roundup Ready-1 (RR-1) cultivar, UA 5414RR, were produced in 2014. Moreover, foundation seed were produced for large-seeded (R08-4004; 885 units), high protein (R09-3789, released as UA 5814HP; 589 units), and high sugar (R07-2000; 400 units) lines in 2014. Small scale pre-foundation and breeder seed for other promising high-yielding lines were also produced in Stuttgart, Ark. for future release.

Evaluating our promising pipeline products in the USDA Uniform Tests helps to determine the best lines for future release and areas of adaptation. A total of 15 lines were evaluated in the 2014 USDA Uniform Test for MG IV, V, or VI, and these lines yielded 92-108% of the check mean. In particular, three lines in MG V test across 17 locations, R10-230, R11-262, and R11-245 ranked 1st, 3rd, and 5th, respectively, with 105-108% check yield (Osage, Ellis, JTN-5203, 95Y70, AG5332RR2Y, AG 5534RR1; 56.6 bu/ac). In the MG VI test across 13 locations, two lines, R11-1057 and R11-2419, yielded 103% and 102 % of the check yield (Dillon, NCC07-8138, NC-ROY, NCC06-1090, and AG 6534; 57.4 bu/ac) respectively.

A total of 17 University of Arkansas lines were evaluated in the 2014 USDA Uniform Preliminary Test for MG IV, V, or VI. In MG IV test across 10 locations, 5 Arkansas lines yielded 82-104% of the check (Ellis, AG 632RR2Y, AG 4907, and AG 4933RR2; 55.1 bu/ac). R09-5026 yielded 104% of the check mean and ranked 2nd in the test. In the MG-V test across 10 locations, 6 Arkansas lines yielded 91-103% of the check mean (Osage, Ellis, JTN-5203, AG 5332RR2Y, 95Y70, AG 5534RR2; 57.4 bu/ac). R10-5086 yielded 103% of the check mean. In MG-VI test across seven locations, 6 Arkansas lines yielded 102-108% of the check mean (Dillon, NCC07-8138, NC-ROY, NCC06-1090, and AG 5634; 55.3 bu/ac). Two lines, R11-171 and R11-2517 yielded 106% and 108% of the check yield, respectively. These promising lines with high yield will be evaluated in the 2015 USDA Uniform Test.

In addition, 17 advanced high-yielding lines were evaluated in 2014 Arkansas Soybean Variety Tests and 18 specialty lines (6 high oil, 6 high protein, 4 modified fatty acid, and 2 high sucrose and low stachyose/phytate) were evaluated in the 2014 Southern Regional Quality Traits Test for potential release in the future.

Also evaluated in 2014 were 179 advanced and 400 preliminary conventional lines, 27 advanced and 240 preliminary RR-1 lines, 90 advanced and 360 preliminary RR-2 lines, 60 advanced and 180 preliminary genetic diversity lines, 45 advanced and 120 preliminary drought tolerant lines, and 45 advanced and 60 preliminary disease resistant lines (Table 1). In addition, specialty lines were tested in 2014: 45 advanced and 120 preliminary high protein, 30 advanced and 60 preliminary high oil, 310 advanced and 510 preliminary modified fatty acid (low linolenic, low stachyose, and/or high oleic), and 45 advanced and 120 preliminary high sugar/low phytate (Table 2). A total of 1246 plant populations were also advanced for breeding purposes. In addition, 16,924 progeny rows were evaluated in 2014 and 3247 of which were selected for 2015 preliminary tests. Some of the important breeding materials were sent to winter nurseries in Costa Rica and Argentina for generation advancement to speed up the breeding process.

PRACTICAL APPLICATIONS

Yield, market price, and production cost are important factors in determining the economics of the soybean industry. The University of Arkansas breeding program provides high-yielding cultivars with low seed cost to growers and seeds for the conventional and RR-1 cultivars that can be saved and re-used for planting. The continued release of public varieties such as Ozark, UA 4805, Osage, UA 5612, UA 5213C, UA 5014C, and UA 5414RR in recent years not only ensured the availability of high-yielding varieties with production premiums and low seed cost for Arkansas growers, but also served as excellent crossing materials for many public and private breeding programs in the U.S.

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Table 1. Overview of Arkansas soybean breeding and genetics program tests in 2014.

Test	No. of entries
Released varieties	4
USDA Uniform/Preliminary Tests	32
AR Variety Testing Program	17
Arkansas advanced lines	296
Arkansas preliminary lines	1000
Progeny rows	16,924
Breeding populations (F_1 – F_4)	1246
New crosses	560

Table 2. Overview of food-grade and specialty trait tests in Arkansas soybean breeding and genetics program in 2014.

Specialty type	No. of advanced lines	No. of preliminary lines
Tofu/milk	50	180
Edamame	20	20
Natto	120	120
High Protein	45	120
High Oil	30	60
High Oleic	310	510
Sugar	45	120
Flood	30	30
Drought	45	120
Diversity	60	180

Soybean Germplasm Enhancement Using Genetic Diversity

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ABSTRACT

The University of Arkansas System Division of Agriculture's Soybean Breeding Program uses "exotic" germplasm from different sources to enhance the genetic diversity of the parental stock. As a result of the use of exotic germplasm, we have developed high-yielding lines with diverse pedigree and different traits of value. In 2014 we proposed the release of a high-protein line, R09-3789, with 45.5% protein and 107% of the check yield. Another proposed release was a high-sucrose line, R07-2000, with 8.0% sucrose, low stachyose (0.4%) and low phytate (1406 ppm of inorganic phosphorus), and yielding 87% of the check yield. In addition, a large-seeded line R08-4004 (1900 seed/lb), with high protein (43%) and yellow hilum was released for tofu/soymilk production. Three of our diversity lines: R10-5086, R11-7141, and R10-4892 (with 25% exotic germplasm in pedigree) yielded 103%, 99% and 96% of the check, respectively, when evaluated in the 2014 USDA Uniform Tests in several southern locations. We have also developed lines with high yield under irrigation and less yield reduction on dryland. Other lines have been developed for resistance to soybean cyst nematode (SCN), sudden death syndrome (SDS), phomopsis seed decay (PSD), soybean mosaic virus (SMV), frogeye leaf spot (FLS), and Asian soybean rust. All of these lines are currently in the yield and disease evaluation stage.

INTRODUCTION

Genetic diversity is an important aspect in a breeding program. Introduction of exotic germplasm into the local parental stock can add new "yield" genes, as well as other genes controlling traits such as drought tolerance, pest resistance, or seed composition. In the U.S. the soybean genetic base used in breeding for cultivar development is relatively narrow. Only 26 ancestors accounted for 90% of the total ancestry of cultivars used from 1947 to 1988 (Gizlice et al., 1994). Genetic distance between parents is inversely associated with the expected gain from selection in breeding populations for high yield (Manjarrez-Sandoval et al., 1997). An exotic germplasm must have a comparable yield with the local adapted parents in order to be used for high yield breeding. Thus, more than one breeding cycle may be necessary to improve the agronomic performance of the introduced germplasm before it can be crossed with the local parents.

Through the years, several soybean varieties and lines have been released from our program as a result of use of germplasm in the breeding effort, including three high-protein lines: R95-1705, R05-1415, and R05-1772 (Chen et al., 2008; Chen et al., 2011a); three genetically diverse germplasm: R99-1613F, R01-2731F, and R01-3474F (Chen et al., 2011b); two sustained nitrogen fixation lines under drought stress: R01-416F and R01-581F (Chen et al., 2007); and several food-grade varieties for the tofu and edamame market.

The University of Arkansas System Division of Agriculture's Soybean Breeding Program uses exotic germplasm to increase genetic diversity for yield improvement and also breed for pest resistance, modified-seed composition, food-grade soybean, and stress tolerance.

PROCEDURES

Approximately 100 crosses are made every year for germplasm enhancement. The breeding populations are advanced using the modified single-pod descent method (Fehr, 1987) from F_2 to F_4 generations. Single plants are selected in F_4 and individually harvested to generate pure lines. The lines with the best agronomic performance are extensively evaluated in Arkansas and other southern states for yield, maturity, lodging tolerance, and specific traits according to the breeding objective (seed composition, pest reaction, protein content, or stress tolerance).

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RESULTS AND DISCUSSION

Genetic Diversity for Yield Improvement

We are developing high-yielding lines with exotic germplasm in the pedigree. Results from the 2014 USDA Uniform and Preliminary Tests across 10 - 13 southern U.S. locations (Table 1) showed that three of our lines, R11-7141, R10-5086, and R10-4892 (25% exotic germplasm in pedigree) yielded similar to the commercial checks (99, 103, and 96% of the check yield). In addition, a total of 55 advanced and 162 preliminary lines with exotic germplasm in the pedigree were tested in Arkansas in 2014. A total of 97 new lines were selected to be evaluated in preliminary yield trials in 2015. Additionally, 74 genetic populations were advanced and 38 new crosses were made for diversity enhancement purposes.

Pest Resistance

New germplasm has been introduced into the breeding program with resistance to soybean cyst nematode (SCN), sudden death syndrome (SDS), phomopsis seed decay (PSD), soybean mosaic virus (SMV), frogeye leaf spot (FLS), and Asian soybean rust. In 2014, yield potential of 41 advanced and 58 preliminary lines derived from parents with SDS and SCN resistance were evaluated. High-yielding lines from this study will be tested for pest resistance. We also selected 140 new lines to be evaluated in preliminary tests in 2015. In addition, a population derived from the cross Hartwig x Camp was grown for mapping genes for SDS and SCN resistance.

Seed Quality Traits

Breeding is ongoing for high oil, high protein, high oleic, low linolenic, high sucrose, low stachyose, and low phytate contents. The University of Arkansas Soybean Breeding Program is in the process of releasing two new lines: R09-3789, a high protein line with high yield (45.5% protein and 107% of the check yield; Table 2) and R07-2000, a high-sucrose (8.0%), low-stachyose (0.4%), and low-phytate (1406 ppm of inorganic phosphorus) line (87% of the check yield; Table 3). Other candidates for future release are two high-oil lines (R02-6268F and R10-3747, 23-24% oil; 102-105% of the check yield). In 2014 for the first time, we evaluated the agronomic performance of lines with 74-82% oleic acid content. High-yielding lines with high oleic content will be evaluated in 2015 test and also used as parents for crossing in a new breeding cycle. In addition, genetic populations were advanced and new crosses were made for all seed quality traits in 2014.

Food-Grade Soybean

In 2014, we released a large-seeded line R08-4004 (1900 seed/lb) with high protein (43.1%) and yellow hilum (Table 4) for tofu/soymilk production. In addition, 60 advanced and 184 preliminary large-seeded lines for tofu and edamame were evaluated in 2014. Furthermore, 249 new lines (96 for edamame and 153 for tofu) were selected from the progeny row test and will be included in a 2015 preliminary test.

Drought Tolerance

A total of 39 advanced drought lines were evaluated under full irrigation and dryland conditions in 2014. Our best drought-tolerant line was R10-2436 with 78.2 bu/a under irrigation and a 28% yield reduction under dryland conditions, compared to the check mean (AG4933, AG5332, and AG5831; 73.4 bu/a with irrigation and a 42% yield reduction on dryland). The line R10-2436 has showed less yield reduction due to drought in previous years. A total of 115 preliminary high-yielding lines with drought tolerance were evaluated in 2014 and 115 new lines were selected to be evaluated in preliminary yield trials in 2015.

PRACTICAL APPLICATIONS

The University of Arkansas System Division of Agriculture's Soybean Breeding Program has been successful using the available germplasm in the development of high-yielding soybean varieties with improved seed-quality traits such as high protein, high oil, high oleic, low linolenic, and high sugar for specialty markets. These lines will be used, once released, by Arkansas farmers in the production of value-added soybean crop. These new lines will also be used in our and other breeding programs in the U.S. to start a new cycle of breeding for yield and trait improvement.

ACKNOWLEDGMENTS

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Table 1. Yield of three advanced lines with 25% of exotic germplasm in the pedigree, evaluated in the 2014 USDA Uniform and Preliminary Tests in several southern U.S. locations.

Line	Yield bu/ac	% check mean yield mean
Test UP4L[a]		
R11-7141	54.3	99
Check mean[b] Fisher's least significant difference (LSD) test	55.1	
Test UP5[c]		
R10-5086	58.9	103
Check mean[d]	57.4	
Test UP6[e]		
R10-4892	55.1	96
Check mean[f]	57.2	

[a] 2014 USDA Preliminary Maturity Group 4 Late Test in 10 southern U.S. locations.
[b] Combined yield of checks: Ellis, AG4632, AG4907, and AG4933.
[c] 2014 USDA Preliminary Maturity Group 5 Test in 10 southern U.S. locations.
[d] Combined yield of checks: Osage, Ellis, JTN-5207, AG 5332, 95Y70, and AG5534.
[e] 2014 USDA Uniform Maturity Group 6 Test in 13 southern U.S. locations.
[f] Combined yield of checks: Dillon, NCCC07-8138, NC-Roy, NCC06-1090, and AG6534.

Table 2. Agronomic characteristics and seed composition of R09-3789 in four years of evaluation (2010-2013) in the University of Arkansas Soybean Breeding Program.

Cultivar	Yield bu/ac	Maturity[a] days	Protein[b] %	Oil [b] %
R09-3789	58.8	41	45.5	20.6
AG 4907	54.3	31	40.8	22.7
AG 5606	54.2	37	40.8	22.2
Osage	56.9	38	43.7	21.3

[a] Maturity are days after 31 August.
[b] Dry-weight basis.

Table 3. Yield and seed composition of R07-2000 evaluated in 15 environments from 2009 to 2013 in the University of Arkansas Soybean Breeding Program.

Line	Yield bu/a	Sucrose %	Stachyose %	Pi [b] ppm
R07-2000	49.6	8.0	0.4	1406
Check Mean[a]	57.3	5.0	3.8	230

[a] Combined data of commercial checks AG 4903, AG 4907, AG 5605, and AG 5606.
[b] ppm of inorganic phosphorous.

Table 4. Agronomic performance and seed characteristics of R08-4004 evaluated from 2010 to 2012 in the University of Arkansas Soybean Breeding Program.

Cultivar/Line	Yield bu/ac	100-seed weight g	Hilum Color[a]	Protein[b] %	Oil[‡] %	Lodging[c] 1 to 5
R08-4004	49.7	22.0	Y	43.1	20.8	2.2
MFL-159	45.7	24.7	Bf	42.9	21.5	2.0
R08-4002	48.6	21.0	Bf	45.5	19.7	2.3
R05-4969	53.9	20.1	Bf	41.3	22.0	1.6
5002T	60.5	15.7	Bl	39.3	23.7	1.3

[a] Y = yellow, Bf = buff, Bl = black.
[b] Dry-weight basis.
[c] 1= all erect, 5 = all down.

Purification and Production of Breeder Seed and Foundation Seed of University of Arkansas Soybean Lines

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ABSTRACT

The University of Arkansas System Division of Agriculture's Soybean Breeding and Genetics Program focuses on developing high-yielding varieties and providing pure breeder seed for commercialization. It is the goal of this program to provide a pipeline of products to southern producers that have improved yield, quality, and disease resistance. Selected lines with desired characteristics are advanced and maintained for purity for future release to seed dealers and farmers. This report summarizes the effort during the 2014 growing season.

INTRODUCTION

There has been an increasing interest among soybean growers for conventional or non-genetically modified (non-GM) cultivars. The Soybean Breeding and Genetics program of the University of Arkansas System Division of Agriculture has been instrumental in releasing high-yielding conventional cultivars. Increased demand for conventional varieties has solidified the need for public breeding programs as private companies focus on primarily genetically modified (GM) varieties. As the patent for the Roundup Ready-1 technology expires in 2015, soybean varieties are continuing to be developed and released with the Roundup Ready-1 technology that will have lower seed cost to the producers and the additional benefit that producers will be able to save seed of these varieties for their own planting purposes the following season. In addition, we incorporate specialty quality traits in our breeding program to develop high-yielding varieties with high protein, high oil, high sugar, or modified fatty acids. These specialty varieties will help farmers make extra profit in production.

PROCEDURES

We strive to provide high-yielding varieties to our farmers and maintain the highest level of genetic purity. We grow out our breeder seed, plant row purifications and take meticulous care in rogueing for off-types or mixtures. Eight varieties were in foundation and pre-foundation production in 2014: 58 acres of UA 5414RR, 28 acres of Osage, and 18 acres of UA 5213C were grown in Stuttgart at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center; 30 acres of UA 5612, 30 acres of UA 5014C, 20 acres of UA 5814HP, 15 acres of R07-2000, and an additional 15 acres of UA 5213C were grown at the Pine Tree Experiment station near Colt, Ark. In agreement with the non-exclusive licensing, we also grew and purified 30 acres of R08-4004 for industry.

In 2014, 300 single plants of the each variety/promising line (R08-4004, UA 5612, and UA 5014C) were pulled, threshed, grown in plant rows, and screened for plant type, flower color, pubescence color, maturity, seed size and hilum color. Seeds harvested will be used as breeder seed for the 2015 growing season. A promising Roundup Ready-1 line in the pipeline is R07-6614RR, which has competitive yield with commercial checks. A thousand plants of R07-6614RR were pulled for purification and release in 2015.

Foundation, pre-foundation, and breeder seed lots were all rogued for off-types throughout the growing season and checked for seed traits in the lab. Each line was tested for protein, oil, sugar, and fatty acid content. Each line was also submitted for disease testing: root-knot, reniform, soybean cyst nematode, stem canker, sudden death syndrome, frog-eye leaf spot, and salt tolerance. All of these lines were evaluated in multiple states' variety testing programs and in USDA trials.

RESULTS AND DISCUSSION

In 2014, the Arkansas Soybean Foundation Seed program received orders of 2746 units of conventional soybean in total: 210 units of Hutcheson, 444 units of Ozark, 834 units of Osage, 476 units of UA 5612, and 782 units of UA 5213C. These cultivars have competitive yield with maturity group (MG) late-4 and early to mid-5 commercial cultivars available in the south.

There has also been a renewed interest in Roundup Ready-1 varieties as patent expires in 2015 and farmers can save seeds for planting. In 2014, we released our first glyphosate-resistant variety, UA 5414RR. This variety is a MG 5.4 with determinate growth habit. A total of 58 acres of UA 5414RR were grown in Stuttgart, Ark. and will be available to farmers in 2015. It was rogued for off-types at flowering and at harvest. In addition, two acres were heavily rogued to be used as new foundation seeds

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for 2015 production. A total of 2425 units of foundation seed were sold in 2015 and there are 1283 units pre-ordered for 2016.

In addition, we have three conventional lines that are being considered for release. In 2014, release proposals were submitted for: R05-3239 (UA 5014C), an early MG 5 with tawny pubescence color and determinate growth habit; and R09-3789 (UA 5814HP), a MG 5.8, with tawny pubescence color, determinate growth habit, and a high protein content. Release proposals for R05-3239 and R09-3789 were approved in 2015 and referred as UA 5014C and UA 5814HP respectively. In 2015, 1020 and 587 units of foundation seed were sold for UA 5014C and UA 5814HP, respectively.

Moreover, we have three promising conventional lines in the pipeline: R09-430 and R10-230 with high yield, and R07-2000 with high sucrose, low stachyose, and low phytate content in the seed that could be used in the food-grade or feed market.

In 2014, we licensed R08-4004, which is a large-seeded conventional variety with high protein and clear-hilum. This line has been of great interest to many in the tofu and soymilk industry. It was licensed non-exclusively to three independent companies and we look forward to seeing it thrive in the specialty food-grade market.

PRACTICAL APPLICATIONS

Production of breeder and foundation seed of the different varieties (conventional, Roundup Ready-1, and modified-seed composition) developed in our breeding program provides high seed quality (purity and % germination) to the local soybean producers, enhancing the competitiveness of Arkansas soybean in both, national and international markets.

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Table 1. 2014-2015 Foundation Seed Production.

Name	Type	2014 Planted (ac)	Plant Row Purification	Certified 2014	2015 Seed Orders (units)	2015 Available (units)	2015 Breeder Seed (units)
Osage	Conventional	28	2013	yes	560	1070	50
UA 5612	Conventional	30	2013	yes	710	1101	50
UA 5213C	Conventional	18 Stuttgart 15 Pine Tree	2015	yes	530	1037	60
UA 5014C	Conventional	30	2013	yes	0	1032	50
UA 5414RR	RR1	58	2015	yes	3145	Estimated 1800	50
R09-6614RR	RR1	2	2014	no	0	0	15
R08-4004	Large-seeded	30	2013	yes	Licensed	885	50
UA 5814HP	High protein	20	2015	yes	0	593	50
R07-2000	High sugar	15	2015	yes	0	Estimated 400	50

Evaluation and Development of Flood-Tolerant Varieties and Breeding Lines

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ABSTRACT

Flood is a common environmental stress that limits plant growth and seed yield. The University of Arkansas System Division of Agriculture's Soybean Breeding Program is devoted to developing high-yielding, flood-tolerant varieties/lines for the southern soybean-producing regions. The program encompasses screening of germplasm for identification of flood-tolerant sources; assessment of effective protocols for flood tolerance evaluation; study of the effect of flood on foliar chlorophyll and mineral contents; and the advancement of flood-tolerant genetic populations. This report deals with the flood-tolerant soybean breeding effort made at the University of Arkansas in 2014.

INTRODUCTION

Flood is a major abiotic stress caused by prolonged periods of rain, excessive irrigation, rainfall after irrigation, and impermeable soils. Soybean cultivars are generally intolerant to flood (Russell et al., 1990), and yield losses are estimated to be between 17% and 43% when flood stress occurs during the vegetative stage, and between 50% to 56% during the reproductive stage (Oosterhuis et al., 1990). However, genetic variability for flood tolerance in soybean exists among different cultivars (VanToai et al., 1994). A three-year field study reported a 40% yield reduction in a soybean flood-tolerant group versus an 80% reduction in a flood-susceptible group (Shannon et al., 2005). It is important, therefore, to develop soybean varieties that can withstand waterlogging without significant yield reduction. Screening and identifying sources of flood tolerance has become an ongoing goal of the University of Arkansas System Division of Agriculture's Soybean Breeding Program.

PROCEDURES

The yield potential of 27 advanced soybean lines was evaluated in one final test (FLF) without flooding in two Arkansas locations (Marianna and Rohwer) with three replications. A four-replication flood test to assess the flood tolerance of these lines was conducted in the Rice Research and Extension Center in Stuttgart, Ark. In addition, 30 lines with flood-tolerant pedigrees (5002T x 91210-350; PI 471931 x R08-2416; R01-52F x 91219-350; and R08-2416 x Jake) were evaluated in a preliminary flood test without flooding in two Arkansas locations (Stuttgart and Marianna) with one replication. In a separate study, a total of 115 new lines derived from flood-tolerant pedigrees (5002T x N97-9658, N97-9658 x 91210-350, RA 452 x 91210-350, R08-2416 x Jake, PI 567682B x R08-2416, PI 471931 x R08-2416, and R08-2464 x PI 567436) were evaluated in a progeny row test in Stuttgart, Ark. In addition, several flood-tolerant genetic populations were advanced using either modified single-pod or single-plant descent methods. Furthermore, parental materials were collected from the UA Soybean Breeding Program, other U.S. breeding programs, and the USDA World Soybean Collection to combine traits including flood tolerance, yield, and special seed quality.

Additional sets of screening tests for flood tolerance were conducted in the field at Stuttgart, Ark. with the purpose of identifying sources of flood tolerance for future crossing. In these screenings, varieties/lines from the UA Soybean Breeding Program including 34 high-yielding conventional and RR1 lines; 54 high-yielding RR1 and R2Y lines; 105 Arkansas historic high-yielding varieties, released germplasm and specialty lines (large-seeded, small-seeded, high protein, high oil, modified fatty acids, low phytate, and modified sugars); 39 drought-tolerant lines; and 54 plant introduced (PI)-derived lines were grown in sets of 3-replication tests. A total of 274 commercial varieties from Arkansas Variety Testing Program were also screened. For all tests, 100 seeds of each variety/line were planted in a 10-feet row in June 2014; once plants reached R1 growth stage (first flower at any node), flood was imposed for 10 days (irrigating water 4 to 6 inch above the soil surface). Foliar damage score (FDS) and plant survival rate (PSR) were recorded in 3-day intervals for three times after the flood was removed. In the UA Soybean Breeding Program, a 0 to 9 scale, based on FDS, is used to evaluate flood tolerance, where 0 means no obvious foliar injury, while 1 and 9 mean less than 10% and over 90% of the plants showing foliar injury or death, respectively. Varieties/lines are considered highly flood-tolerant if average FDS ≤ 4.0; moderately-tolerant if average FDS = 4.1 - 6.0; sensitive if average FDS = 6.1 - 7.9; and highly-sensitive if average FDS ≥ 8.0.

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In order to identify an effective flood-tolerance screening method, a separate set of tests was conducted. Forty varieties/lines from the UA breeding program with contrasting responses to flood (based on a preliminary screening; data not shown), were selected and evaluated in 3-replication tests at two growth stages: V5 (fifth node with a developed leaf) and R1, and five different durations of flooding (3, 6, 9, 12, and 15 days). Foliar damage and plant survival rate were scored in 2-day intervals for four times. In addition, a SPAD 502 Chlorophyll Meter was used to compare leaf chlorophyll content between flooding and no flooding treatment. Leaf samples were also collected from each variety/line in the 6-day flooding test at R1 stage to evaluate the effect of flooding on foliar mineral content. Several additional collaborative tests with the Universities of Missouri and Georgia, and the USDA-ARS North Carolina were conducted to identify flood-tolerant varieties/lines and molecular markers associated with this trait.

RESULTS AND DISCUSSION

Among the lines tested in FLF without flooding, four lines (R10-197RY, R04-342, R07-10322, and R09-430) yielded 110-113% of the checks (AG4933, AG5332, AG5832; 57.4 bu/ac). Under flood conditions, three lines (R04-342, R11-6870, and R10-4892) showed high yield (higher than the check mean), low foliar damage score (3.8-4.0) and high plant survival rate (70.1-79.6%) (Table 1). Results from both studies showed that the line R04-342 performed well under both conditions. In the preliminary flood test, four lines (R13-12690, R13-12695, R13-12552, and R13-12754) yielded 107-119% of the check (AG4632, AG5332, AG5832, 95Y70, and Osage; 56.1 bu/ac) (Table 2). High-yielding lines from this test will be selected for yield and flood tolerance evaluation in 2015. A total of 14 progeny rows were visually selected based on plant uniformity and overall field performance at maturity. In addition, 11 new flood-tolerant crosses were made.

In the screening for identification of flood-tolerant sources for future crossing, a screening of 34 high-yielding conventional and Roundup Ready lines showed seven lines (R10-230, R11-245, R11-262, R10-4892, R11-1578, R11-1617, and R09-5026) with high tolerance to flood. The screening of 54 high-yielding RR1 and R2Y lines showed three lines (R12-6740RR, R11-89RY, and R10-309RY) with high tolerance to flood (Table 3). In addition, the screening of 105 genotypes including historic varieties, released germplasm, and specialty lines, showed ten varieties/lines (UA 5612, Walters, R10-230, R01-976, R04-342, R05-235, R11-237, R05-1947, RM-1144, and R11-8346) with high tolerance to the 10-day flooding treatment (Table 3). Results indicate that the line R10-230 was consistently flood-tolerant in both screenings and may be a good parent for crossing purposes. This tolerance seems to come from its parental cultivar UA 5612. In the screening of 39 lines developed for drought tolerance, R11-2933 and R12-2653 exhibited high flood tolerance (Table 3). In the flood tolerance screening of 54 lines derived from crosses with 25-50% PI in the pedigree, three lines R11-6870, R11-7636, and R12-5328 were highly flood tolerant (Table 3). In the screening of commercial cultivars, fifteen cultivars (HALO X440, NK S41-J6 Brand, Dyna-Gro S43RY95, MorSoy Extra 44X82, REV® 46R64™, AvDx-D814, Armor 50-R44, R09-430, HALO X451, MPG 5214NRR, S11-20124, HALO 5:45, MorSoy Extra 54X41, JTN-5110, and Progeny P 5960 LL) exhibited high tolerance to flood stress (Table 3).

Results from the tolerance screening method and mechanism test showed that the optimum flood treatment for genotype screening in the field was either 6 days of flooding at R1 stage, or 9 days at V5. For both the FDS and PSR, the greatest differences among genotypes were visible at these flood durations and corresponding growth stage. (Table 4). In the 3-day flood test at V5 and R1 stages (D3V5 and D3R1), all cultivars/lines evaluated appeared to be highly tolerant to flood stress with low FDS (< 2.0) and high PSR (≥ 99.4% for V5 and ≥ 86.5% for R1). These results suggest that most soybeans are able to survive 3-day flooding, thus this treatment was not useful to distinguish tolerant soybean genotypes from sensitive ones (Table 4; Figs. 1 and 2). In the 6-day flooding test, 77.5% of the cultivars/lines were tolerant at V5, but only 37.5% were tolerant at R1. In general, 6-day flooding at V5 had an average of 3.2 FDS and 69.1% PSR as compared to 4.6 FDS and 53.9% PSR for R1 (Table 4; Figs. 1 and 2). In the 9-day flooding test at V5 stage (D9V5), only 27.5% of the cultivars/lines were tolerant, but at R1 stage (D9R1), all cultivars/lines were sensitive to flood (Table 4; Figs. 1 and 2). Most of the plants were sensitive to flood stress in the 12- and 15-day flooding tests at both grow stages (Table 4; Figs. 1 and 2). Overall, the longer flood duration at either V5 or R1, the more damage in terms of foliar score and plant survival rate. In addition, most soybean plants will not be able to survive after 12 days of flooding in the field.

Preliminary measurement of chlorophyll using a SPAD 502 Chlorophyll Meter, showed a significant reduction in chlorophyll content after flooding treatment (Table 4), which explained the change in leaf color (from green to yellow) after flooding. Results from the effect of flood on foliar mineral composition indicated that after flooding, P, K, Ca, Mg, S, Zn, Cu, and B contents decreased while Fe and Mn contents increased, while Na content remained the same (data not shown). Results from the collaborative tests with the University of Missouri, the University of Georgia, and USDA-ARS North Carolina were sent back to those institutions for analysis.

PRACTICAL APPLICATIONS

The University of Arkansas Soybean Breeding Program has successfully developed an effective and relatively inexpensive methodology for field screening for flood tolerance. This has allowed the identification of new sources of flood tolerance from diverse germplasm. Once this trait is incorporated into high-yielding background, it will be possible to offer the growers waterlogging-tolerant varieties that will maintain their yield under flood stress.

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Table 1. 2014 Arkansas flood final test (FLF) grown in 2 locations with 3 replications.

Entry	Name	Pedigree	Yield[a] bu/ac	% Cks[b]	FDS[c]	PSR[d] (%)
9	R09-430	BA 743303 x R00-684	65.1	113	5.7	51.7
19	R07-10322	R97-1634 x V00-3824	64.2	112	5.8	48.1
21	R04-342	R97-1650 x 98601	64.1	112	3.9	70.1
12	R10-197 RY	Ozark BC1F4	63.4	110	6.1	49.2
20	AG5831	N/A	62.0	108	6.7	24.9
29	UA 5612	R97-1650 x 98601	61.8	108	5.4	64.4
4	R11-6870	5002T x R01-3474F	61.4	107	4.0	79.6
10	AG4933	N/A	61.0	106	6.8	32.8
28	Osage	Hartz 5545 x KS4895	60.6	106	5.8	53.8
16	R11-2965	R01-52F x Osage	59.4	103	6.5	32.8
17	R10-2346	R01-52F x R02-6232F	58.3	102	6.0	36.8
3	R10-4892	5002T x R01-3474F	57.6	100	3.8	71.7
13	R10-130 RY	Ozark BC1F4	57.3	100	5.8	46.1
7	R09-5088	5002T x UA 4805	56.0	98	5.8	45.3
15	AG5332	N/A	54.3	95	7.2	29.1
26	R11-555G	RA-452 x R01-581F	53.9	94	6.0	41.9
23	R11-3598	RA-452 x Osage	53.6	93	5.9	47.8
1	R11-115G	5002T x 91210-350	53.3	93	6.0	51.2
6	R10-230	5002T x R04-357	53.3	93	4.6	69.3
30	UA 5213C	R98-1523 x 98601	52.7	92	5.2	56.0
11	R07-6669	Lonoke x R00-33	52.4	91	3.9	75.8
14	R11-12215	R01-52F x N97-9658	52.2	91	6.2	44.2
5	R05-374	Lonoke x DP4748	52.1	91	6.6	28.6
22	R11-382G	RA 452 x Osage	52.0	91	6.2	33.3
2	R11-55G	5002T x 91210-350	50.2	87	4.0	73.6
8	R10-5721	5601T x R01-2195	50.0	87	6.8	27.0
27	R10-1288	S00-9925-10 x UA 4805	46.9	82	5.7	42.0
18	R11-3053	R01-52F x R05-5559	44.5	78	6.9	31.8
24	R11-358G	RA-452 x Osage	43.5	76	5.8	50.5
25	R11-3625	RA-452 x Osage	43.2	75	5.9	48.9
		Check mean	57.4			
		CV	10.2			
		Grand mean	55.3			
		LSD	6.4			

[a] Average yield of 2 locations.
[b] Percentage of check yield.
[c] Foliar damage score.
[d] Plant survival rate.

Table 2. 2014 Arkansas flood preliminary test (2 locations, 1 replication).

Test	Entry	Name	Pedigree	Yield[a] bu/ac	% Cks[b]
14FLP	25	AG5831	N/A	69.6	124
14FLP	30	R13-12754	Caviness x R08-2496	67.0	119
14FLP	2	R13-12552	5002T x 91210-350	63.1	112
14FLP	16	R13-12695	RA 452 x 91210-350	60.5	108
14FLP	14	R13-12690	RA 452 x 91210-350	59.8	107
14FLP	20	95Y70	N/A	59.6	106
14FLP	28	R13-12746	Caviness x R08-2496	59.2	105
14FLP	9	R13-12643	R01-52F x 91210-350	58.3	104
14FLP	10	AG5332	N/A	58.0	103
14FLP	1	R13-12535	5002T x 91210-350	56.7	101
14FLP	24	R13-12730	RA 452 x 91210-350	56.4	100
14FLP	18	R13-12707	RA 452 x 91210-350	55.3	98
14FLP	26	R13-12741	Caviness x R08-2496	55.2	98
14FLP	19	R13-12711	RA 452 x 91210-350	55.1	98
14FLP	13	R13-12683	R08-2416 x Jake	51.3	91
14FLP	6	R13-12623	PI 471931 x R08-2416	50.8	90
14FLP	21	R13-12712	RA 452 x 91210-350	49.4	88
14FLP	12	R13-12670	R08-2416 x Jake	49.1	87
14FLP	27	R13-12744	Caviness x R08-2496	48.8	87
14FLP	5	AG4632	N/A	48.5	86
14FLP	29	R13-12750	Caviness x R08-2496	47.7	85
14FLP	17	R13-12699	RA 452 x 91210-350	44.8	80
14FLP	15	Osage	Hartz 5545 x KS4895	44.7	80
14FLP	22	R13-12721	RA 452 x 91210-350	41.5	74
14FLP	7	R13-12631	PI 471931 x R08-2416	41.4	74
14FLP	8	R13-12638	R01-52F x 91210-350	40.3	72
14FLP	3	R13-12566	5002T x 91210-350	36.1	64
14FLP	11	R13-12669	R08-2416 x Jake	33.8	60
14FLP	4	R13-12618	PI 471931 x R08-2416	30.0	53
14FLP	23	R13-12728	RA 452 x 91210-350	28.3	50
			Check mean	56.1	

[a] Average yield of 2 locations.
[b] Percentage of check yield.

Table 3. 2014 Screening tests for flood tolerance in Arkansas.

Flood tolerance	FDS[a]	PSR[b] (%)	Number of varieties/lines					
			CV[c] + RR1	RR1+ R2Y	Elite[d]	Drought[e]	PI[f]	Commercial
High	≤ 4.0	60.0 - 79.5	7	3	10	2	3	15
Moderate	4.1 - 6.0	38.0 - 73.5	15	17	52	2	12	55
Sensitive	6.1 - 7.9	15.5 - 52.6	12	34	42	31	38	195
Highly sensitive	≥ 8.0	4.0 - 20.0	0	0	1	4	1	9
		TOTAL	34	54	105	39	54	274

[a] FDS = foliar damage score.
[b] PSR = plant survival rate.
[c] Conventional lines.
[d] High-yielding conventional and Roundup Ready lines, Arkansas historic high-yielding varieties and released germplasm, and specialty lines.
[e] Drought-resistant lines.
[f] PI-derived lines developed for diversity purpose.

Table 4. 2014 Flood duration test in Arkansas.

Test[a]	FDS[b]	PSR[c] (%)	Number of cultivars/lines			Chlorophyll SPAD	
			Tolerant	Moderately tolerant	Sensitive	Check average	Treatment
D3V5	1.1	99.4	40	0	0		
D3R1	1.7	86.5	40	0	0	32.3	25.6
D6V5	3.2	69.1	31	8	1		
D6R1	4.6	53.9	15	17	8	32.1	23.5
D9V5	5.3	42.0	11	19	10		
D9R1	7.5	15.9	0	1	39	32.2	18.8
D12V5	6.0	36.1	2	19	19		
D12R1	8.7	4.0	0	0	40	31.9	21.3
D15V5	7.3	16.5	0	6	34		
D15R1	8.4	8.0	0	0	40	33.0	22.6

[a] D3V5 = 3-day flooding duration at V5 stage; D3R1 = 3-day flooding duration at R1 stage;
D6V5 = 6-day flooding duration at V5 stage; D6R1 = 6-day flooding duration at R1 stage;
D9V5 = 9-day flooding duration at V5 stage; D9R1 = 9-day flooding duration at R1 stage;
D12V5 = 12-day flooding duration at V5 stage; D12R1 = 12-day flooding duration at R1 stage;
D15V5 = 15-day flooding duration at V5 stage; D15R1 = 15-day flooding duration at R1 stage.
[b] FDS = foliar damage score.
[c] PSR = plant survival rate.

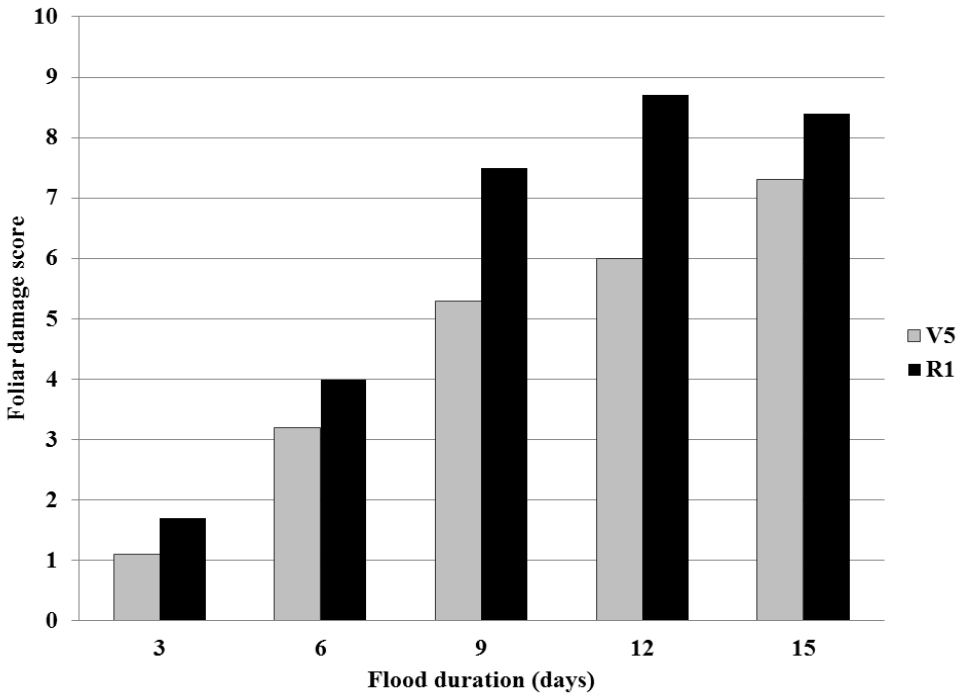

Fig. 1. Plant foliar damage under flooding for different durations.

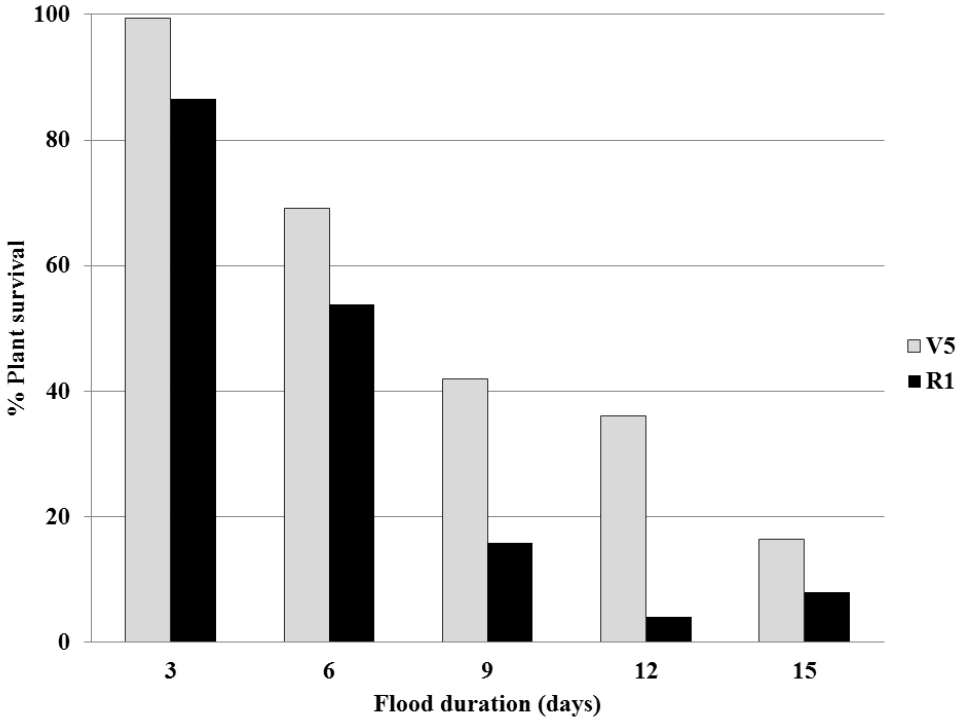

Fig. 2. Plant survival rate under flooding for different durations.

Development of a Web-Based Pedigree Database to Support Soybean Breeding Efforts

X. Huang[1], Z. Li[2], and P. Chen[2]

ABSTRACT

We are building a soybean pedigree database and developing a web-based pedigree lineage interface to visualize soybean variety pedigrees, help soybean breeders make their crossing and selection decisions, and improve soybean breeding efficiency.

INTRODUCTION

Soybeans are the world's largest source of vegetable protein and the second largest source of vegetable oil. The United States is the leading soybean producer and exporter in the world (USDA-ERS, 2015). The narrow genetic base in U.S. soybean breeding is a major limitation to the rate of yield improvement (Carter et al., 2004; Gizlice, 1994; Mikel et al., 2010). Therefore, selecting diverse high-yielding parents and developing high-yielding soybean cultivars will improve the rate of genetic gain in Arkansas as well as in the U.S.

Over 600 soybean public varieties have been released in the U.S. in the past 70 years and many breeding lines are generated each year in soybean breeding programs. However, with complicated pedigrees and availability of breeding lines for selection, one of the main challenges for the soybean breeder in a soybean breading program is how to select parents to make crosses, which give highest probabilities to generate the high-yielding breeding lines. Moreover, during the parental selection process, the breeders also want to know if the lines that they select carry the desired agronomic traits or have the desired marker haplotypes for the traits of importance.

The intention of this project is to build a pedigree database including all released U.S. soybean cultivars and germplasm from soybean breeding programs to allow the soybean breeders to quickly view the pedigrees of their cultivars and germplasm and phenotypic information and to select appropriate lines to make crosses. In addition, this database will also incorporate DNA marker data to help breeders make their decisions. The database can also be used for soybean geneticists to understand the pedigree linage and population structures in their genetic studies. Support from the Arkansas Soybean Promotion Board has been helpful to achieve the overall project goals and implement a professional database and breeder friendly application interface to support soybean breeding programs.

PROCEDURES

We briefly describe the procedures of the project. First, we will build a rational SQL pedigree database to store soybean pedigree and phenotypic and genotypic data; Second, we will develop a web-based pedigree lineage interface for viewing the pedigree, while we gather the pedigree information from the released soybean varieties and germplasm; Furthermore, we will gather the phenotypic information for these varieties and germplasm, and also analyze the SNP marker data for these released lines. Third, we will incorporate data and conduct statistical analysis. As the outcome of the project, we will test the database and web-interface, and implement it for breeders' use in Arkansas and the U.S.

RESULTS AND DISCUSSIONS

During Year 1 of this project, significant progress has been made. We have built a preliminary SQL database to hold soybean pedigree and phenotypic information (For a pedigree tree display, please refer to Fig. 1; for various search functions, please refer to the pedigree database web interface link: http://bioinformatics.astate.edu/pedigree/, and Fig. 2). We have developed a web-based interface application with various search functions including drop down menu, search by plant introduction (PI) number, by year, by institute, or by maturity, and wild card search. These search functions are user-friendly. We have also uploaded the pedigree information of released varieties into the system.

Currently, we are refining the SQL database system and optimizing the web-based interface. We plan to upload DNA marker data and integrate computational and statistical analysis functions.

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The successful completion of this project "development and implementation of a web-based soybean pedigree lineage interface and a soybean pedigree database" will provide a useful tool for soybean breeders to make their crossing and selection plans. The database will also be used for soybean geneticists to understand the pedigree lineage and population structures. With the implementation of such a database, it will help improve soybean breeding efficiency to develop high-yielding soybean varieties. Eventually, soybean farmers in Arkansas and in the U.S. will benefit by using these cultivars developed from the soybean breeding programs.

ACKNOWLEDGMENTS

This research is supported through funds administered by the Arkansas Soybean Promotion Board. We also thank Drs. Randall Nelson and Thomas Carter at USDA-ARS for providing soybean variety pedigrees. Support also provided by the University of Arkansas System Division of Agriculture.

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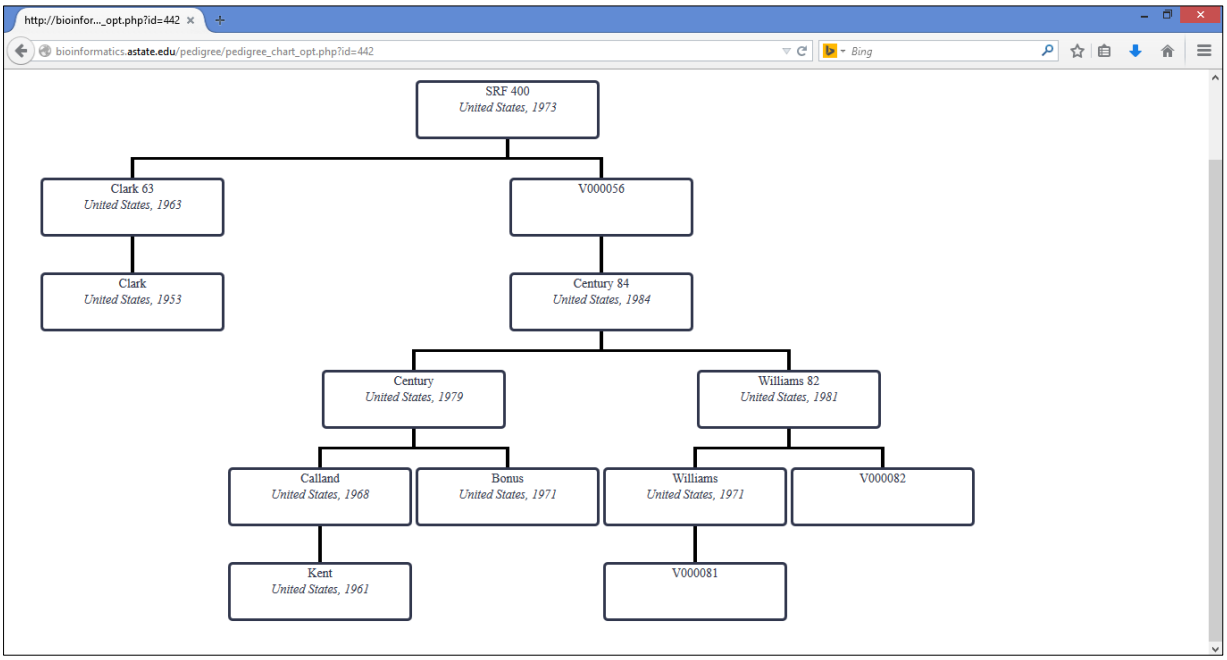

Fig. 1. An example pedigree display in the SQL website shown in a screen shot.

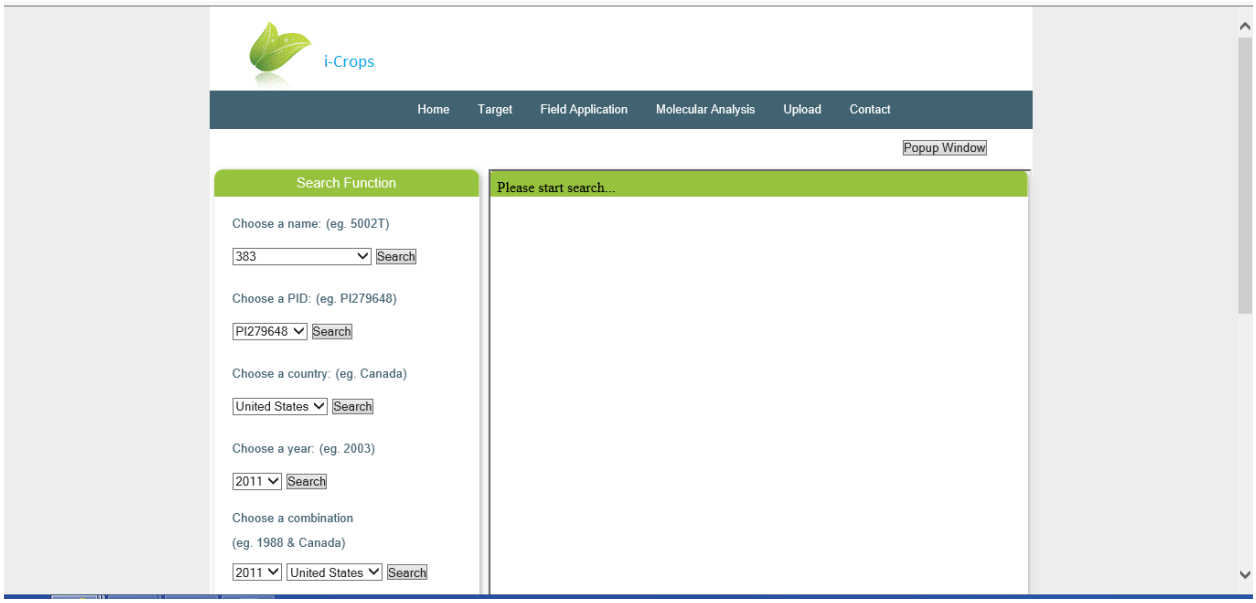

Fig. 2. Screen shot display of the various search functions in the SQL website.

Assessment of Soybean Varieties in Arkansas for Sensitivity to Chloride Injury

S. Green and M. Conatser

ABSTRACT

Some of the agricultural soils in Arkansas contain high levels of chloride salts. Various crop species, including soybean, are adversely affected by high chloride concentrations that can lead to reduction in yield. Therefore, chloride screening of soybean varieties and breeding lines has become increasingly important due to the expanded use of chloride-affected soil and irrigation water. Soybean cultivars were screened by this program for reaction to elevated chloride salts. A 50-mM chloride salt solution treatment was used to induce a genotypical uptake response in soybean plants. Leaf tissue from treated plants was collected and analyzed for chloride content. A level of tolerance to elevated chloride salts was determined for each soybean cultivar based on leaf tissue chloride content. Treated soybean cultivars were compared to a standard, based on leaf tissue chloride content. Cultivars having high levels of leaf tissue chloride content are known as includers while those having low leaf tissue chloride content are known as excluders, and cultivars having a segregating population of individual plants with high and low chloride content are known as mixed.

INTRODUCTION

Arkansas has some of the most fertile and productive soils in the world: the Mississippi River Delta. This region is a centerpiece of soybean, rice, corn, milo, cotton, wheat, vegetable, and oilseed crop production. Groundwater is available for irrigation in most areas, but some areas contain elevated levels of chloride salts. Unfortunately, soybean is one of the crops that is sensitive to elevated levels of chloride.

Chloride toxicity has been recognized in soybean fields of the Mississippi River Delta in Arkansas since 1990. This problem is usually due to salt accumulations following repeated applications of well water with elevated salt content to soils with poor internal drainage (Rupe et al., 2000). Certain soil series within this region can also contain natural horizons with elevated chloride salts within their profile.

Soybean plants take up chloride salts, which is then either translocated to the foliage (includer cultivars) or stored in the roots (excluder cultivars). Although chloride can reduce yields in both types of cultivars, yield losses are greater for includer cultivars, where the chloride causes symptoms ranging from faint foliar chlorosis to plant death, as leaf and stem chloride concentrations increase. At intermediate to high chloride concentrations, plant canopies of affected includer cultivars appear scorched (Rupe et al., 2000).

PROCEDURES

Soybean cultivars were tested for reaction to elevated chloride salts using a protocol developed by the late Darell Widick (Rupe et al., 2000). In the greenhouse, seed from each variety was germinated in potting soil media. Once the soybean plants emerged and reached the VC stage, plants were transplanted into a hydroponic system made from MacCourt Super Tubs (MacCourt Products, Inc., Denver, Colo.) and aerated by a regenerative blower (Sweetwater; Pentair, Ltd., Schaffhausen, Switzerland). The hydroponic system used deionized water for the first 48 hours following transplanting. After 48 hours, a modified Johnson's nutrient solution (Johnson, 1980) was added to the hydroponic system (Table 1).

Upon reaching the V3-V4 growth stage, a chloride salt solution was added in three parts, at 48-hour intervals, to bring the total chloride concentration of the combined nutrient and salt solution to 50-mM (Table 2). After the 50-mM chloride concentration had been maintained in the hydroponic system for 72 hours, the upper trifoliate leaves from each plant were collected and packaged individually. The soybean leaf tissue sample from each plant was dried in a Fisher Isotemp laboratory oven (Thermo Fisher Scientific, Inc., Waltham, Mass.) at 40 °C for 24 hours. After drying, samples were ground using a Wiley mill (Thomas Scientific, Swedesboro, N.J.) with a #20 sieve (0.833-mm opening).

One hundred milligrams of each sample was placed in a corresponding 250-mL Erlenmeyer flask, 50-ml deionized water added, and shaken on an orbital shaker for 20 minutes. The samples were filtered through Whatman 2 filter paper into 125-mL wide-mouth bottles. Three milliliters of each leaf tissue sample extract was transferred to 8-mL glass vials containing 1-mL of acid reagent (containing 0.4 M acetic acid and 0.024 M nitric acid). Samples were analyzed for leaf solution chloride concentration using a Haake-Buchler digital chloridometer (Buchler Instruments, Inc., Saddlebrook, N.J.) in lower power mode, which was calibrated with a 50-ppm chloride standard solution (made from reagent grade NaCl).

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RESULTS AND DISCUSSION

Based on the soybean leaf tissue chloride content of each sample, a genotypical response could be noted when compared to other samples within the test and known checks inserted into each test. The cultivars that have the ability to exclude chloride ions from the soil to the root tissues have been termed excluder cultivars, and those that translocate the ions to other tissues have been termed includer cultivars (Abel, 1969). Therefore, a determination of chloride excluder was made for soybean cultivars in which every individual plant contained low levels of leaf tissue chloride. A chloride includer determination resulted when every plant within a cultivar contained high levels of leaf tissue chloride. A mixed determination was made if a soybean cultivar contained a segregated population in which some individual plants contained low levels of leaf tissue chloride, while others contained high levels.

Three-hundred-eighteen soybean cultivars from the University of Arkansas System Division of Agriculture's Variety Testing Program were evaluated in 2014. This population of testing material consisted of maturity group four (MG4), maturity group five (MG5), and non-Roundup Ready (NRR) soybean cultivars. Twenty percent of MG4 cultivars showed an excluder genotype response, while MG5 cultivars had a 29% excluder reaction to elevated chloride salts (Fig. 1). This increase of MG5 excluders over MG4 soybean cultivars is most likely due to an influence of the excluder cultivar 'S-100' in the MG5 pedigree (Carter et al., 2004).

PRACTICAL APPLICATIONS

The goal of this program is to provide soybean breeders and producers with information differentiating soybean cultivars based on tolerance to elevated chloride salts. Data is made available to allow Arkansas soybean producers and breeders to select soybean lines and varieties suitable for growing at certain locations affected by high chloride concentrations occurring naturally within the soil or added by poor quality irrigation water.

ACKNOWLEDGMENTS

The investigators thank the Arkansas Soybean Promotion Board and Arkansas soybean producers for their support and funding. We also thank our cooperators Jeremy Ross, Rick Cartwright, Pengyin Chen, and Don Dombek. Support also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Modified Johnson nutrient solution.

Element	Final Element Concentration (mM)
Macronutrients	
N	7.0
P	1.0
K	4.0
Ca	2.0
Mg	1.0
S	1.0
Micronutrient Solution A	
B	50.0
S	12.5
Mn	10.0
Zn	2.0
Na	1.0
Cu	0.5
Mo	0.5
Micronutrient Solution B	
N	100.0
Fe	50.0
Na	50.0

Table 2. Salt solution.

Element	Final Element Concentration (mM)
Cl	50.0
Ca	20.0
Na	10.0

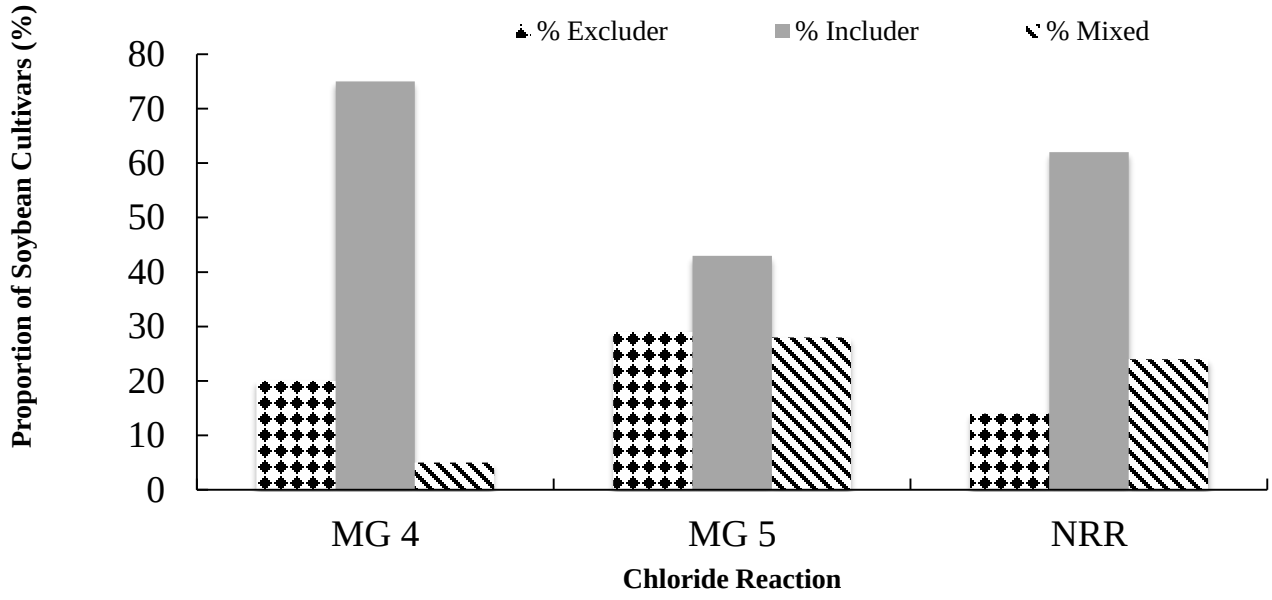

Fig. 1. Soybean chloride reaction. Bars represent proportion of soybean cultivars exhibiting the particular chloride reaction within each test (maturity group 4, maturity group 5, and non-roundup ready).

Genetic and Physiological Components that Contribute to Salt Tolerance in Chloride-Includer and -Excluder Soybean Varieties

A. Zeng [1], C. Lopez-Ramirez [1], L.D. Nelson [1], A.G. Laney [1], P. Chen [1], and K.L. Korth [1]

ABSTRACT

Salinity can be a limiting factor for crop production. Soybean [*Glycine max* (L.) Merr.] is a moderately salt-tolerant crop species; however, salt accumulation can reduce yields. The mechanism for salt tolerance in soybean is not clear, and there are varying types of plant responses to salt among soybean genotypes. We have focused these studies on identifying genetic factors that can be useful in developing chloride-tolerant soybean lines using both classical breeding and marker-assisted selection (MAS), and to characterize the salt-tolerance mechanism using physiological and molecular measurements. In addition, we have developed a salt-tolerance screening method, which results in a rapid differential response when plants were grown in sand or soil subjected to 120 mM NaCl. This greenhouse method was further optimized by monitoring leaf Cl^- content over time, by determining the threshold for duration of salt treatment for genotypic and phenotypic differentiation. Salt-sensitive chloride includer varieties show a significantly greater reduction in photosynthesis and chlorophyll levels in response to salt treatment, compared to chloride excluders. Importantly, these differences were found to occur well before visible symptoms of salt injury occur. Genetic populations were constructed for quantitative trait locus (QTL) mapping for salt-tolerance. A major salt-tolerance QTL on chromosome (Chr.) 3 (linkage group N; LG N) was confirmed in *cv*. Osage. The single nucleotide polymorphism (SNP) marker ss245206324 identified in this study could be used in MAS for salt-tolerant soybean lines.

INTRODUCTION

One of the goals of the University of Arkansas System Division of Agriculture's Soybean Breeding Program is to develop soybean breeding materials that will result in improved selection of existing varieties, and/or development of new varieties, with enhanced tolerance to environmental stress such as chloride toxicity. Salinity is a major abiotic stress that adversely affects crop productivity and quality (Chinnusamy et al., 2005). Salinity causes osmotic stress, ion toxicity, nutrient deficiencies, and affects physiological processes (Munns et al., 2002). Salt-affected soils continue to increase in the Arkansas Delta due to the intensified use of irrigation and localized decreases in aquifer water-quality. Salt affects soybean emergence and seedling survival, and decreases yield potential later in the season. Soybean varieties vary in resistance to salt damage, depending mostly on their genetic makeup as chloride "includers" or "excluders".

Use of salt-tolerant soybean cultivars is an effective approach to minimize soybean yield loss where salinity is an issue (Parker et al., 1983). To evaluate salt responses, screening studies have been carried out using different varieties; however, methods were labor intensive, time-consuming, costly, and even unreliable. Development of a quick and reliable screening method is critical for soybean breeding programs and genetics studies. In combination with phenotypic screening methods, marker-assisted selection (MAS) is an efficient method to identify salt-tolerant soybean lines. Quantitative trait loci (QTL) and associated markers can be used to screen for salt-tolerant lines. A major QTL for salt tolerance, accounting for up to 69% of genetic variance for salt tolerance, has been reported on Chr. 3 (LG N) across distinct genetic backgrounds in soybean (Lee et al., 2004). Physiological and molecular studies of soybean responses to salt can also be useful to address our goal of identification and improvement of salt exclusion mechanisms used by soybean plants. The objectives of these studies were to optimize a rapid method for screening salt tolerance in soybean, to determine physiological changes in soybeans subjected to salt stress, and to determine the presence of salt-tolerance QTLs.

PROCEDURES

Screening Method. Salt screening was carried out in a greenhouse (25 ± 2 °C, 14 hour photoperiod) at the University of Arkansas, Fayetteville, Ark. Four soybean varieties, chloride includers Williams and Dare, and chloride excluders S-100 and Lee 68, were grown in three media: sandy loam soil, river sand, and potting mix. Plants were treated with four levels (0, 80, 120 and 160 mM) of NaCl solution for two hours each day for two weeks. Salt treatment was initiated at V2 stage. Leaf scorch score (LSS) was taken on a 1-9 scale (1 = no chlorosis to 9 = necrosis). Shoots were analyzed for Na^+ and Cl^- concentrations.

Optimization of Salt Screen Method. A chloride excluder, Osage and a chloride includer, Dare, were treated with 120 mM NaCl, 120 mM KCl, or tap water for 2 hours per day for up to six weeks. The treatment was imposed beginning at the V1 stage and continued until the plants died. Leaves were collected every two days after the initiation of salt treatment. Chloride concentrations were measured using the ICP-OES method.

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Physiological Effects of Salt Stress. A Li-Cor 6400 CO_2 gas exchange monitor (Li-Cor; Lincoln, Neb.) was used to measure rates of photosynthesis. Measurements were taken on fully expanded leaflets of the first trifoliate after seven days of salt treatment. The instrument was calibrated according to the manufacturer's recommendations and used at: reference CO_2, 400 µmol CO_2 mol^{-1} and photosynthetically active radiation value (PAR), 350 µmol $m^{-2}s^{-1}$. Chlorophyll content of soybean leaves was measured after seven days of treatment, with a SPAD meter (Spectrum Technologies, Aroura, Ill.). Three readings on the same leaf were recorded per plant and averaged to obtain a SPAD value for the plant.

Salt Response Evaluation and QTL Mapping. A total of 28 specific SNP markers were designed in the previously reported salt-tolerance QTL region on Chr. 3 (LG N). For genetic map construction, DNA samples from 124 $F_{4:6}$ lines (RA-452 x Osage) and parents were sent to LGC Genomics for SNP genotyping. A total of 124 $F_{4:6}$ lines (RA-452 x Osage) and parents were screened for 2 hours per day with 120 mM NaCl or 120 mM KCl, respectively.

RESULTS AND DISCUSSION

The greenhouse screening method we developed is fast, reliable, and inexpensive for testing soybean varieties. Sand or sandy loam soil were found to be the best growing media, as in combination with 120 mM NaCl, the clearest differential phenotypes and mineral accumulation were noted between salt-tolerant and -sensitive lines (Table 1). Varieties scored between 7- 9 were considered as sensitive and those with scores between 2-4 classified as tolerant.

To optimize the screening method, chloride accumulation was measured over time in chloride excluder Osage and chloride includer Dare. Foliar symptoms became visible when the Cl^- content accumulated to 30,000 mg/kg under the NaCl treatment (120 mM) (Fig. 1A), and 40,000 mg/kg under the KCl treatment (120 mM) (Fig. 1B). In addition, plants died when Cl^- accumulated to 65,000 mg/kg under the NaCl treatment, and 80,000 mg/kg under the KCl treatment. Therefore, the best window for tissue sampling/foliar scoring is 9-12 days after the initiation of NaCl treatment (Fig. 1A), and 6-9 days after the initiation of KCl treatment (Fig. 1B). These data also suggest that under our screening conditions, Na^+ content contributes to salt toxicity more than K^+.

Treatment of salt tolerant and sensitive soybean varieties clearly shows that the presence of salt can negatively impact plant health and physiology. Prior to any visible salt damage on the plants, photosynthesis and chlorophyll are significantly reduced in both Cl^- includers and excluders, but to a greater extent in the includer variety (Fig. 2).

Genetic mapping of a soybean population derived from a RA-452 x Osage cross demonstrates that the majority of salt tolerance in Osage is controlled by the QTL on Chr. 3 which has been previously reported for S-100. We fine-mapped this QTL to within 7 Kb. The SNP marker ss245206324 identified in this study could be used in MAS for salt-tolerant soybean lines.

PRACTICAL APPLICATIONS

Environmental stresses such as drought and salt damage continue to present limitations to soybean production in Arkansas. We take a multi-faceted approach to develop breeding tools to improve salt tolerance in Arkansas soybean lines. We have applied the screening technique to develop markers for improved breeding lines of direct interest and value to Arkansas growers. The project takes advantage of the respective strengths of the investigators, and benefits from applying different techniques to address a serious problem for soybean production. Resistance to salt has often been linked to tolerance of other environmental conditions such as drought and cold, and so identification of salt-tolerance components could also help in development of improved varieties resistant to other abiotic stresses. Understanding how soybeans cope with these stresses and development of improved varieties with enhanced tolerance would represent clear benefits to Arkansas growers. The finding from this work of a single QTL that contributes a large genetic proportion of salt tolerance in soybean could provide a valuable breeding tool in developing improved varieties. Furthermore, because we showed that plant physiological changes occur well before one can visibly observe the negative impacts of salt stress, it is clear that even under mild-salt conditions this stress can have an important effect on plant health. Understanding the mechanism of chloride tolerance should provide valuable information for developing improved lines and better information to develop management tools.

ACKNOWLEDGMENTS

We are grateful for generous support from the Arkansas Soybean Promotion Board. Additional support comes from the Arkansas ASSET II Initiative P3 Center, and we thank members of the University of Arkansas System Division of Agriculture's Soybean Breeding Program for their assistance.

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Table 1. Na^+ (top) and Cl^- (bottom) content in sensitive (S) and tolerant (T) cultivar shoots after 15 days of treatment at different levels of NaCl, as compared in commercial potting mix, river sand, or sandy loam soil.

	Commercial mix				Sand				Soil			
Na^+ [d]	**S**	**T**	**Δ[a]**	***P*<[b]**	**S**	**T**	**Δ[a]**	***P*<[b]**	**S**	**T**	**Δ[a]**	***P*<[b]**
0	28	20	7	NS[c]	38	20	18	*	48	27	21	**
80	15308	10634	4674	NS	33786	30684	3103	NS	26481	21182	5299	**
120	34029	26656	7373	**	39442	38135	1307	NS	39471	32216	7256	**
160	32959	30742	2217	NS	47835	49208	-1374	NS	55658	44534	11124	**

	Commercial mix				Sand				Soil			
Cl^- [d]	**S**	**T**	**Δ**	***P*<**	**S**	**T**	**Δ**	***P*<**	**S**	**T**	**Δ**	***P*<**
0	3548	1292	2256	**	4424	1959	2465	**	7119	1853	5266	**
80	50128	27868	22260	**	80490	63943	16548	**	70573	43288	27285	**
120	88820	61513	27308	**	81475	71110	10365	**	96153	69385	26768	**
160	82923	61135	21788	**	91560	80948	10613	*	97433	80785	16648	**

[a] Δ indicates difference in concentration values between S and T lines.
[b] P< column indicates statistical significance at $P = 0.05$.
[c] NS indicates results that were not statistically significant.
[d] Units of mineral concentration are mg/kg dry weight for both Na^+ and Cl^-.

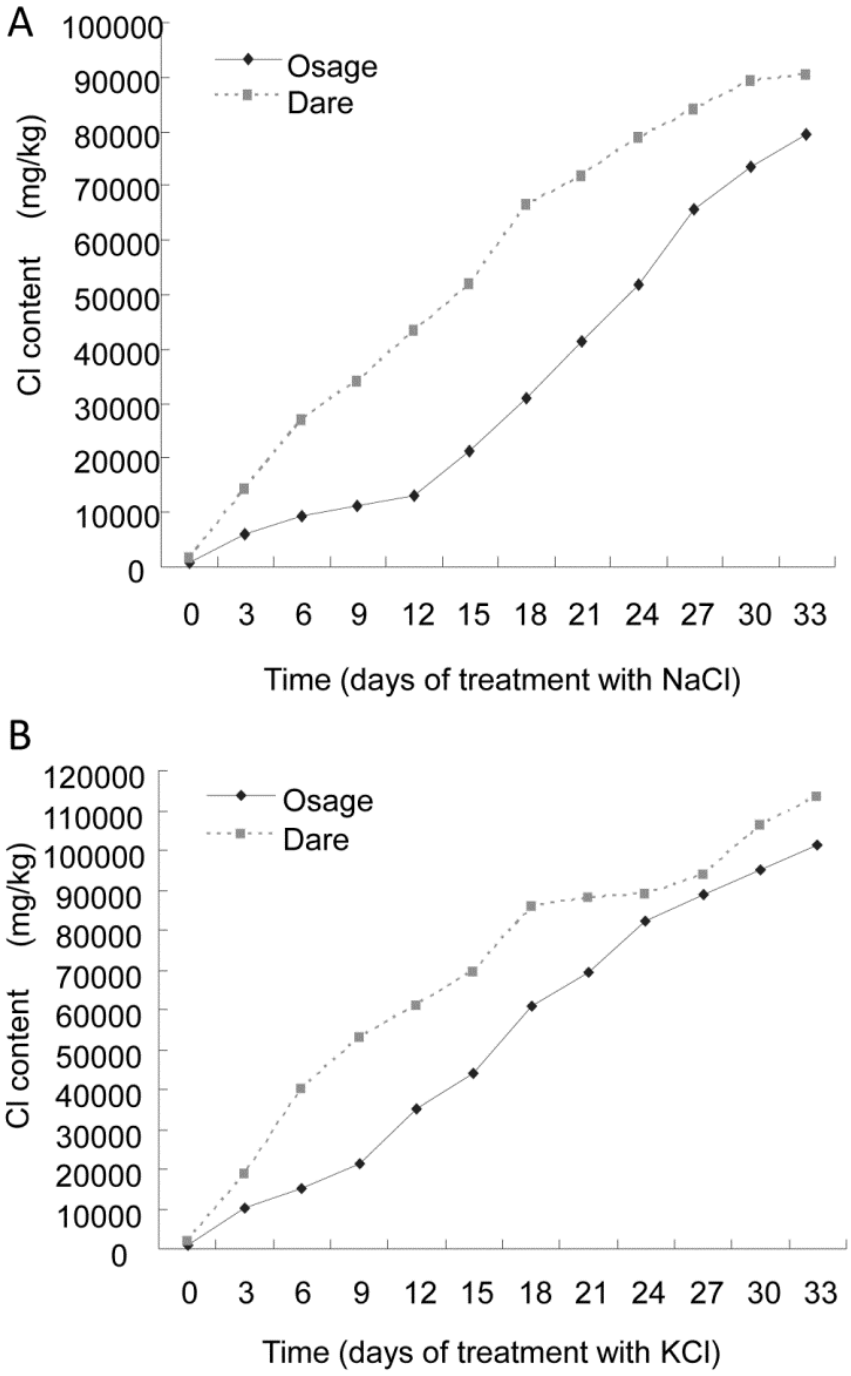

Fig. 1. Chloride accumulation in foliar tissue of plants treated with 120 mM NaCl (A) or 120 mM KCl (B) over time.

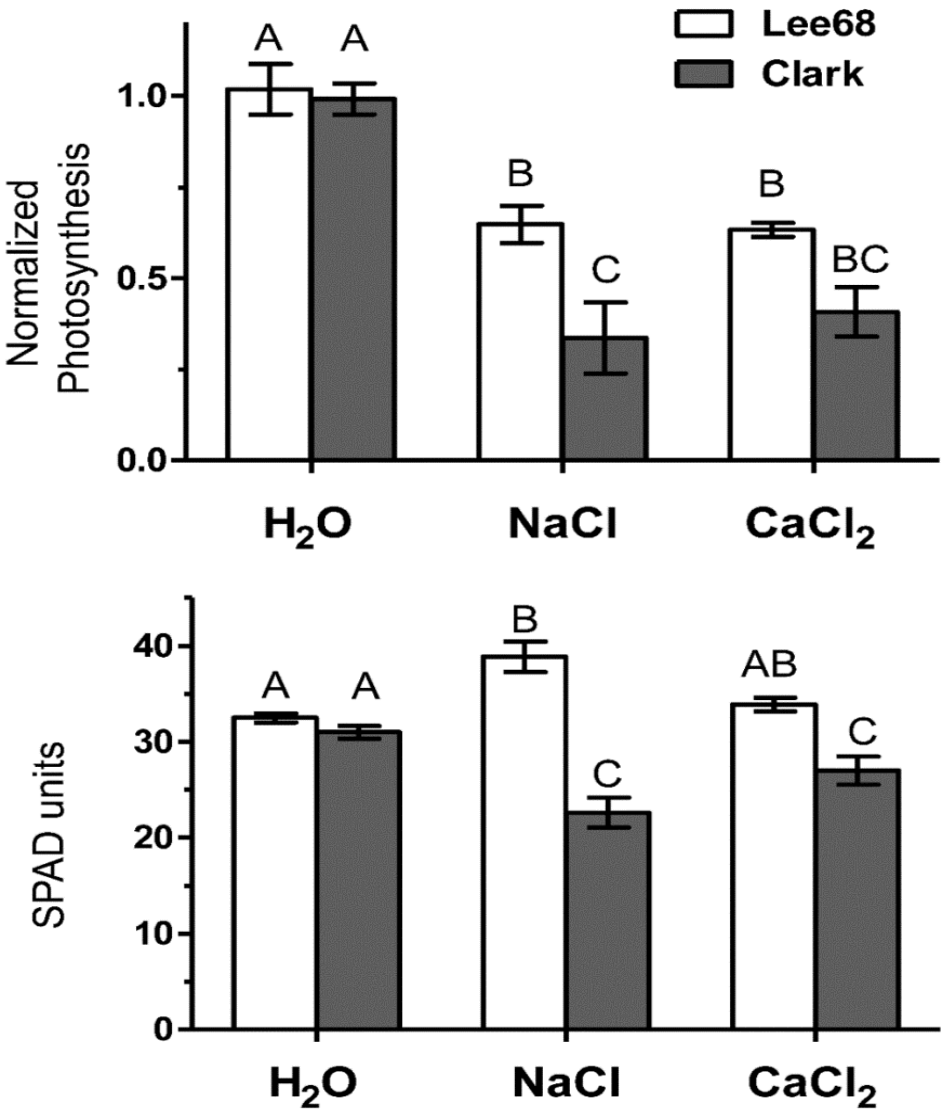

Fig. 2. The rate of photosynthesis is significantly impacted by salt treatment in both chloride excluders (Lee68) and includers (Clark), although salt treatment has a significantly stronger negative impact on the includer. Likewise, salt treatment leads to significantly lower chlorophyll levels as measured with a SPAD meter, in the salt-sensitive cv. Clark. Bars with different letters have means that are significantly different ($P < 0.05$; n = 3).

Expression Analysis of Soybean *ERECTA* Genes

M. Khodakovskaya[1], M. Alimohammadi[2], S. Nandy[2], and V. Srivastava[2]

ABSTRACT

ERECTA (*ER*) family of genes are among key players of plant development and stress signaling. Involvement of soybean *ER* genes in stress signaling has not been demonstrated so far. Based on the hypothesis that down-regulation of *ER*-mediated signaling in soybean would lead to improved drought tolerance, this study analyzed expression of the predicted soybean *ER* genes, *GmERL1*, *GmERL2* and *GmERL3* using real-time polymerase chain reaction (PCR). All three genes were functional in 10-day-old soybean leaves, with *GmERL3* exhibiting the highest level of expression. Towards suppressing the *GmERL* genes, a dominant-negative form of *Arabidopsis ER* gene was cloned into the soybean transformation vector, pTF101.1, and used for developing transgenic soybean lines. Transgenic soybean lines will be analyzed for drought stress response in the near future.

INTRODUCTION

Recently, we demonstrated that transgenic tomato plants suppressed in *ERECTA (ER)* gene function exhibited tolerance to water-deficit stress without suffering yield loss as determined by fruit size and number per plant (Villagarcia et al., 2012). We reasoned that reduction of total leaf area (evaporating surface area) in the transgenic tomato plants conferred drought tolerance. *ERECTA*, a receptor kinase protein, is an essential component of signal pathways controlling developmental processes, including pleiotropic growth, inflorescence formation, shoot apical meristem regulation, stomatal proliferation and patterning, and stress response (Shpak, 2004; Uchida et al., 2011, 2012a,b; van Zanten et al., 2009). We found sequence similarity between Arabidopsis *ER* genes and the predicted soybean *ER* genes, and named them the *ER*-like genes, *GmERL1* (NP_0017639), *GmERL2* (NP_001235330) and *GmERL3* (XP_003534036) (Villagarcia et al., 2012). Due to high sequence similarity, *Arabidopsis* and soybean signal pathways mediated by ER are expected to be conserved. As the first step of the project, we determined relative expression of the three predicted soybean *ER* genes in young soybean leaves (VC stage), and cloned the dominant-negative *Arabidopsis ER* allele, *AtΔkinase*, in soybean transformation vector, pTF101.1, for developing transgenic soybean lines.

PROCEDURES

Soybean seeds (cv. Williams 82) were provided by Soybean Germplasm Collection (USDA, Agricultural Research Service). Seeds were germinated on soil (Sun Gro, Bellevue, Wash.), in a growth chamber with low light intensity, 23 °C, 12 hours of daylight, and 45% humidity. First leaves of the seedlings, ten days after germination (VC stage), were snap-frozen in liquid nitrogen, ground to a fine powder, and used for total RNA extraction by RNeasy Plant Mini Kit (Qiagen, Germantown, Md.). Total RNA was subjected to cDNA synthesis using oligo (dT) primers by SuperScript III Kit (Invitrogen Inc., Grand Island, N.Y.), and the resulting cDNA used for qPCR using primers (see Table 1) in a SYBR Green PCR master mix (Applied Biosystems, Inc., Grand Island, N.Y.) with a CFX96 Real-Time detection system (Bio-Rad, Hercules, Calif.). The cloning of *AtΔkinase* gene into pTF101.1 was done by the standard cloning approach involving restriction enzymes and ligation.

RESULTS AND DISCUSSION

In order to determine the expression level of the soybean *ER* gene family in the seedlings, we monitored expression of the three predicted soybean *ER* genes (*GmERL1*, *GmERL2* and *GmERL3)* in first two soybean leaves using quantitative RT-PCR (Fig. 1). We found that all three genes were actively expressed in the young leaves. The highest level of expression was observed for *GmERL3* gene and the lowest level for *GmERL1* among the three tested genes. The three genes may be temporally-spatially regulated; therefore, all three genes will have to be suppressed in order to suppress ER signaling in soybean. Therefore, the use of the dominant-negative allele of *ER* is critical in suppressing the *GmERL* gene family. We are currently in the process of developing transgenic soybean lines expressing the *Arabidopsis* (dominant-negative) *ER* allele, *AtΔKinase.* Towards this, we cloned ~8 kb *AtΔKinase* gene in the soybean transformation vector, pTF101.1, and initiated soybean transformation in collaboration with the Iowa State University, Plant Transformation Facility. We hypothesize that overexpression of *AtΔKinase* in soybean will disrupt *ER* signaling leading to plant architecture changes and drought tolerance. The molecular and phenotypical analysis of the *AtΔKinase* soybean lines will be conducted in Year 2 of this project.

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PRACTICAL APPLICATIONS

Drought tolerance in crop plants is a quantitative, multigenic trait, and therefore extremely challenging to combine effectively in breeding through a rapid selection process. On the other hand, the development of drought-tolerant crops by genetic engineering can be very effective if key genes involved in plant stress signaling are known. In our previous work, we demonstrated that suppression of *ERECTA* signaling improves drought-tolerance in tomato, without altering fruit size and number. This project addresses, whether the same principle could be applied to soybean to develop drought-tolerant soybean lines.

ACKNOWLEDGMENTS

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Villagarcia H., A.-C. Morin, E.D. Shpak, and M. Khodakovskaya (2012) Modification of tomato growth by expression of truncated ERECTA protein from *Arabidopsis thaliana. J. Exp. Bot.* doi:10.1093/jxb/ers305.

Table 1. Primers used in gene expression analysis by qPCR.

Primer	Sequence (5' – 3')
18S Forward	AGGCCGCGGAAGTTTGAGGC
18S Reverse	ATCAGTGTAGCGCGCGTGGG
GmERL1 Forward	GCTCGGAATAGGCTCAGTGG
GmERL1 Reverse	ACGATATGTCCAGGTACTGCAA
GmERL2 Forward	CTAGTGGAACTGGGCAAGG
GmERL2 Reverse	TGGGTGGCCATAATAATACTAAGCA
GmERL3 Forward	TGTTGGCTTTTGTGGGCAAG
GmERL3 Reverse	TCGCTGAGTGGTGAAGCAAA

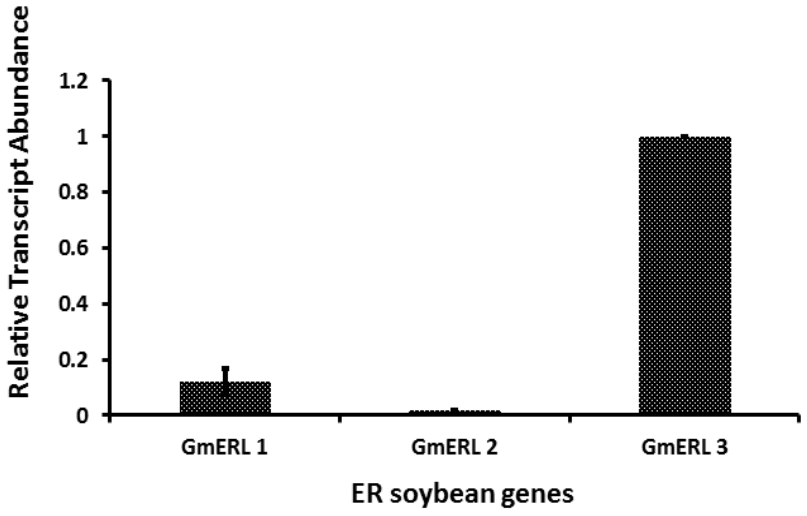

Fig. 1. Relative expression of soybean *ERECTA* gene family (*GmERL1, GmERL2, GmERL3*) in soybean seedlings determined by real-time quantitative polymerase chain reaction. Three independent biological replicates were used in the analysis. Vertical bars indicate ±SE. 18S was used as a loading control.

High Throughput Phenotypic Evaluation of Drought-Related Traits in Soybean

H. Bai[1], L C. Purcell[1], and V. Skinner[1]

ABSTRACT

The response of soybean to drought during reproductive development was evaluated in two experiments in 2014 with the objective of developing screening tools to identify drought tolerant genotypes. For the first experiment, five cultivars ranging from maturity group (MG) II through V were included in well watered (WW) and drought (DR) treatments. Beginning at R5, leaf N concentration was determined weekly for the rest of the season. Pictures of each plot were taken at ground level to determine canopy greenness using the Dark Green Color Index (DGCI). DGCI values were closely associated with leaf N concentration. The results indicated leaf N was greater for the WW treatment than the DR treatment showing that leaf N decreased more quickly under drought. Ground DGCI increased with increasing leaf N from 1% to 4% and decreased slightly at leaf N greater than 4%. Yield of WW treatment was significantly higher than that of the DR treatment. A canopy temperature experiment was established with cultivars previously characterized as fast or slow wilting and included three water treatments: well watered (WW), partially watered (PT), and rainfed (RF). Aerial infrared images were taken with a balloon or kite platform throughout the growing season. The respective canopy temperature differences between WW and PT, and PT and RF treatments were 0.7 °C and 0.2 °C, which illustrates the sensitivity of the infrared camera. In general, slow wilting genotypes had either greater or equivalent yield to the fast wilting genotypes.

INTRODUCTION

Drought has a negative impact on biological nitrogen fixation (Purcell, 2009). Nitrogen is a key element of chlorophyll and a loss of nitrogen results in decreased chlorophyll and leaf yellowing. Thus, canopy color can reflect the nitrogen status of crops, which is amenable to measurement by remote sensing. Karcher and Richardson (2003) reported a method of digital image analysis that measured the greenness of plants using the dark green color index (DGCI), which is on a scale of 0 to 1 with higher values related to a darker green color. Rorie et al. (2011) found that DGCI values were closely associated with leaf N concentration.

Infrared (IR) imaging is now a developed technology with agricultural applications in which an IR camera can detect small changes in plant temperature. When plants have an inadequate water supply, water evaporation through the leaves (transpiration) decreases, causing leaf temperature to increase. Thus, IR imaging makes an ideal screening tool to identify soybean genotypes that are drought tolerant.

PROCEDURES

Canopy Greenness Experiment. A field experiment was conducted at the University of Arkansas System Division of Agriculture's Experiment Station in Fayetteville, Arkansas that included well-watered (WW); and drought (DR) treatments evaluating cultivars from MG II, III, IV and V. Canopy greenness was determined once a week after R5 to calculate DGCI by taking digital color pictures of the canopy at ground level as well as from the air (~75 m) with a balloon or kite platform. On the same day pictures were made, three leaves were sampled from each plot for nitrogen analysis. At maturity, plants from central rows were harvested, weighed, and yields were converted to 13% moisture content.

Canopy Temperature Experiment. A field experiment was conducted that had four replications, three water treatments (well watered, WW; partially watered, PT; and rainfed, RF), and ten genotypes that were previously characterized as fast (5) or slow (5) wilting. Once the canopy was completely closed, aerial canopy temperature measurements were made at a height of about 75 m by attaching a FLIR Tau 640 IR camera (FLIR Systems, Goleta, Ga.) to either the line of a 2-m-diameter balloon (on calm days) or to a large kite (on windy days). The average relative temperature of a plot was determined by: (1) capturing an image of the experiment from the recorded video stream; (2) excising a bordered section of the image containing an individual plot using GIMP (www.gimp.org); and (3) averaging the relative temperature values of the pixels contained in the central portion of the plot (8000-10,000 pixels). At maturity, plots were harvested and yield was expressed at 13% moisture.

[1] University of Arkansas System Division of Agriculture, Department of Crop, Soil and Environmental Sciences, Fayetteville, Ark.

RESULTS AND DISCUSSION

Canopy Greenness Experiment. Leaf N decreased after R5, and cultivars differed in how quickly leaf N decreased. Throughout seed filling, leaf N was greater for the WW treatment than the DR treatment (Fig. 1a). These results are consistent with data from 2013 showing that leaf N decreased more quickly under drought. Fig. 1b indicates that ground DGCI measurements increased with increasing leaf N concentration from 1% to 4%. At leaf N concentrations greater than 4%, there was a slight decrease in ground DGCI. The aerial images are still being analyzed. However, in a previous year, the aerial images were able to separate the difference of DGCI under WW and DR conditions, which indicates that the aerial images are more sensitive than ground images in detecting treatment differences.

There were significant main effects of water treatment and cultivars on yield but no significant interaction. The WW treatment, averaged over cultivars, had a yield of 4528 kg/ha (67 bu/ac), whereas yield of the DR treatment was 3740 kg/ha (56 bu/ac). Yield among varieties ranged from 3676 to 4519 kg/ha (55 to 67 bu/ac) when averaged across water treatments (Fig. 1c). The lowest yielding variety was S25-E5 (MG2), which would not typically be grown in Arkansas.

Canopy Temperature Experiment. Aerial infrared images were taken 10 times during the growing season. Data from two dates have been analyzed, but only one date showed an effect of water treatment (Fig. 2a) due to the mild temperature and drought conditions of 2014. The IR camera gives a relative temperature value for each pixel ranging from 0 (cool) to 255 (hot) with a total temperature span of 12.5 °C. Therefore each unit of relative temperature corresponds to 0.05 °C (12.5÷256). The average relative canopy temperature for the WW, PT, and RF treatments were 47, 61, and 65. Therefore, the respective absolute canopy temperature differences between WW and PT, and PT and RF treatments were 0.7 °C and 0.2 °C, which illustrates the sensitivity of the infrared camera. Fig. 2b is an example of an IR image and shows the relative canopy temperature of several plots; the wide red bar indicates the irrigation source with water availability decreasing as distance from irrigation source increase.

Yield for the canopy temperature experiment was affected by wilting type and genotype within wilting type. In general, slow wilting genotypes had either greater or equivalent yield to the fast wilting genotypes (Fig. 2c).

Ongoing Measurements. The aerial images are being analyzed for aerial DGCI. However, the aerial images in a previous year were more sensitive than ground images. Carbon and oxygen isotope discrimination ($\Delta^{13}C$ and $\Delta^{18}O$) in the canopy temperature experiment are also being determined from leaves sampled at late R5 and from seed at harvest. Isotope $\Delta^{13}C$ can be used as an alternative measurement for crop water use efficiency, whereas $\Delta^{18}O$ determines the relative amount of water a crop used. The IR imaging was also used to characterize a large breeding population at Stuttgart for drought tolerance. These data are also being analyzed.

PRACTICAL APPLICATIONS

The remote-sensing technology using balloons and kites in this research is an alternative to the use of drones, which are highly restricted for research use by the FAA. Drought-tolerant genotypes can be identified by using this remote sensing technology along with high throughput screening methods for water use efficiency, and the genes associated with drought tolerance can eventually be transferred into elite varieties in a breeding program.

ACKNOWLEDGMENTS

We gratefully acknowledge funding from the Arkansas Soybean Promotion Board. Support also provided by the University of Arkansas System Division of Agriculture.

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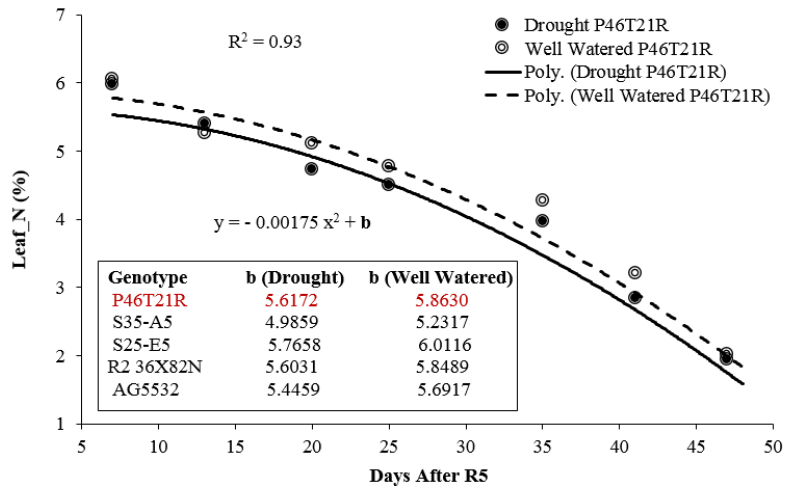
a



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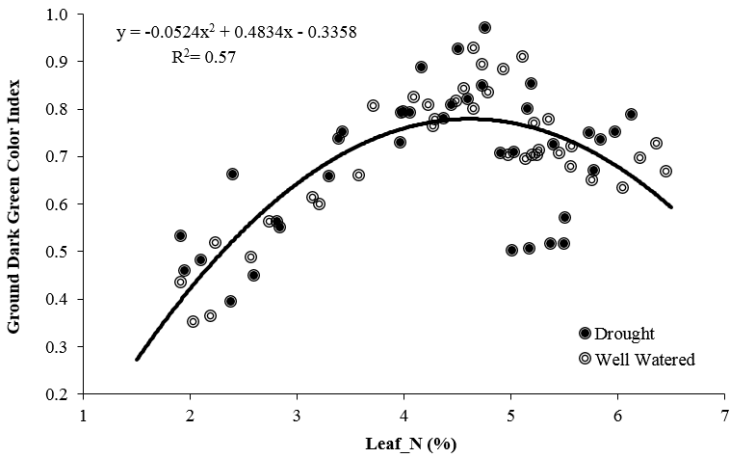

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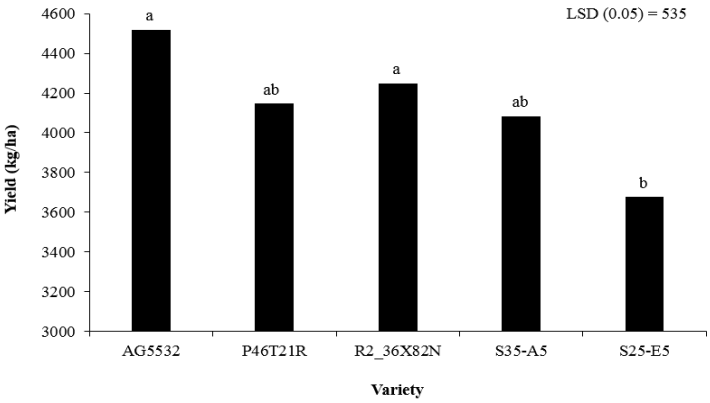
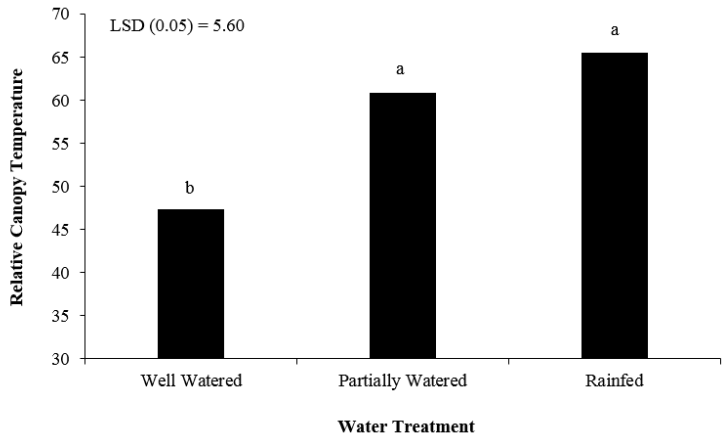


Fig. 1(a). Leaf N concentration versus days after R5. For all cultivars, leaf N was greater for the well watered treatment than the drought treatment. This figure only includes the cultivar P46T21R. Others have similar trends, as indicated by the coefficient "b" shown in the legend. 1(b) Ground dark green color index (DGCI) measurements versus leaf N concentration for well watered and drought treatments (not significant) during seedfill. Data points represent the DGCI values of five cultivars under drought and well-watered conditions throughout the seedfill period, averaged over four replications. 1(c) Yield among varieties in the greenness experiment, averaged over water treatments. Different letters above the bars indicate significant differences at *P* =0.05 as determined by a least significant difference test.

a



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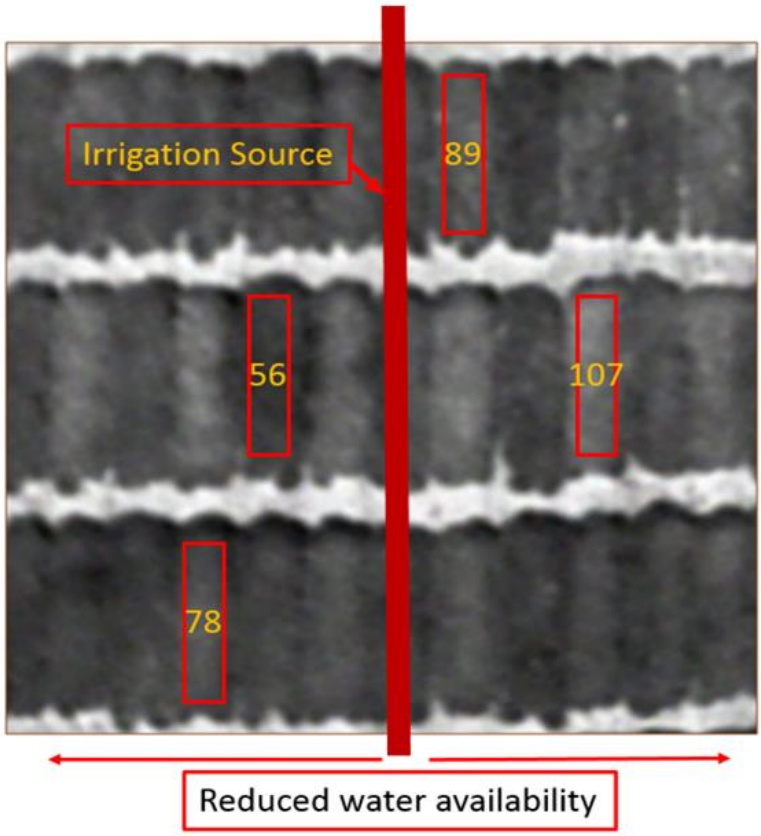

Fig. 2(a) The relative canopy temperature for well watered, partially watered, and rainfed treatments averaged over genotypes (n.s.). The infrared camera gives a relative temperature value ranging from 0 (cool) to 255 (hot) with a total temperature span of 12.5 °C. Therefore each unit of relative temperature corresponds to 0.05 °C (12.5÷256). Different letters above the bars indicate significant differences at *P* =0.05 as determined by a least significant difference test. 2(b) Example of an infrared image showing the relative canopy temperature of several plots; the wide red bar indicates the irrigation source with water availability decreasing as distance from irrigation source increases. The numbers represent the relative canopy temperatures.

C

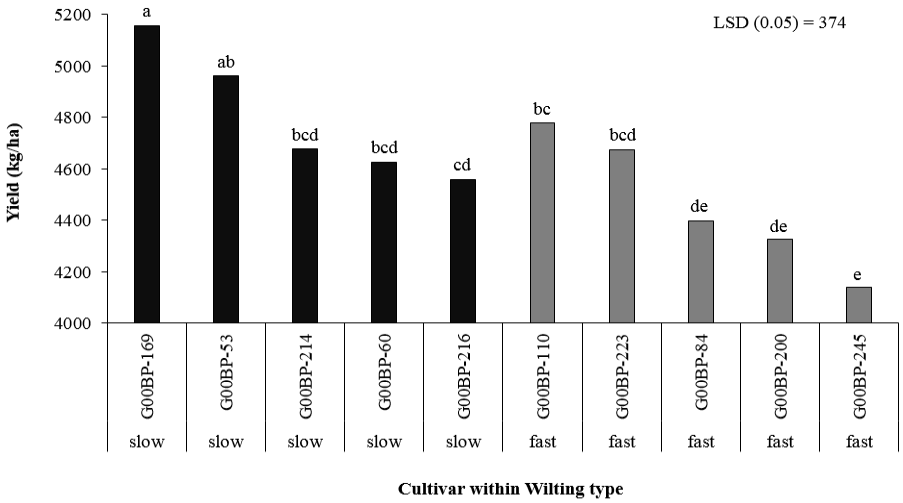

Fig. 2 *Continued.* (c) Yield of the canopy temperature experiment associated with cultivar within wilting type, averaged across water treatment. Different letters above the bars indicate significant differences at *P* =0.05 as determined by a least significant difference test. In general, slow wilting cultivars had either greater or equivalent yield to fast wilting cultivars.

New Transgenic Approaches to Control Diseases of Soybean in Arkansas

B.H. Bluhm[1], N. Lawson[1], J.E. Smith[1], and Y. Ramegowda[1]

ABSTRACT

Diseases caused by fungal pathogens negatively impact Arkansas soybean production. Frogeye leaf spot (caused by *Cercospora sojina*) and Cercospora leaf blight (caused by *C. kikuchii*) are particularly problematic in Arkansas due to their frequent and widespread occurrence throughout the state. Management of these two diseases is hampered by insufficient genetic resistance and limited chemical control options. Thus, new management strategies are urgently needed to reduce the impact of *Cercospora* diseases. In this project, we are developing a transgenic approach utilizing RNA interference (RNAi) to create novel sources of resistance to *C. sojina* and *C. kikuchii*. In this approach, known as host-induced gene silencing (HIGS), soybean plants are engineered to express transgenes that silence fungal pathogenicity genes via RNAi. We have successfully identified pathogenicity genes to target *C. sojina* and *C. kikuchii*, and have created expression constructs for transformation into soybean. Future efforts will focus on evaluating resistance in the newly created transgenic soybean lines. If successful, these efforts will provide novel sources of genetic resistance to *Cercospora* diseases of soybean, and the overall approach will be easily adaptable to other important fungal pathogens.

INTRODUCTION

In Arkansas and other Southeastern states, frogeye leaf spot (FLS; caused by *C. sojina*) and *Cercospora* leaf blight (CLB; caused by *C. kikuchii*) are two of the most important foliar diseases of soybean. Frogeye leaf spot is identifiable by circular lesions that enlarge into brown spots with reddish margins (Fig. 1A), which can coalesce and cause severe defoliation. *Cercospora* LB is characterized by bronze to reddish-purple lesions on soybean leaves in the top of the canopy (Fig. 1B). Lesions often merge as they mature, which causes defoliation and impaired photosynthetic capacity. Frogeye leaf spot can incur yield losses of 30% or greater on susceptible soybean varieties. When severe, CLB can substantially reduce yields due to premature plant defoliation.

Management of FLS and CLB is challenging because of limited chemical control options and inadequate genetic resistance. Recently, FLS and CLB have developed resistance to strobilurin fungicides through spontaneous mutation. In *C. sojina*, resistance to strobilurins has been documented in Arkansas (T. Faske, *pers. comm.*). In *C. kikuchii*, resistance to strobilurins originated at least 15 years ago (Price et al., 2013), and was recently detected in Arkansas (B. Bluhm., *unpublished*). Genetic resistance against FLS conveyed by *Rcs3* is currently effective, but is not present in all commercial germplasm and potentially could be overcome; the identification of genetic resistance to CLB has thus far proven elusive.

The goal of this project is to develop novel, transgenic approaches to manage FLS and CLB by utilizing a new phenomenon known as host-induced gene silencing (HIGS). In HIGS, transgenically expressed RNA molecules travel from host plants into fungal pathogens to inhibit growth and disease development via RNA interference (RNAi) (Tinoco et al., 2010). Thus, the specific objectives of this project are to: 1) identify suitable fungal genes to target for silencing via transgenic (RNAi) approaches; 2) create transgenic soybean lines with resistance against pathogenic fungi; and 3) evaluate transgenic soybean lines in laboratory and field conditions.

PROCEDURES

Candidate pathogenicity genes were identified by homology with genes characterized in other fungal pathogens. Initial efforts focused on *CZK3*, previously identified in *C. zeae-maydis* (Shim and Dunkle, 2003). To determine if *CZK3* was a suitable target for silencing, the gene was disrupted in *C. sojina* via homologous recombination, and the resulting mutants were tested for the ability to cause disease. The working hypothesis was that if fungal disruption mutants were impaired in pathogenesis, this would indicate that *CZK3* is involved in pathogenesis and thus would be an excellent candidate for transgene targeting via HIGS.

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Prior to this project, genetic transformation of *C. sojina* had not been reported. Thus, we developed an *Agrobacterium*-mediated transformation protocol for *C. sojina* based on earlier work we performed with *Phomopsis longicolla* (Li et al. 2013). Additionally, we created a binary vector (pBYR14; Fig. 2A) for targeted fungal gene disruption via *Agrobacterium*-mediated transformation. This plasmid was further modified to target *CZK3* of *C. sojina*. Fungal gene disruption mutants of *CZK3* were screened as described by Ridenour and Bluhm (2014) and phenotyped for their ability to cause disease.

A novel plasmid (pBYR3; Fig. 2B) was created to shuttle transgenes into soybean. This plasmid is designed to accept fungal target gene fragments with a single cloning step using Gateway technology, thus allowing the high-throughput creation of transgenes for evaluation in soybean.

RESULTS AND DISCUSSION

Homology-based searches led to the successful identification of *CZK3* in *C. sojina* (Fig. 3) and *C. kikuchii* (data not shown). A segment of *CZK3* was cloned into plasmid pBYR14 and used to disrupt the gene in *C. sojina* (data not shown). Disruption of *CZK3* led to a drastic reduction in pathogenesis, and essentially abolished the ability of *C. sojina* to induce lesions on soybean leaves (Fig. 4). This reduction in pathogenesis was consistent with previous observations after disruption of *CZK3* of *C. zeae-maydis* (Shim and Dunkle, 2003), and confirmed that *CZK3* was a promising candidate to target via HIGS in *C. sojina*. Due to significant homology between the DNA sequences, it is possible that a HIGS construct targeting *CZK3* in *C. sojina* will also be effective against the *CZK3* gene of *C. kikuchii*.

To facilitate HIGS in soybean, a plasmid was constructed (pBYR3) for the rapid cloning of fungal hairpin RNAs (as required for RNAi) that can also shuttle transgenes into the soybean genome. This plasmid carries Gateway-based site-specific recombination elements for directional cloning of transgenes into the plasmid backbone. Transgene expression is driven by tandem copies of a strong, constitutive promoter, which will ensure high levels of transcription.

The next phase of the project is to obtain seed of transgenic soybean lines, confirm that the transgene is being expressed properly, and evaluate the effect of transgene expression on suppression of *C. sojina* and/or *C. kikuchii*. In parallel, we have identified additional candidate genes for silencing, and will continue to evaluate them as potential targets for HIGS. We anticipate that adjustments may need to be made to optimize the effectiveness of HIGS in soybean, such as altered levels of transgene expression and/or tissue-specific localization.

PRACTICAL APPLICATIONS

Cercospora diseases of soybean are common in Arkansas, and could increase in incidence and severity due to the emergence of strobilurin resistance throughout the state. Fungicide resistance limits management options, and thus transgenic approaches would provide a cost-effective management tool. If successful, this project will provide new transgenes to combat *Cercospora* diseases of importance to Arkansas soybean production. Moreover, the development of HIGS-based techniques for soybean will facilitate a new avenue of transgenic control for a wide variety of fungal diseases.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the Arkansas Soybean Promotion Board for their financial support of this research. Support also provided by the University of Arkansas System Division of Agriculture.

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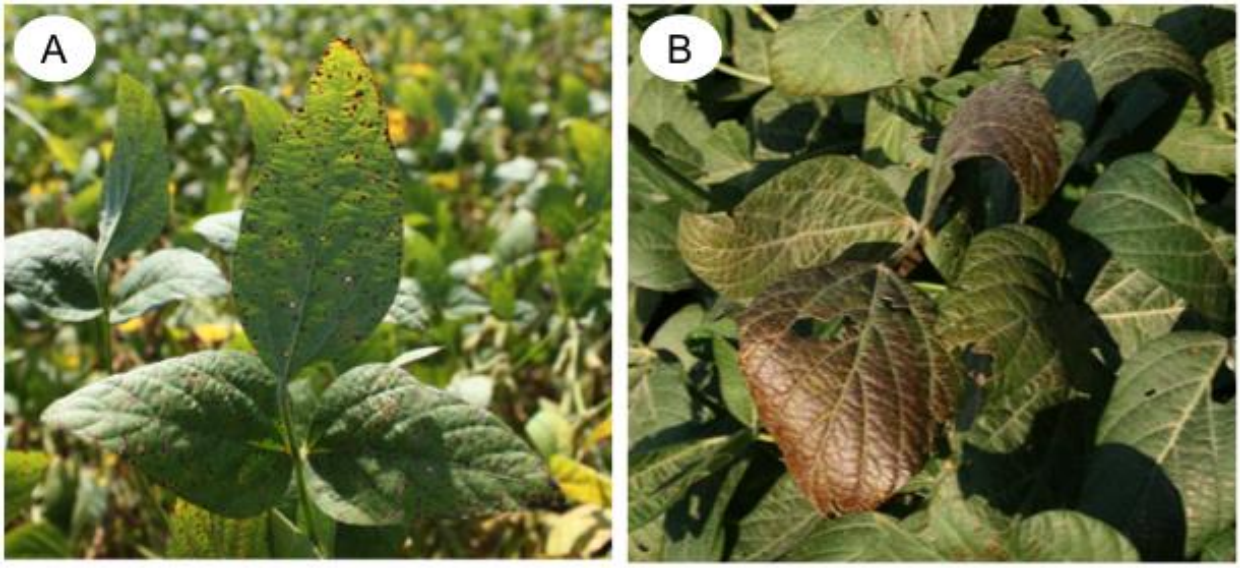

Fig. 1. Typical symptoms of frogeye leaf spot (A) and *Cercospora* leaf blight (B).

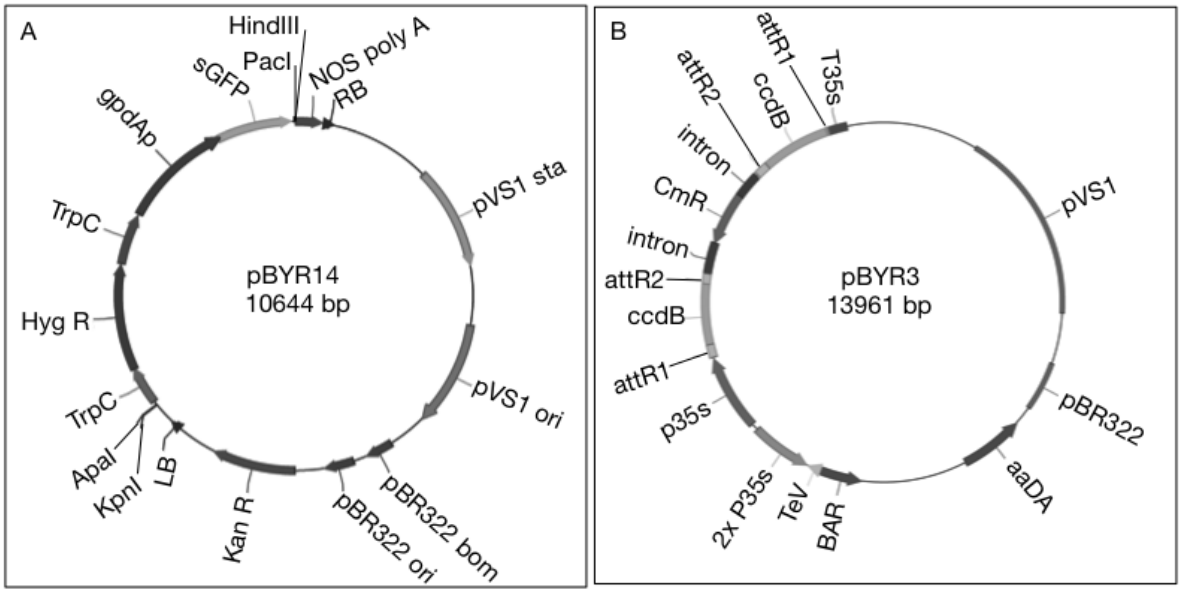

Fig. 2. (A) Map of pBYR14 fungal gene disruption vector. pBYR14 was generated by cloning the cassettes for hygromycin phosphotransferase (Hyg R) and green fluorescent protein (sGFP) into a binary vector for *Agrobacterium* transformation. KpnI and ApaI restriction sites upstream of Hyg R allowed directional cloning of the 5 prime flank of *CZK3*, while PacI and HindIII restriction sites allowed directional cloning of the 3 prime flank of *CZK3*. (B) Map of pBYR3 plant expression vector. pBYR3 contains tandem copies of the cauliflower mosaic virus (CaMV) 35S promoter (2X P35S) to drive expression of the RNAi construct. Gateway cloning is used to replace the ccdB (lethal) gene with the target gene sense and antisense fragments. These gene fragments are separated by an intron containing a chloramphenicol resistance gene (CmR), which is used for selection and to allow proper hairpin formation.

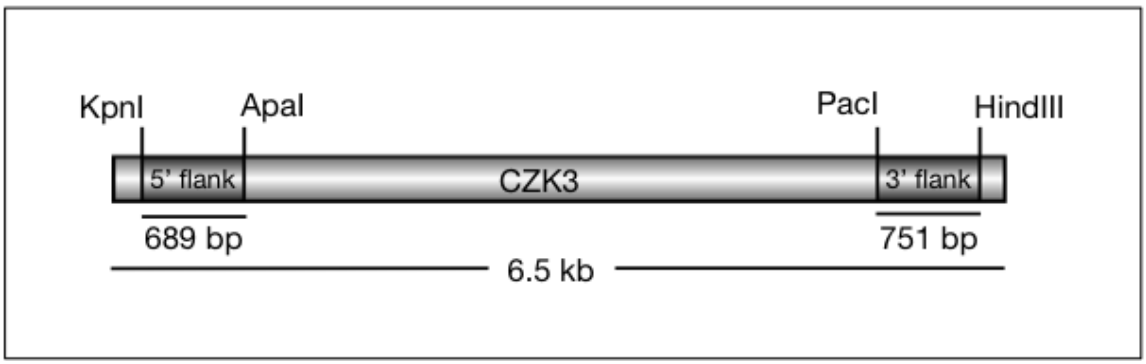

Fig. 3. Gene diagram for *CZK3* of *C. sojina*. Locations for the 5 prime and 3 prime sites used to create the deletion cassette are depicted.

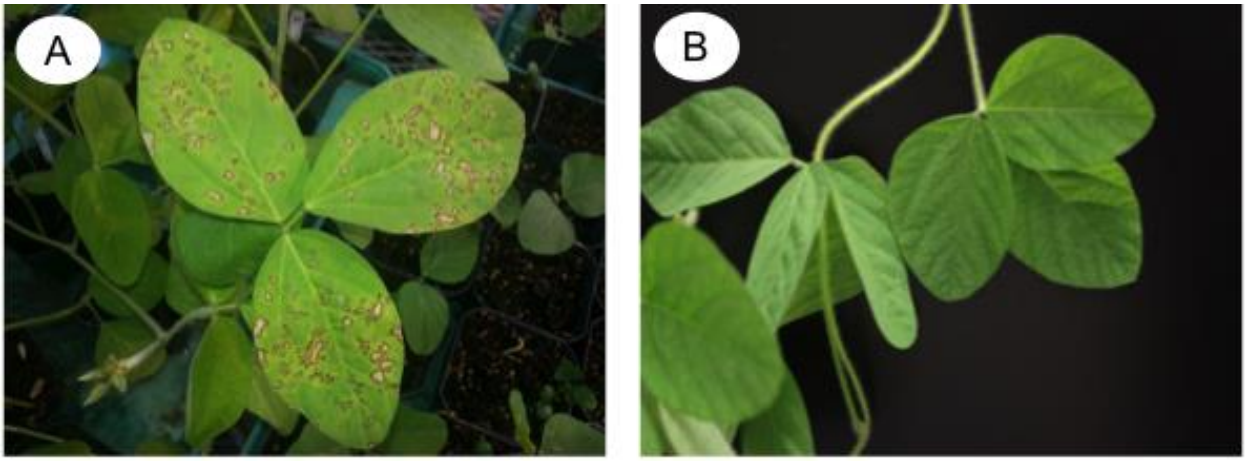

Fig. 4. *CZK3* of *C. sojina* is required for pathogenesis. In greenhouse conditions, the wild type strain induced typical symptom development (A), whereas disruption of *CZK3* rendered the pathogen unable to induce lesions (B).

Evaluation of Triazole Fungicides for Management of Strobilurin-Resistant Frogeye Leaf Spot of Soybean in Arkansas

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ABSTRACT

Frogeye leaf spot (FLS) is an important foliar disease of soybean in Arkansas. The causal agent of this fungal disease is *Cercospora sojina*. In 2012, isolates of *C. sojina* collected in Arkansas were confirmed to be resistant to strobilurin fungicides. Currently, few studies have investigated the efficacy of commercially available triazole fungicides to control these new fungicide-resistant strains of FLS. The objective of this study was to evaluate six triazole fungicides to control FLS. The experimental design was a randomized complete block design and each treatment was replicated four times. The field was artificially inoculated with several isolates of strobilurin-resistant FLS at R1-R2 growth stage. Fungicides were applied at R5 growth stage with ~1% disease severity of FLS. Lower (P = 0.05) FLS disease severity was observed at 7 days after treatment (DAT) for nearly all triazole fungicides, including Alto, Domark, Proline, Tilt, and Topguard compared to the non-treated control. Numerically, a lower FLS rating was observed at 14 DAT for all triazole fungicides, which was effective at protecting soybean yield potential resulting in a numerically higher yield. Triazole fungicides appear to be an effective strategy to suppress strobilurin-resistant FLS.

INTRODUCTION

Frogeye leaf spot (FLS) is an important foliar disease of soybean in Arkansas. This fungal disease is caused by *Cercospora sojina*, which is widely distributed across the southern soybean producing states. Generally, yield losses range from 12% to 15% on susceptible soybean varieties, but can reach as high as 30% with severe leaf blight (Phillips, 1999). In 2012, it was estimated that FLS contributed to a loss of 2.9 million bushels of soybean across the southern soybean producing states (Koenning, 2013).

Fungicides are commonly used to control FLS. The most common fungicides on soybean consist of the quinone outside inhibitors (QoI; also known as strobilurin) and demethylation inhibitors (DMI; also known as triazoles) to manage foliar diseases. In 2010, isolates of *Cercospora sojina*, causal agent of FLS, collected from Lauderdale Co., Tenn. were confirmed to be resistant to strobilurin fungicides (Zhang et al., 2012a; Zhang et al., 2012b). As a result, strobilurin fungicides like Quadris and Headline are no longer effective at controlling these new strains of FLS. In 2012, the first strobilurin-resistant isolates of *C. sojina* were detected in Arkansas. Since then the majority of the counties along the Mississippi River have been confirmed to contain isolates of strobilurin-resistant FLS. Given the recent detection of strobilurin-resistant FLS, few studies have investigated the efficacy of commercially available triazoles fungicides to control strobilurin-resistant FLS. Thus, the objective of this study is to evaluate commercially available triazoles fungicides for suppression of FLS.

PROCEDURES

Commercially available triazole fungicides were applied at the highest recommended rates in the fall for control of strobilurin-resistant FLS. This trial was located at the Newport Extension Center in Newport in a field of Dundee silt loam previously cropped to corn. The soybean cultivar 'Armor 48R40' was planted on 5 June at a seeding rate of 150,000 seed/A. Weeds were controlled using Gramoxone + Valor + NIS (48 fl oz/A + 2 oz/A + 0.25 % v/v) applied pre plant on 5 June followed by Roundup + Dual II Magnum (1 qt/A + 1 pt/A) applied post emergence on 26 June. Plots consisted of four, 27-ft-long rows spaced 30-in. apart. The experimental design was a randomized complete block design with four replications separated by a 3-ft fallow alley. Plots were artificially inoculated with several isolates of strobilurin-resistant *Cercospora sojina* at 413 conidia/ft of row on 22 July and 1326 conidia/ft of row on 29 July and irrigated overhead to promote disease development. Fungicides were broadcast through flat-fan nozzles (Tee-Jet 110015VS) spaced 30-in. apart on the two center rows per plot using an air pressurized multi-boom plot sprayer. Fungicides used in this study consisted of Quadris® (azoxystrobin; industry standard), Domark® (tetraconazole), Alto® (cyproconazole), Proline® (prothioconazole), Muscle® (tebuconazole), Topguard® (flutriafol), Tilt® (propiconazole), and a non-treated control. It should be noted that tebuconazole fungicides are not labeled for use to control FLS in soybean and were added for the purpose of this experiment. The sprayer was calibrated to deliver 15 gal/A at 32 psi. Fungicide treatments were applied at R5 growth stage (11 Aug). Frogeye leaf spot severity was assessed at 8, 16, and 21 days after treatment based on a 10-point rating scale of the upper one-third of the plant canopy. Plots were harvested on 9 Oct using a K Gleaner combine equipped with a Master Scales Weighing System. Data was subject to analysis of variance using Agricultural Research Manager Software v. 9.0. (Gylling Data Management, Inc., Brookings, S.D.).

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RESULTS AND DISCUSSION

Conditions were favorable for disease development during the 2014 cropping season at Newport. Although plots were inoculated, this site has a history of FLS (Emerson et al., 2014), which likely contributed to the development of this disease. Plots were treated when FLS disease severity was near 1% and disease development increased in all plots by 5% to 10% (rating of 3 and 4, respectively) on 19 Aug. across all fungicides. Disease severity was lower (P = 0.05) in plots treated with Domark, Alto, Proline, Topguard, and Tilt on 19 Aug. compared to the non-treated check (Table 1). Disease suppression by these triazole fungicides was similar to that reported in Mississippi, Tennessee, and Louisiana (Kelly, 2014; Price et al., 2014; Wilerson et al., 2014). Numerically, all triazole fungicides had a lower severity rating of FLS on 29 Aug. compared to the non-treated control. Given that the majority of spores were produced by strobilurin-resistant FLS the strobilurin fungicide, Quadris, was the least effective at suppressing the rate of disease development. Although, strobilurin fungicides can be effective in fields within the same county where no strobilurin-resistant isolates have been detected (Kelly, 2014), testing each field is impractical. Therefore, awareness that these isolates are present in a given area of the state should encourage the use of fungicides with more than one mode of action in fields where FLS may affect yield. A low incidence (1% to 2%) of triazole phytotoxicity was observed for Proline and Topguard (data not shown), but had little or no effect on yield. Numerically, soybean yield for all triazole fungicides was higher than the non-treated control. Similar studies have been reported of good efficacy by triazole fungicides to suppress FLS and protect yield potential across the mid-South states (Emerson et al., 2014; Kelly, 2014; Price et al., 2014; Wilerson et al., 2014). Finally, triazole fungicides appear to be effective at suppressing disease development of strobilurin-resistant FLS, especially across the mid-South where strobilurin-resistant FLS is an important foliar disease.

PRACTICAL APPLICATIONS

Since strobilurin-resistant FLS was detected in Arkansas, fungicides have been applied that are ineffective against these new pathogen strains. This study provides efficacy data to support the use of triazole fungicides to manage these strobilurin-resistant FLS; and late applications at growth stages (R5) when disease is present can be effective at suppressing disease development and protecting yield potential.

ACKNOWLEDGMENTS

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Table 1. Effect of six commercially available triazole fungicides on the suppression of strobilurin-resistant frogeye leaf spot of soybean compared to the standard strobilurin fungicide and a non-treated control.

Treatment, rate/ac	Frogeye Leaf Spot Severity [a] (19 Aug)	Frogeye Leaf Spot Severity (26 Aug)	Yield (bu/ac)[b]
Non-treated check	4.8 a[c]	5.8 a	59.8 a
Quadris 2.08 SC, 6 fl oz	4.3 ab	5.5 ab	61.8 a
Domark 230 ME, 5 fl oz	3.0 c	4.3 bc	66.2 a
Alto 100 SL, 5.5 fl oz	3.5 bc	4.3 bc	65.5 a
Proline 480 SC, 3 fl oz	3.0 c	4.3 bc	65.1 a
Muscle 3.6F, 4 fl oz	4.0 abc	5.0 abc	63.6 a
Topguard 1.04 SC, 14 fl oz	3.3 bc	3.8 c	71.9 a
Tilt 3.6 EC, 6 fl oz	3.0 c	4.5 abc	67.5 a

[a] Frogeye leaf spot severity was based on a 10-point scale where 0 = no disease and 9 = 51% to 75% leaf area affected.
[b] Adjusted to 13% moisture
[c] Numbers within the same columns followed by the same letter are not significantly different ($\alpha = 0.05$) according to Tukey's honest significant difference test.

Use of Plant Elicitor Peptides for Broad-Spectrum Nematode Resistance in Soybean

F. Goggin[1], M-W. Lee[1], A. Humphreys[1], and A. Huffaker[1]

ABSTRACT

Three plant elicitor peptides (PEPs) from soybean were artificially synthesized and applied to soybean seeds, and results showed that one of these three seed treatments, GmPEP3, strongly induced protective defense responses in seedlings after germination. Work is underway to determine if this seed treatment can provide protection against nematode infection, and also to genetically engineer soybean lines with enhanced PEP expression. In addition, proof-of-concept experiments with the model plant *Arabidopsis thaliana* (which is faster and easier to transform than soybean) have shown that boosting PEP expression can protect plants against the loss of vigor and health that is normally caused by root-knot nematode infestation. Moreover, PEPs can in some cases increase seed pod production even in the absence of nematodes. These results suggest that PEPs have great promise as a tool for nematode management in soybean.

INTRODUCTION

Currently, there are no soybean lines that are resistant to all three of the main nematode pests in Arkansas: soybean cyst, root-knot, and reniform nematodes. Moreover, many of the sources of resistance that are currently available can have considerable yield penalties. In addition, soil fumigation for nematode control is costly, and the options for chemical fumigants are becoming increasingly limited due to environmental concerns about pesticide safety. As a result, nematode management is complex and costly, and yield losses to nematodes can exceed 50% in heavily infested fields. The objective of this study is to evaluate the effectiveness of plant elicitor peptides (PEPs) as a tool to confer broad-spectrum nematode resistance in soybean.

Plant elicitor peptides are short chains of amino acids that are found in all major crops, and that can trigger broad-spectrum plant defenses that protect against nematodes, insects, and pathogens. A recent study has demonstrated that nematode infestations on the model plant *Arabidopsis thaliana* can be suppressed by engineering increased expression of a PEP gene from that plant, *AtPROPEP1* (Sekora, 2014). In addition, applying synthetic peptides to the leaves of numerous crops, including soybean, can induce protective defense responses in the plants, as long as the peptides are derived from the same or similar species (Huffaker et al. 2013). This raises the exciting possibility that PEPs could be used as a foliar or seed treatment to immunize plants against pests without the need for genetic modification. This study explored both transgenic and non-transgenic options for using plant PEPs to immunize plants against pests.

PROCEDURES

Characterization of PEPs from Soybean. To determine which PEPs from soybean are most promising candidates for inducing resistance, and to test whether seed treatments are a viable way of applying PEPs, three PEPs from soybean were artificially synthesized and applied to soybean seeds. Following application of PEPs, expression of three defense genes (a peroxidase, polyphenol oxidase, and a cytochrome P450, selected based on results from Casteel et al., 2008) were measured in the seedlings to detect induced resistance. The GmPep1 (Amino acid sequence: ASLMATRGSRGSKISDGSGPQHN), GmPep2 (ASSMARRGNRGSRISHGSGPQHN), and GmPep3 (PSHGSVGGKRGSPISQGKGGQHN) were synthesized by the Biomatik Corporation, (Wilmington, Del.) and purity and mass was verified by C18 HPLC and mass spectrometry, respectively. Soybean seeds (Williams82) were imbibed in petri dishes at room temperature (24 °C) overnight in a solution of water and 0.05% Tween20 containing 1 µM of a peptide (GMPep1, GmPep2, or GmPep3). Control seeds were treated with water and Tween20 only. Seeds were then germinated in soil under greenhouse conditions (16:8 L: D photoperiod, 21-27 °C); and after germination, the first true leaves were collected for gene expression analysis. Next, RNA was extracted with Trizol, cDNA was generated with Superscript III reverse transcriptase and oligo-dT primers, and quantitative polymerase chain reaction was performed with an Applied Biosystems StepOnePlus thermal cycler using a QuantiTect SYBR Green PCR kit, (Qiagen, Germantown, Md.).

Testing the Effects of Enhanced PEP Expression in Arabidopsis. The CaMV 35S strong constitutive promoter was used to generate transgenic Arabidopsis lines with enhanced expression of four different PEPs from Arabidopsis (AtPEP1, AtPEP2, AtPEP3, and AtPEP6). Transgenic and wild-type (normal) plants were grown in sandy soil, inoculated with root-knot nematodes (*M. incognita*, ~1000 eggs/plant) at 13 days after germination, and scored for plant vigor (based on size and number of leaves) and health (based on greenness or yellowing) on a scale from 1 (small/unhealthy) to 5 (optimal) at 5 weeks after inoculation. Additional, un-inoculated plants were grown in soil and monitored weekly for vegetative growth and seed production to assess the potential effects of PEPs on plant development in the absence of pests.

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RESULTS AND DISCUSSION

Characterization of PEPs from Soybean. Seed treatment with GmPep3 strongly induced expression of all 3 defense genes in soybean seedlings, with as much as a 1000-fold increase in the case of peroxidase (Fig. 1). These results indicate that seed treatments with PEPs can effectively induce defenses in young plants. A bioassay is currently underway with each of the three PEPs to test whether seed treatments can suppress root-knot nematode infection. Our results also suggest that GmPep3 is the most promising of the PEPs found in soybean for defense induction, and so work is underway to generate soybean lines with genetically enhanced GmPep3 expression. This will allow us to compare the relative effectiveness of seed treatments versus genetic enhancement of PEP expression for nematode management.

Effects of Enhanced PEP Expression in Arabidopsis. When Arabidopsis plants were inoculated with root-knot nematodes, wild-type plants showed stunted growth and extensive yellowing, whereas plants with enhanced expression of *AtProPep1, AtProPep2*, or *AtProPep3* remained relatively healthy and vigorous (Figs. 2 and 3). Analysis of root-knot nematode numbers on the plants is pending. Among plants that were not inoculated with nematodes, plants that had enhanced expression of *AtProPep3* produced more seed pods than wild-type (normal) plants (Fig. 4), which suggests that certain PEPs can also benefit yields even in the absence of pests.

PRACTICAL APPLICATIONS

By inducing broad-spectrum plant defenses against nematodes and other pests, PEPs could increase yields, decrease management costs, and simplify nematode management decisions. Moreover, our results suggest that it may be possible to protect plants from pests using PEPs as seed treatments, which would give growers a flexible, non-GM management tool that would be compatible with a wide variety of cultivars. Furthermore, certain PEPs may also promote yields in the absence of pests.

ACKNOWLEDGMENTS

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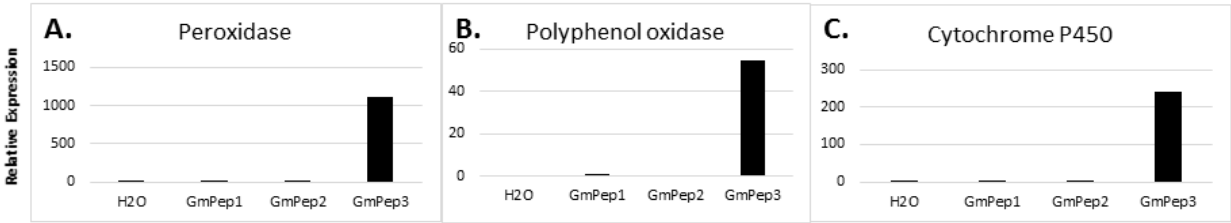

Fig. 1. Induction of plant defenses in soybean by seed treatments with plant elicitor peptides (PEPSs). Soybean seeds were treated with synthetic peptides (GmPep 1, 2, or 3) or with water (a negative control), and then qRT-PCR was used to measure the expression of 3 marker genes that are indicators of plant defenses responses (A, B, or C). Expressions of these genes in the three peptide treatment groups were calculated relative to the water-treated controls (H2O) and normalized relative to the uniformly-expressed housekeeping gene *ELF1b*(GLyma02g44460). Peptide GmPep3 strongly induced expression of *cytochrome P450* (BU551360.1) *Polyphenol oxidase* (AC235190.1) and *peroxidaseI* (AW349107.1) Primers to amplify fragments of three transcripts are as follows: Cytochrome P450 forward primer, 5'CTA GAC GCG TTC CAA GG 3' and reverse primer, 5' GGC AAC ATT GAC AGT GG 3'; Polyphenl oxidase forward primer 5' GAC CTA CCC GCA GGT GTA AA 3', and reverse primer 5' CAA CGA TGG AAA GGG AAG AA 3'; Peroxidase forward primer 5' AAC TTC AGA GCC CGC ATC TA 3', and reverse primer, 5'TTG GAG CCA GTG AGA GA CT 3'; and ELF1b forward primer, 5' AAG GGA GGC TGC TAA AAA GC 3', and reverse primer 5'CAA CTG TCA AGC GTT CCT CA 3'.

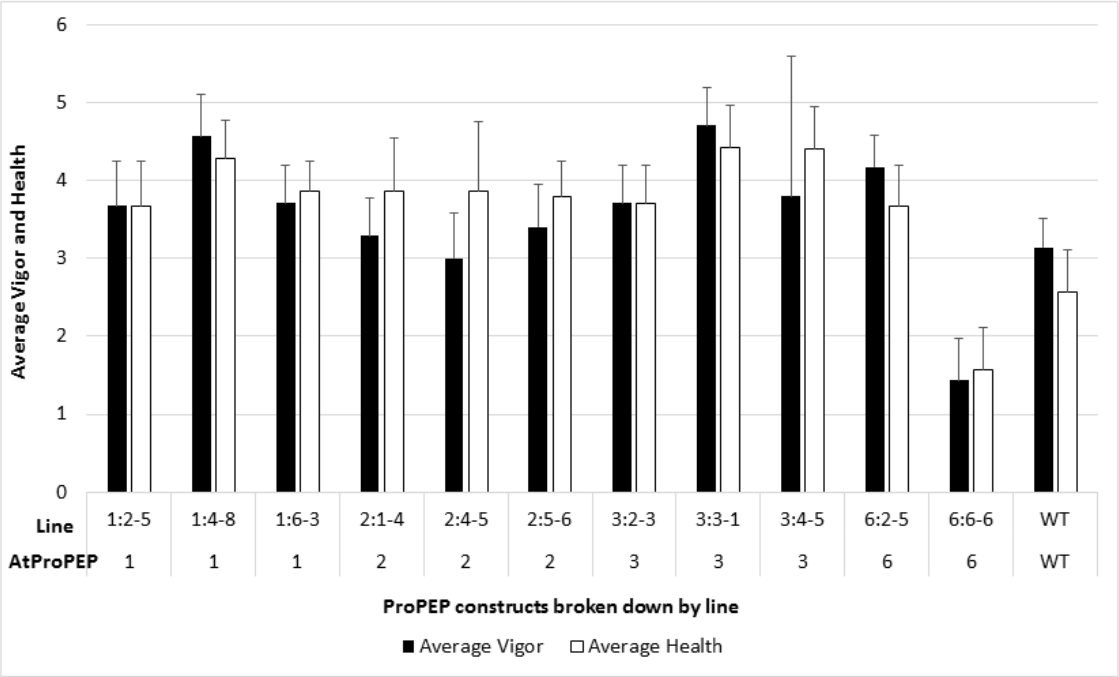

Fig. 2. Health and vigor of Nematode-infested Arabidopsis lines that have enhanced expression of Arabidopsis Plant Elicitor Peptides (PEPs) 1, 2, 3, and 6. Two to three independently transformed lines were assayed for each PEP (7 plants each), and all were compared to the untransformed (WT) control line. All plants were innoculated with root-knot nematodes, and 5 weeks after innoculation, the impact of infestation on plant vigor (as measured by overall plant size) and health (as measured by the number of green versus yellowing leaves) was scored on a scale of 1 to 5 (with 1 = small/yellow, and 5 = large/green) > Plants with enhanced expression of AtProPep1, AtProPep2, and AtProPep3 all had significantly greater scores for health than WT plants ($P < 0.05$), and AtPro Pep1 and AtProPep3 also had enhanced vigor, suggesting that these peptides protected plants from the negative impacts of nematodes on health and vigor.

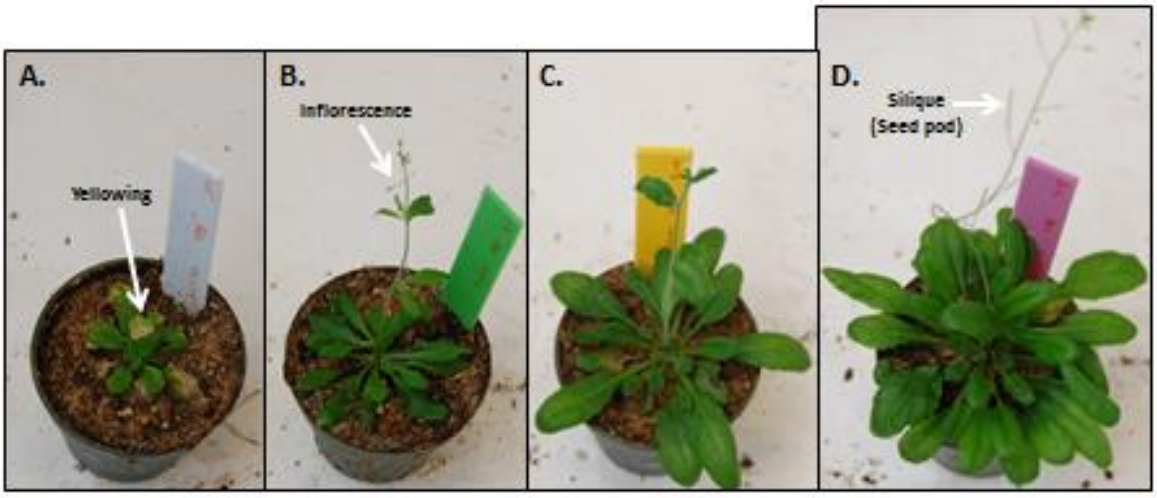

Fig. 3. Visual assessments of the health and vigor of nematode-infested arabidopsis lines. Plants that showed severe stunting as a result of nematode infestation were given a score of 1 for vigor (A), whereas the largest plants were given scores of 5 (D), and plants that were intermediate in size received intermediate scores B = 2, C = 4). Plants that showed extensive yellowing of the leaves also received a score of 1 for health, whereas the greenest plants received a score of 5. As summarized in Fig. 2, enhanced expression of AtProPep1, AtProPep2nts received a score of 5. Plants with better health and vigor in general also produced more inflorescences and siliques than plants with poor health. These photographs show representative samples of wild type plants (A) and plants with enhanced expression of AtProPep1 (B., line 1:6-3), AtProPep2 (C., line 2:5-6), and AtProPep3 (Line3:3-1) 5 weeks after nematode infestation. As summarized in Fig. 2, enhanced expression of AtProPep1, AtProPep2, and AtProPep3 appeared to allow plants to stay healthier and more vigorous than wild type plants when challenged with nematodes. Results for plants over-expressing AtProPep6 (not shown) were highly variable between lines, and were consistent with previous reports that this peptide does not strongly induce plant defenses.

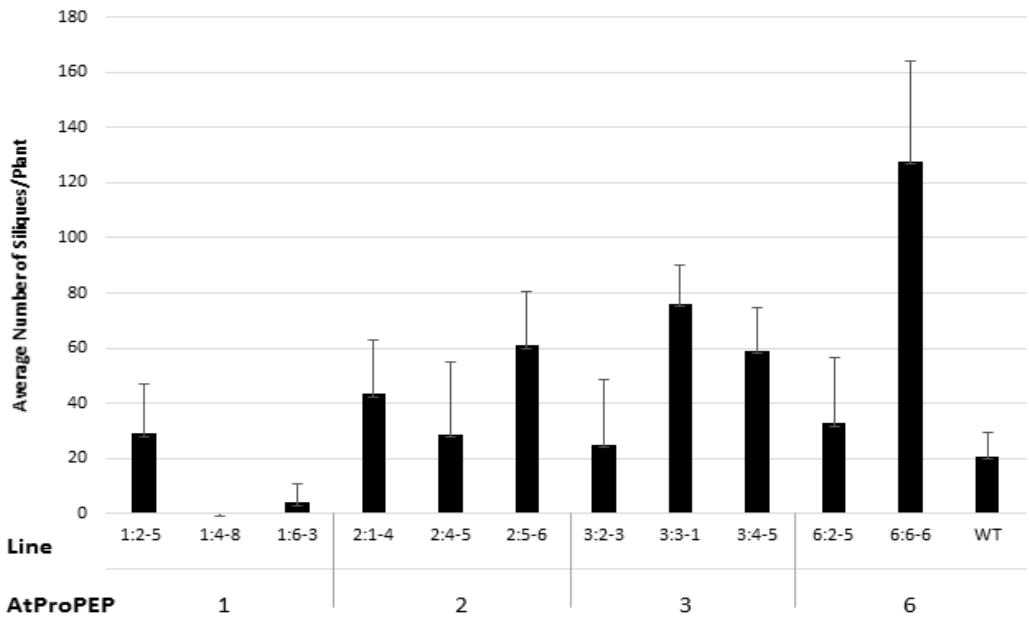

Fig. 4. Production of Siliques by Arabidopsis lines theat have enhances expression of Plant Elicitor Peptides (PEPs) 1, 2, 3, or 6. Silique (seed pod) production was compared among uninfested plants with normal (WT) or enhanced expression of AtProPep1, AtProPep2, AtProPep3 and AtProPep6, to see if there are any yield costs associated with overexpression of PEPs (2-3 independent lines/peptide, 3 plants/line). Although two of the lines with enhances AtProPep1 expression had reduced silique production, all other lines had similar or enhanced silique numbers compared to WT, with AtProPep3 and AtProPep6 significantly (*P* =0.05) enhancing silique numbers.

Comprehensive Disease Screening of Soybean Varieties in Arkansas

T.L. Kirkpatrick[1], K. Rowe[1], T. Faske[2], and M. Emerson[2]

ABSTRACT

Each year, Arkansas conducts the most comprehensive soybean disease screening program in the southern U.S. A combination of field nurseries and greenhouse tests are used to evaluate all cultivars that are entered into the official University of Arkansas System Division of Agriculture's Variety Testing Program (OVT) each year for resistance to major diseases of concern in Arkansas. Because of their importance in Arkansas soybean production, nematodes are a major focus of the screening program. The southern root-knot nematode, the soybean cyst nematode, and the reniform nematode all are evaluated against OVT cultivars and certain advanced breeding lines in greenhouse trials at Hope and Fayetteville. In addition, field nurseries located at Newport are used to screen the cultivars and lines for resistance to southern soybean stem canker and frogeye leaf spot. Results from the screens are the basis for our annual Soybean Update and the SOYVA cultivar selection program, and are used by countless soybean growers around the state to make more informed decisions during their cultivar selection process.

INTRODUCTION

Foliar and soil borne diseases caused an estimated loss of about 413 million bushels of soybeans in the U.S. annually from 2006-2009 (Koenning and Wrather, 2010). In Arkansas, nematodes, various foliar diseases, and soil borne fungal diseases account for a vast majority of the disease-induced loss in yield potential for soybean growers (Wrather and Koenning, 2006). Three nematodes, the southern root-knot nematode, the soybean cyst nematode (SCN), and the reniform nematode are considered economic. Recent surveys indicate that root-knot, soybean cyst, and reniform nematodes occur at about 20%, 41%, and 16% incidence in the state, respectively (T.L. Kirkpatrick, unpublished). Frogeye leaf spot leads the list of economic foliar diseases, and the recent development of fungicide resistance in Arkansas populations of the causal pathogen focuses attention much more fully on the use of genetic resistance for management of this disease (Faske et al., 2014). Southern stem canker, charcoal rot and sudden death syndrome (SDS) have historically been our most costly soil borne fungal pathogens. Little effective genetic resistance is known to the charcoal rot pathogen, but effective resistance has been incorporated into soybean cultivars to both stem canker and SDS.

The comprehensive screening program for soybean cultivars that is administered annually in Arkansas is conducted at various locations throughout the state, and supported cooperatively by the University of Arkansas System Division of Agriculture's Agricultural Experiment Station and the Cooperative Extension Service, with support from the Arkansas Soybean Promotion Board. Currently, we have field disease nurseries established at the Newport Extension Center for evaluating stem canker and frogeye leaf spot. Fields that are used for the screens are equipped with overhead irrigation that, in combination with supplemental inoculation with appropriate pathogens allow us to develop consistent and severe disease pressure for our evaluations. We also conduct soybean cyst (multiple races), root-knot, and reniform nematode screens in greenhouses at the Southwest Research & Extension Center in Hope and the Cralley-Warren laboratory on the Fayetteville campus farm.

PROCEDURES

In 2014, 269 cultivars were screened for root-knot, reniform and soybean cyst nematode, stem canker, and frogeye leaf spot. Because biotypes (races) of soybean cyst differ from field to field, races 2, 4, 5, and 14 were evaluated in separate trials.

Root-knot Nematode Screening. The screening was conducted in the greenhouse at the Southwest Research and Extension Center by Kim Rowe from early to late summer. All entries were planted and inoculated with 5000 eggs of *Meloidogyne incognita*, replicated 4 times, and allowed to grow for 40 days. After 40 days of reproduction, each root system was given a visual gall rating of 0-5. Ratings were averaged by cultivar to establish a designation on level of susceptibility.

Reniform Nematode Screening. The screening was conducted in Fayetteville at the Cralley-Warren Laboratory greenhouse by Bob Robbins. It consisted of 184 new cultivars for 2014. Each cultivar was planted in five replications and was inoculated with 2000 *Rotylenchulus reniformis* nematodes. After a reproduction period of approximately 50 days, each pot was extracted, nematodes quantified and compared to a susceptible standard to determine level of susceptibility.

Soybean Cyst Nematode Screening. The screenings were conducted in Fayetteville at the Cralley Warren Laboratory greenhouse by Devany Crippen. Each cultivar was planted and then inoculated with 5000 eggs of races 2, 4, 5, and 14 of *Heterodera glycines* and replicated 4 times. After 40 days, the soil and roots were extracted using a semi-automatic elutriator and female cysts were quantified. Results are reported as a reproduction index based on a susceptible standard.

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Stem Canker Screening. The screen was conducted at the Newport Extension Center by Kim Rowe and Michael Emerson on all 269 cultivars. Each cultivar was planted in single-row plots and replicated three times. In each rep, the stems of 10 plants were inoculated by hand with toothpicks infested with *Diaporthe phaseolorum var. meridionalis* at the V5 growth stage. After approximately 80 days, each inoculated plant was given a rating based on presence and length of canker and ratings were averaged to determine level of susceptibility for each cultivar.

Frogeye Leaf Spot Screening. This screening was also conducted at Newport by Michael Emerson and Kim Rowe on all 269 cultivars. Each cultivar was planted and replicated three times. *Cercospora sojina* spores in a water suspension were applied using a sprayer twice; once at 6 weeks post planting, and then again at two weeks later. Visual ratings were taken approximately 12 weeks post planting as percentage of leaf area affected.

RESULTS AND DISCUSSION

The results of the 2014 disease screens were consistent with previous years' results. On average, the nematode screens showed that 90% of entries were susceptible to reniform, root-knot, and race 2 of soybean cyst nematodes (Figs. 1, 2 and 3). Races 5 and 14 of SCN (Figs. 4 and 5) showed slightly more variation in the categories, although the percentage of resistant varieties was still very low, ranging from 1-3%. Race 4 of SCN was screened, but the results were not reported due to a possible shift in races. The stem canker screen results showed that 91% of entries were resistant to the disease, 1% were moderately resistant, 1% were moderately susceptible, and 7% were susceptible (Fig. 6). Although the majority of cultivars were resistant, this indicates that an evaluation of new soybean cultivars for stem canker resistance is still necessary to avoid unpleasant and costly surprises in grower fields. The frogeye leaf spot screen showed the most variation between levels of susceptibility, and like stem canker, the 8% of varieties in the susceptible category could mean trouble for growers (Fig. 7). A copy of all data from the 2014 disease screens in Excel spreadsheet form is available at www.arkansasvarietytesting.com.

PRACTICAL APPLICATIONS

Most growers select cultivars based primarily on yield performance. Unfortunately, while yield potential is an important factor in cultivar selection, the yield of a cultivar may be drastically reduced by soybean diseases and or nematode infection, so yield performance results may not tell the complete story. In Arkansas, resistance to a number of soybean pathogens is as important as yield potential in selecting an appropriate cultivar. Soybeans are grown on about 3.3 million acres in the state each year, with a value of $1,840,616,000 in 2013 (USDA-NASS, 2013). Diseases result in yield losses of 10% annually by some estimates. By this figure, last year nearly $200 million was lost to soybean diseases in Arkansas alone (Faske et al., 2014). Each year, well over 200 new soybean cultivars become available to Arkansas growers and many of these cultivars are accompanied by little or no information on their resistance to diseases or nematodes. Typically, one variety will be grown in a particular field, so choosing the best variety can be a difficult decision. This program provides comprehensive information on the disease package that each new cultivar contains prior to widespread planting of the cultivars in the state, lowering the risk of severe disease losses due to incorrect cultivar selection.

ACKNOWLEDGMENTS

Many thanks to the Arkansas Soybean Promotion Board for their continued support and funding of this project. Support also provided by the University of Arkansas System Division of Agriculture.

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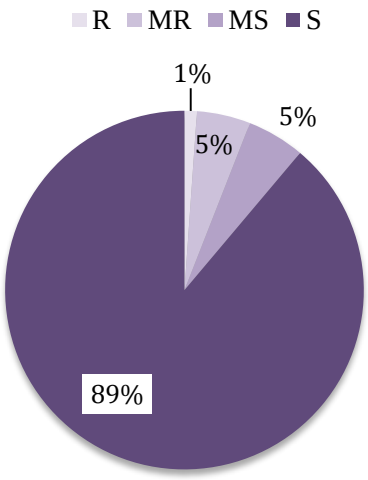

Fig. 1. Percent of cultivars showing resistance to root-knot nematodes.
R = resistant; MR = moderately resistant;
MS = moderately susceptible;
S = susceptible.

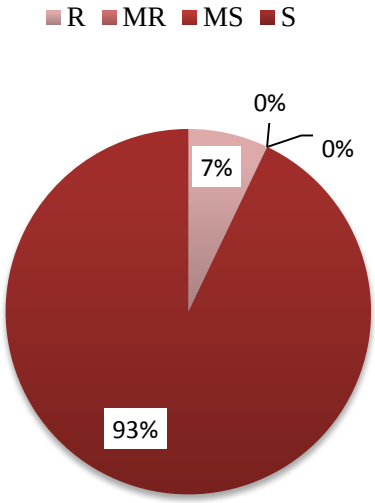

Fig. 2. Percent of cultivars showing resistance to reniform nematodes.
R = resistant; MR = moderately resistant;
MS = moderately susceptible;
S = susceptible.

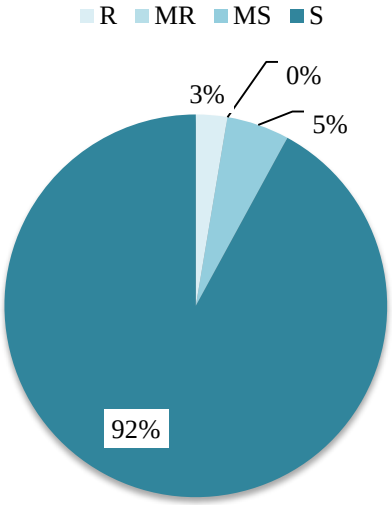

Fig. 3. Percent of cultivars showing soybean cyst (race 2) resistance.
R = resistant; MR = moderately resistant;
MS = moderately susceptible;
S = susceptible.

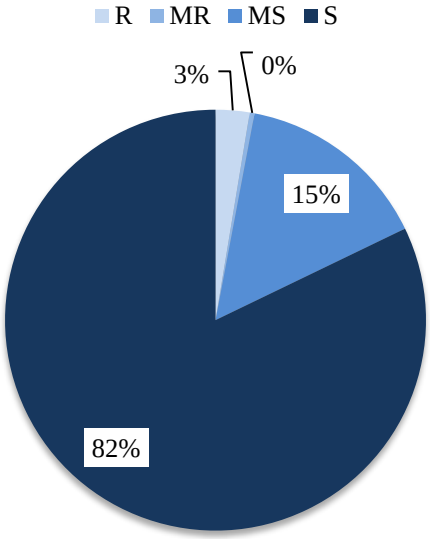

Fig. 4. Percent of cultivars showing soybean cyst (race 5) resistance. R = resistant;
MR = moderately resistant;
MS = moderately susceptible;
S = susceptible.

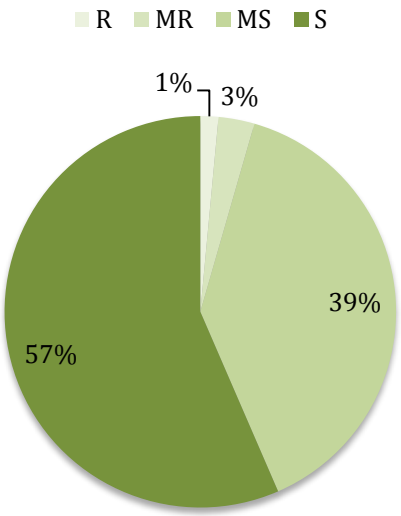

Fig. 5. Soybean Cyst Nematode Race 14 screen results by designation. R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible.

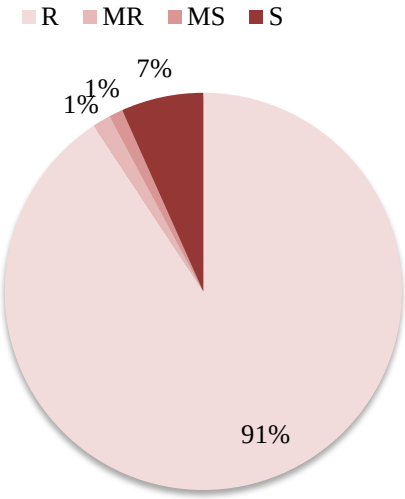

Fig. 6. Stem canker screen results by designation. R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible.

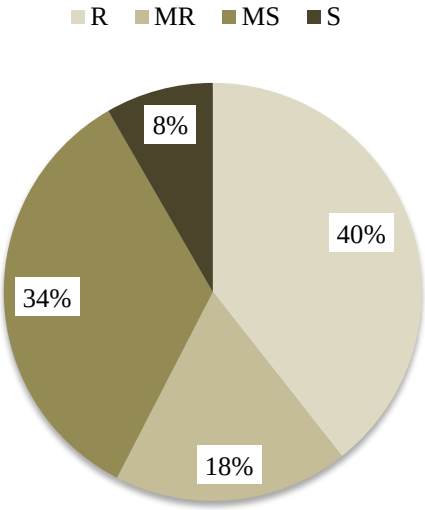

Fig. 7. Percent of cultivars showing frogeye leaf spot resistance. R = resistant; MR = moderately resistant; MS = moderately susceptible; S = susceptible.

Incidence, Population Density, and Distribution of Soybean Nematodes in Arkansas

T.L. Kirkpatrick[1]

INTRODUCTION

The agricultural landscape is changing in Arkansas. Historical acreage of agronomic crops has changed significantly in the state in the last few years. For example, cotton acreage in the state has decreased 44% since 2005; while in the same period of time corn acreage has almost tripled, grain sorghum acreage has increased twofold. Soybean acreage has increased about 10% per year since 2009, and soybeans are now grown on approximately 3.5 million acres in the state (USDA-NASS, 2014). Nematodes account for a significant yield loss in Arkansas soybeans each year (Wrather and Koenning, 2012), both as primary pests and in complexes and interactions with fungal pathogens. Those in Arkansas that are considered to be economic pests of soybean include the soybean cyst nematode, *Heterodera glycines*, the southern root-knot nematode (*Meloidogyne incognita*), the reniform nematode (*Rotylenchulus reniformis*), and lesion nematodes (*Pratylenchus* spp.).

Historically, soybean cyst nematodes were widely distributed and of major concern statewide, and were present in about 66% of Arkansas soybean fields surveyed from 1979-1986 (Robbins, et al., 1987). Both the root-knot nematode and the reniform nematode have been detected at increased frequency in recent years, particularly in regions that were historically cotton-production areas (Bateman and Kirkpatrick, 2011). Major yield loss has been associated with root-knot nematodes in soybean, but there is little information regarding the impact of either reniform or lesion nematodes on soybean yield in the mid-South. The biotype (race) of soybean cyst nematodes has a major impact on the damage potential to specific soybean cultivars. There has not been an attempt made to determine the nematodes or soybean cyst nematode races that are associated with the Arkansas soybean crop in about 30 years—the most recent survey of nematodes associated with soybeans in Arkansas was conducted from 1978-1986 (Robbins et al., 1987). Given the recent changes in cropping system dynamics, it is vital that we learn what nematodes are associated with the soybean crop.

PROCEDURES

The first year of a three-year survey, sponsored by the Arkansas Soybean Promotion Board was conducted statewide during the 2014 season. Because nematode samples must be collected and handled properly prior to assay, an on-line course describing proper sampling and handling techniques as well as how to submit samples to the Arkansas Nematode Diagnostic Laboratory (ANDL) was developed for potential surveyors. This course is accessible via the University of Arkansas System Division of Agriculture's Extension website at: http://courses.uaex.edu/login/index.php. County agents, consultants, and in some cases growers were enlisted to sample fields that were either in soybean in 2014 or would be going into soybean in 2015. Procedures were as follows. Sampling occurred from September 1-December 1. Fields of 40 acres or less were sampled as a unit by collecting a minimum of 20 soil cores (1 inch-diameter) randomly from within the rows after harvest. Larger fields were subdivided into blocks of 40 acres or less and each block was sampled as above. Soil cores were bulked and mixed, then approximately 1 pint was placed into a plastic bag, labeled and sealed. Samples were mailed (priority mail) or sent by courier to the ANDL. Each sample was thoroughly mixed in the laboratory, and a 100 cm^3 subsample was assayed by a semi-automatic elutriator and centrifugal flotation. Nematodes were identified to genus and counted. Where soybean cyst nematodes were detected, the remaining soil was extracted and the cysts that were collected were placed into clay pots in the greenhouse to be increased on soybean, 'Lee 74'. Once populations are increased sufficiently, (ca. 45 days), they will be inoculated on three plants each of Lee 74, Pickett, PI 88788, PI 90763, and Peking—the differentials used to identify races of the nematode—and grown for 30 days in the greenhouse to determine the race.

RESULTS AND DISCUSSION

County agents, crop consultants, and growers collected and submitted 755 samples for assay during the September-December period (Fig. 1). Soybean cyst nematodes were the predominant nematode that was present. This nematode was found in 41% of the samples that were submitted (Fig. 2). Lesion nematodes, *Pratylenchus* spp. were the second most frequently encountered nematode with 23% of fields having detectable populations. Root-knot nematodes, which are capable of causing severe yield losses at high populations were found in 20% of the fields surveyed. Reniform nematodes were recovered from 16% of the fields. It is interesting that soybean cyst nematode was found in almost half of the samples that were collected. Although, based on this limited number of samples, it appears that soybean cyst nematode incidence has declined from the 66% of fields reported in the 1978-1986 survey of the state's soybean acreage (Robbins, et al., 1987). Forty-one percent is still, however, a significant and troubling incidence. In contrast with soybean cyst nematodes, the southern root-knot nematode was not a

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commonly encountered inhabitant of the soybean fields in Arkansas in 1978-1986. This nematode was found in one-fourth of the samples that were collected for our survey this year. The relatively high incidence of this nematode is troubling since root-knot can be severely damaging to soybean. The high incidence of root-knot is likely due in part to two factors: 1) an increased number of fields have recently been converted from cotton monoculture to soybean or soybean-corn cropping systems, and 2) the popularity of the early soybean production system that utilizes earlier maturity soybeans, most of which are highly susceptible to root-knot. Root-knot nematodes are most damaging in lighter-textured sandy soils and are rapidly becoming a major yield-limiting factor in soybean. Similarly, the reniform nematode was not found in the 1978-1986 soybean nematode survey, but was detected in 16% of the fields sampled in 2014. As with root-knot, it is likely that many of the fields in this survey with reniform nematodes were historically in cotton, the preferred host for reniform. It is unclear at this time what impact reniform nematodes will have on soybean production in Arkansas. Several species of the lesion nematode were associated with soybean in the earlier survey, and 23% of the 2014 fields had lesion nematodes. Identification to species has not been done for the *Pratylenchus* found in the 2014 survey, and there is no data on the impact of lesion nematodes on the soybean crop.

Soybean cyst nematode races are currently being identified through bioassay. Although only about 255 of the samples have been assayed for race at this time, to date the majority of populations have been races 2, 5, or 6. The prevalence of these races in Arkansas is somewhat reflective of the race structure of Tennessee soybean fields that was reported in a 1990 survey (Young, 1990) where races 2, 5, and 6 predominated. In the Tennessee survey, races 3, 4, 9, and 14 were also detected, whereas none have been detected to date in the 2014 Arkansas survey.

PRACTICAL APPLICATIONS

The incidence and number of plant-parasitic nematodes in soybean fields change in response to crop history. Since the last nematode survey of soybean in the state was reported about 30 years ago, we have no idea which nematodes are present, how high their populations are, or if there is concern. Because nematodes are microscopic and soil borne, the only way to know if they are a potential threat to soybean production in any particular field is through a nematode assay. For the next three years, the Arkansas Soybean Promotion Board in partnership with the Arkansas Nematode Diagnostic Laboratory will provide growers and crop advisors an opportunity to “know for sure” if nematodes are a potential threat in their fields free of charge. This knowledge will in turn allow development of effective nematode management strategies on a field-by-field basis.

ACKNOWLEDGMENTS

The authors thank the Arkansas Soybean Promotion Board for providing the funding support for conducting a survey to determine the incidence and potential threat of nematodes in soybean fields statewide. Support also provided by the University of Arkansas System Division of Agriculture.

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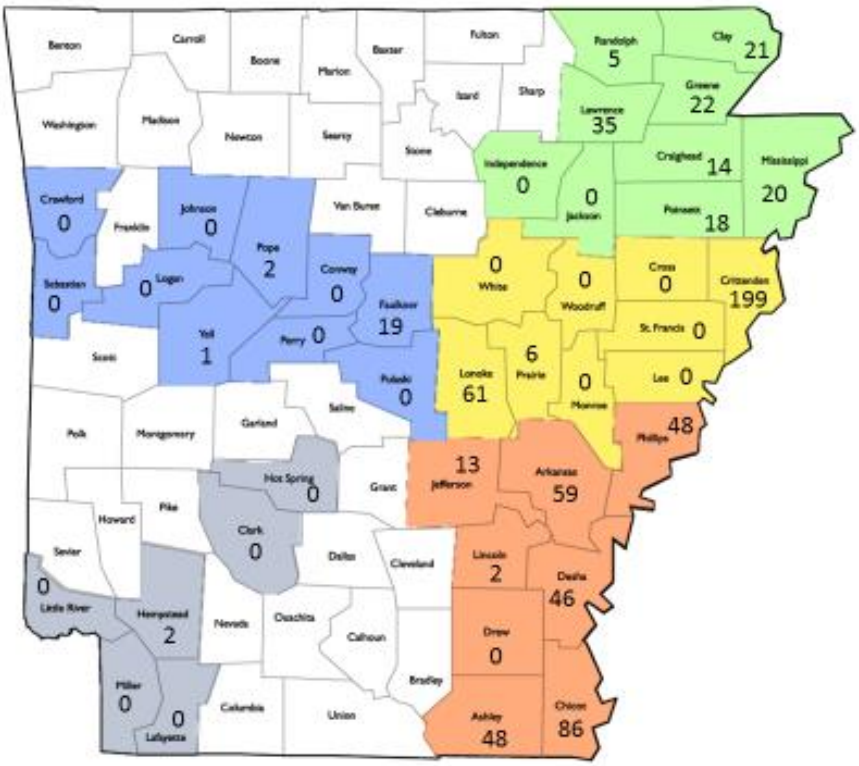

Fig. 1. Counties represented in the 2014 Arkansas Soybean Promotion Board-sponsored soybean survey, and the number of fields that were sampled.

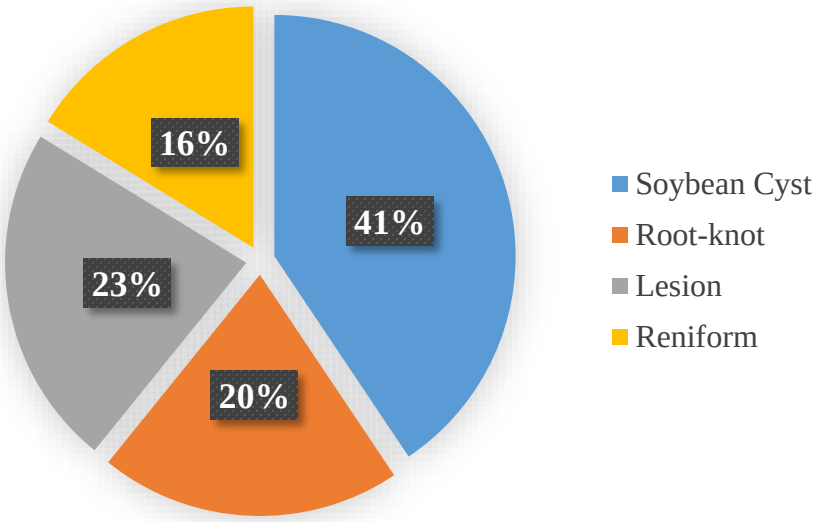

Fig. 2. Percent of Arkansas soybean fields included in survey with presence of soybean cyst, root-knot, lesion, and reniform nematodes, 2014.

Assessment of Fluopyram for Suppression of Root-Knot Nematode *(Meloidogyne incognita)* in Soybean

C.S. Jackson[1], T.R. Faske[1], and T.L. Kirkpatrick[2]

ABSTRACT

Fluopyram is a succinate dehydrogenase inhibitor (SDHI) fungicide that was recently identified to have nematistatic activity on root-knot nematode (RKN), *Meloidogyne incognita*. Few studies have investigated the field performance of fluopyram; thus, the objective of this study was to evaluate the use of fluopyram as a seed treatment (ST) and in-furrow (IF) spray for suppression of RKN. This trial was arranged in a randomized complete block design with abamectin (Avicta®) and *Bacillus firmus* (VOTiVO®) as the industry standard for seed-treatment nematicides. The field site had a natural infestation of RKN and the population density was low at planting. Initially, abamectin-treated seed contributed to fewer (P = 0.05) galls per root system at 30 DAP compared to fluopyram applied as a ST and IF spray. However, at 60 DAP root galling was numerically lower on fluopyram applied as a ST and IF spray than VOTiVO and Avicta. All fluopyram treatments had a numerically higher yield than the non-treated control. Fluopyram applied as an IF spray was more commonly associated with a numeric reduction in root-galling and higher yield than fluopyram-treated seed. These findings suggest fluopyram performs similarly to other commonly used seed treatment nematicides, Avicta and VOTiVO, in regards to RKN suppression and protecting yield potential.

INTRODUCTION

Root-knot nematodes (*Meloidogyn*e spp.) are among the most economically important pathogens that affect soybean production in the United States (Kinloch and Rodriguez-Kabana, 1999). In 2011, approximately 2.5 million bushels of soybean were lost due to root-knot nematode (RKN) in Arkansas (Koenning, 2013), which is estimated to be an economic loss of $31.25 million. Currently, soybean nematode management tactics include the use of host-plant resistance, cultural practices, and nematicides. Though resistance has been shown to be effective in other crops, resistance is lacking in the most common maturity group (Group IV) grown in the state. Crop rotation is one of the oldest and effective management tools; however, rotation is not always a practical option in some production systems. Therefore, producers continue to rely on nematicides to manage soybean nematodes. For the past 10 years there has been an increased movement toward pesticides that have lower toxicity to human health and environmental concern. One such pesticide that is being evaluated for suppression of plant-parasitic nematodes is fluopyram.

Historically, all nematicides were toxic insecticides; however, there have been a few reports of fungicides with nematicidal activity. Pentachloronitrobenzene (PCNB) was one of the first fungicides to be reported to have some activity against RKN and a few other plant-parasitic nematodes in greenhouse trials (Adams et al., 1979). The fungicide thiophanate-methyl was reported to be somewhat effective on soybean cyst nematode, *Heterodera glycines*, but had little effect on nematode suppression in the field (Faghihi et al., 2007). Fluopyram, a succinate dehydrogenase inhibitor (SDHI) fungicide, was reported to be toxic to RKN; and based on nematode motility, its toxicity was similar in magnitude to that of aldicarb and abamectin (Faske and Hurd, 2014). Although fluopyram appears to have nematicidal activity, in vitro field trials are needed determine the usefulness of fluopyram to protect the developing root system. Currently, fluopyram is being evaluated as a seed treatment and in-furrow spray in cotton and peanut for suppression of soil borne fungi and plant-parasitic nematodes, but few studies have been conducted in soybean. The objective of this study is to evaluate the usefulness of fluopyram as a seed treatment and in-furrow spray for suppression of RKN.

PROCEDURES

The study was conducted in a commercial soybean field, with a history of root-knot nematode, near Pine Bluff, Ark. Soybean cultivar ARMOR 53R16 (RKN-susceptible) was planted in four, 25-foot-long row plots and spaced 30 inches apart. Treatments consisted of a non-treated control, 0.15 mg fluopyram/seed, (ILeVO®, Bayer CropScience, Research Triangle, N.C.), 0.15 mg abamectin/seed (Avicta® 500 FS, Syngenta Crop Protection, Greensboro, N.C.), 0.15 mg fluopyram/seed + 0.15 mg abamectin/seed, 0.13 mg clothianidin + *B. firmus*/seed (Poncho/VOTiVO®, Bayer CropScience, Research Triangle Park, N.C.), and an in-furrow (IF) spray of fluopyram (41% a.i.) at 8.5 oz/acre. Population densities of RKN were sampled at-planting, 30, and 60 days after planting (DAP). To determine the suppression of nematode infection, roots were randomly sampled twice at 30 and 60 DAP. Five root systems per plot were collected at 30 DAP and galls were counted per root system. Similarly, five roots were collected at 60 DAP and visually rated for galling (0 to 10 scale, 0 = 0% galling and 10 = 100% galling). Plots were harvested on 9 Oct using a K Gleaner combine equipped with a Master Scales Weighing System. Data was subject to analysis of variance using Agricultural Research Manager Software v. 9.0 (Gylling Data Management, Inc., Brookings, S.D.).

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RESULTS AND DISCUSSION

Fluopyram applied as a seed treatment (ILeVO) and in-furrow spray was as effective as other commercially available seed treatment nematicides at suppressing RKN infection in soybean. Based on root galling, Avicta® contributed to lowest ($P = 0.05$) gall counts per root system at 30 DAP compared to fluopyram applied as a seed treatment (ST) or in-furrow (IF) spray; however, at 60 DAP, galling was comparable among Avicta and these fluopyram treatments (Table 1). Though the solo fluopyram treatments were not very effective at suppressing RKN at 30 DAP, both ILeVO and fluopyram IF treatments had the lowest numeric gall ratings at 60 DAP compared to the other seed-treated nematicides. The combination of fluopyram + abamectin was not as effective at suppressing RKN infection as each nematicide used as a solo agent, which suggests some possible negative interaction between these two pesticides. Fluopyram applied IF spray was associated with a higher numeric reduction in root galling than fluopyram applied as a seed treatment. Thus, product placement, distribution, and concentration may play an important role in the use of fluopyram as a nematicide.

Though there was some phytotoxicity, necrosis along the edge of the cotyledons, on fluopyram-treated seed (data not shown), none was observed on that applied as an IF spray. This phytotoxicity did not have an effect on soybean plant stand as populations were similar among treatments and averaged 127 and 130 plants per 25 ft of row at 11 and 30 DAP, respectively, across treatments (Table 1).

Soybean yield was similar across all treatments and averaged 63.8 bu/ac. Numerically, fluopyram applied as a ST and IF spray had a numerically higher yield over all of the nematicides applied as a seed treatment (Table 1). This field has a history of sudden death syndrome (SDS), which is caused by *Fusarium virguliforme*. Fluopyram has been reported to suppress SDS (pers. comm., Jennifer Riggs). Thus, fluopyram may have provided some yield protection in these trials even though no SDS symptoms were observed. These findings suggest fluopyram-treated seed provide a similar suppression of RKN infection and protection of yield potential as that of other commercially available seed treatment nematicides.

PRACTICAL APPLICATIONS

Currently, there are only two nematicides used as seed treatments (Avicta and VOTiVO) that are labeled for use to manage RKN in soybean in Arkansas. The fungicide/nematicide seed treatment, ILeVO, provides a new mode of action against nematode infection and as a fungicide provides some additive benefit in the suppression of sudden death syndrome. ILeVO was registered for use on soybean in 2014 for suppression of these diseases; therefore, these data provide some preliminary information on the efficacy of ILeVO to suppress nematodes and protect yield potential. Though further testing is needed as to how this new product may benefit soybean producers in other cropping systems, it does provide another option for those dealing with the challenge of growing soybeans in fields infested with root-knot nematodes.

ACKNOWLEDGMENTS

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Table 1. Field response of fluopyram applied as a seed treatment and in-furrow spray in a soybean field with a low population density of root-knot nematode (*Meloidogyne incognita*).

Treatment and rate (mg ai/seed or oz/ac)	Stand[†] 11 DAP	Stand 30 DAP	*Meloidogyne incognita* Gall counts[‡] 30 DAP	*Meloidogyne incognita* Galling (%)[c§] 60 DAP	Yield (bu/ac)
Non-treated control	136.1	132.8	0.8 ab[¶]	1.3	61.4
Fluopyram,0.15 mg	121.3	123.8	1.3 b	0.9	66.8
Abamectin, 0.15 mg	128.5	128.6	0.2 a	1.0	60.9
Fluopyram, 0.15 mg + abamectin, 0.15 mg	123.4	130.7	0.7 ab	2.3	64.2
Clothianidin + *Bacillus firmus*, 0.13 mg	129.0	136.3	0.6 ab	1.4	62.2
Fluopyram (41%), 8.5 fl oz	130.3	133.8	1.3 b	0.0	67.0

[†] Soybean plants per 25 ft of row.
[‡] Total galls per root system at 30 days after planting (DAP).
[§] Root-gall rating was based on a 10-point scale where 1 = 10%, 2 = 20%... 10 = 100% galling.
[¶] Data within the column with a different letter indicate a significant difference at $\alpha = 0.05$ according to the Waller-Duncan Test.

Spatial Distribution of Aerial Blight (*Rhizoctonia solani*) in Soybean Fields under Rice-Soybean Rotation and the Value of Fungicides for the Suppression of Early-Season Colonization of Soybean Plants: A Prelude to Control of Aerial Blight of Soybean

C.S. Rothrock[1], T.R. Faske[2], and T.N. Spurlock[3]

ABSTRACT

Aerial blight, caused by *Rhizoctonia solani* AG1-IA, is a major disease of soybean grown in Arkansas and Louisiana. This pathogen also causes sheath blight of rice. The spatial distribution of the early-season colonization of soybean by *Rhizoctonia solani* was examined in two fields in soybean-rice rotation. In addition to monitoring the progression of aerial blight in these fields, the value of early-season fungicide applications on colonization and disease development was assessed. For a field near Dumas, the early-season fungicide application showed a high level of suppression of colonization by *R. solani*. For the field near Weiner, colonization was much greater with over 50% of the plants being infected by the reproductive stages of development, and fungicides showed no ability to suppress colonization in this field. Aerial blight did not develop in either field in 2014. When populations of *Rhizoctonia solani* colonizing soybean were examined, few isolates were the aerial blight pathogen, AG1-IA, with most isolates being AG11. Early-season fungicide applications appear promising for reducing colonization of soybean by *Rhizoctonia solani* based on the results at Dumas where better fungicide coverage of the plants occurred.

INTRODUCTION

Aerial blight, caused by *Rhizoctonia solani* AG1-IA, is a major disease of soybean grown in Arkansas and Louisiana when conditions are favorable for disease development. This pathogen also causes sheath blight of rice. Thus, intensive soybean-rice rotations in Arkansas increase the potential for *Rhizoctonia solani* to cause economic losses by ensuring a source of inoculum for the subsequent crop. Estimated yearly losses for aerial blight average 12.6 million dollars with the range over a 10 year period being 2 to 46 million dollars, 1998-2007 (Wrather and Koenning, 2009). Management is typically through aerial applications of fungicides. Unlike many other foliar and stem pathogens on soybean, aerial blight is a single-cycle disease. A single-cycle disease means that inoculum produced in the field the previous season is the only source of inoculum for the development of this disease. Thus inoculum location and movement can be mapped allowing the prediction of sites of disease initiation; areas where disease management needs to be focused. From these disease foci, the pathogen grows up the plant and moves to adjacent plants. This research has shown that inoculum of the pathogen is concentrated in logical areas of collection in the levy system for rice production and moves in the direction of lower altitude (Fig. 1). Spatial analyses aids in understanding the survival and movement of *Rhizoctonia solani* and aerial blight distribution and may allow the development of predictive models for high risk areas for disease. Precision agriculture technologies have shown great promise in monitoring stress and damage by collecting spatial data and specialized geographic information system (GIS) and global positioning system (GPS) mapping software for other crops. As part of this proposal designed to spatially characterize the distribution of *Rhizoctonia* species and aerial blight development in fields, the value of early-season fungicide applications are being assessed for limiting colonization of soybean by the pathogen.

PROCEDURES

In 2014, two fields near Dumas and Weiner were used to monitor colonization of *Rhizoctonia solani* early in the season and aerial blight development. Approximately 200 GPS points were monitored in each field for colonization and disease development in 12 passes that represented each field. Ten soybean plants were sampled at each GPS point at the V3 to V5 growth stages. Seedlings were washed, the hypocotyl/stem region of plants at the soil line (8 cm total) was removed, surface disinfested with 0.5% sodium hypochlorite, and plated on TS1 medium, a medium selective for *Rhizoctonia* spp. and other basidiomycetes (Spurlock et al., 2011). *Rhizoctonia* spp. growing on the soybean tissues were cultured and identified. After the initial sampling, the fungicide azoxystrobin was applied to 6 of the 12 passes. Plants were sampled approximately two weeks after fungicide application using a similar procedure to examine the value of this early-season fungicide application on suppression of colonization.

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RESULTS AND DISCUSSION

For the Dumas field, the early-season fungicide application showed a high level of suppression of *Rhizoctonia solani* compared to the number of isolates recovered from the unsprayed runs for the second sampling at R1 (Fig. 2). The level of colonization in treatments without fungicide was approximately 15% of the plants infected with *Rhizoctonia solani*. After fungicide applications, less than 10% of fungicide treated plants had *Rhizoctonia solani* associated with the plants several weeks later. Almost all isolates were not the aerial blight pathogen, AG1-IA, but were AG11 and disease did not develop. A field near Weiner did not get sprayed until R1 to R2. Colonization was much greater at both sampling times, with the early-season sampling having 35% to 40% of the plants infected. By the mid-season sampling (R4), over 50% of the plants were infected. Fungicides showed no ability to suppress colonization, but again AG1-IA was not a common isolate (Fig. 3). The lack of suppression in the Weiner field could have been a result of poor fungicide distribution on the stem of plants because of the crop canopy closure at the later application.

Early-season fungicide applications appear promising based on the Dumas results. Fields for 2015 have been scouted and confirmed as having a history of AG1-IA, with the hope of quantifying the role of fungicides not only in suppressing colonization of the plants but also aerial blight control.

PRACTICAL APPLICATIONS

One of the challenges of aerial blight disease management is recognizing the progression of disease underneath the closed canopy of the crop and getting penetration of fungicides to where disease development is occurring. The new strategy of early fungicide applications may allow better disease control of aerial blight by; 1) getting the product to where the pathogen is developing in association with the soybean plant and 2) halting or interrupting the colonization of the plant prior to yield-limiting disease development. In addition, the spatial analyses used in the research should allow better scouting of the crop for disease and may in the future be used for the precision application of fungicides.

ACKNOWLEDGMENTS

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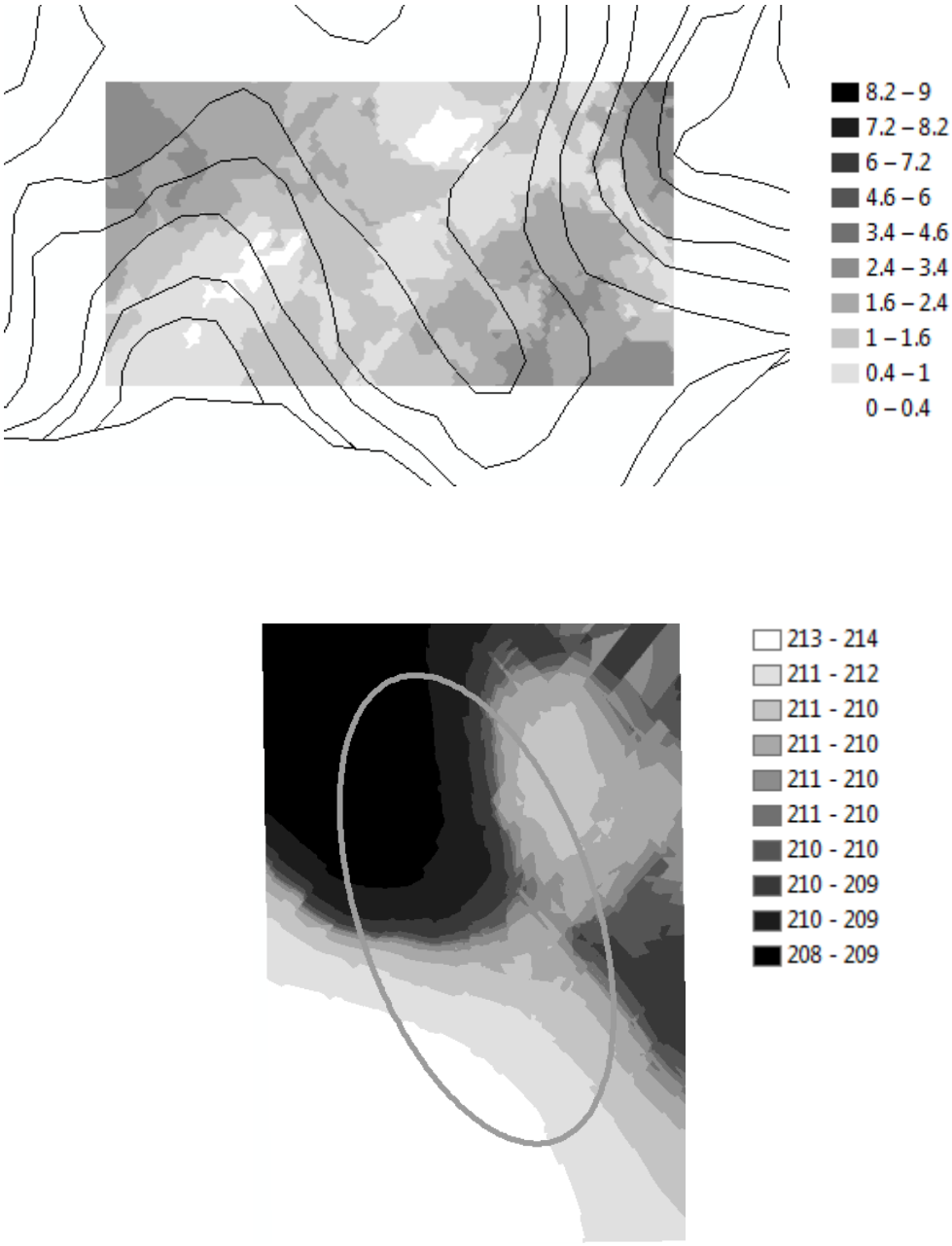

Fig. 1. Spatial distribution of *Rhizoctonia solani* AG1-IA, the cause of aerial blight in soybean, in relation to levee position and direction of water movement in the field, arrow. Darker areas indicate higher frequency of *R. solani* AG1-IA, propagules/kg soil.

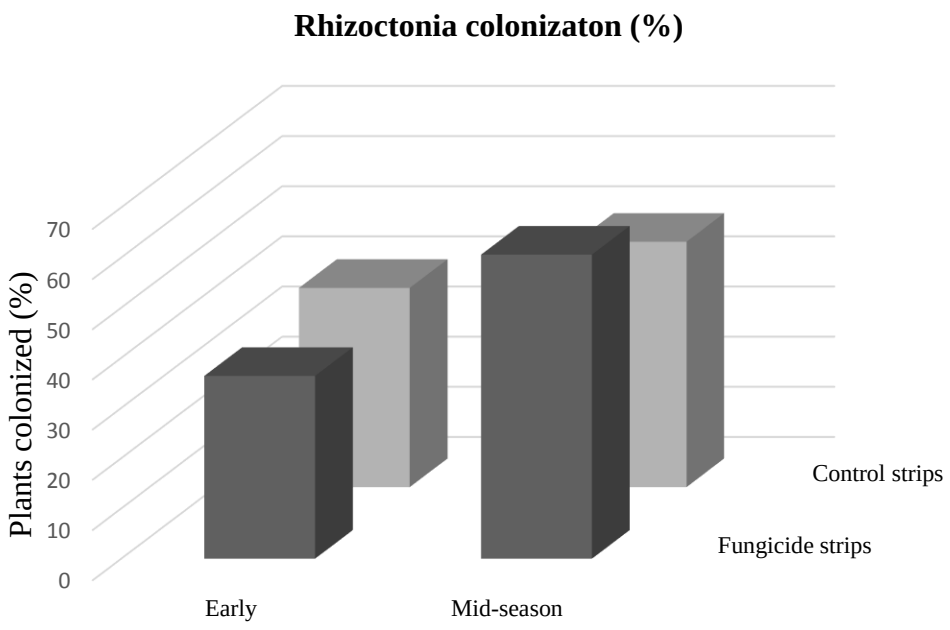

Fig. 2. Colonization before (Early) and after fungicide application (Mid-season) for a field near Weiner, Ark

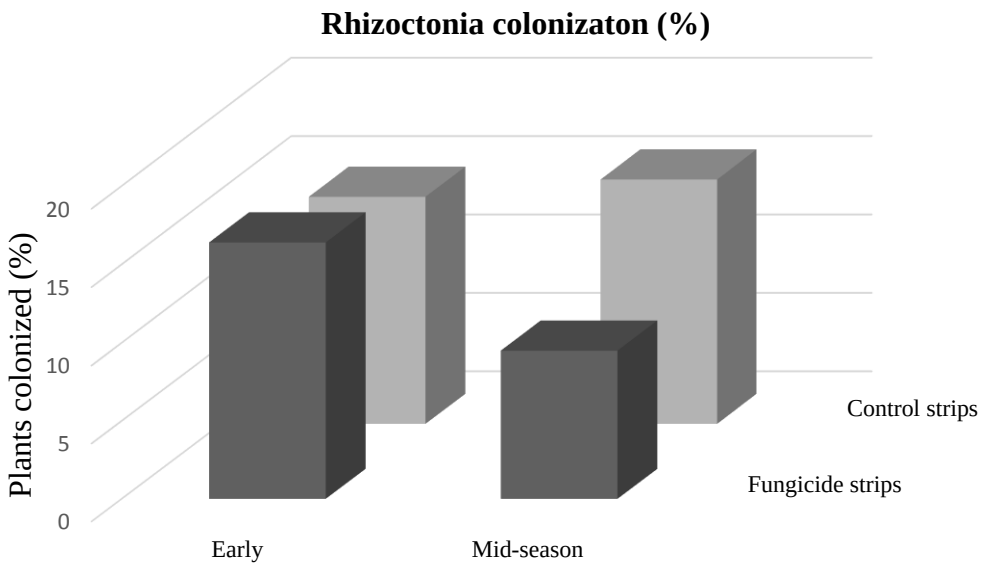

Fig. 3. Colonization before (Early) and after fungicide application (Mid-season) for a field near Dumas, Ark

Effect of Seed Treatments on Stand and Yield in Arkansas Soybean Production

J.C. Rupe[1], R.T. Holland[1], A.J. Steger[1], C.S. Rothrock[1], and M.P. Popp[1]

ABSTRACT

Nine registered fungicide and fungicide/insecticide seed treatments were tested at three planting dates and three locations: Keiser, Stuttgart, and Rohwer, Ark. To enhance disease, half the plots were irrigated 24 h after planting. Seed treatments did not significantly increase stands compared to the untreated check, but yields were significantly increased with Trilex® 2000 + Gaucho® 600 at Keiser in June and Stuttgart in May. In addition, ApronMaxx®, ApronMaxx+Dynasty®, and ApronMaxx +Dynasty + Cruiser® also increased yields over the untreated check in May at Stuttgart and as did ApronMaxx + Dynasty + Cruiser in June. Seed treatments did not affect stands or yields in any of the tests at Rohwer. Irrigation 24 h after planting did seem to increase seedling disease.

INTRODUCTION

Seedling diseases are a major constraint to soybean production by reducing yields due to low stands and reduced plant vigor and may require replanting. Annual yield losses to seedling disease were estimated to cost U.S. soybean growers as much as 44 million bushels (Wrather and Koenning, 2009). Since seedling diseases are associated with wet soils, the poor internal and surface drainage typical of our soils make seedling diseases particularly severe in Arkansas. While seedling diseases are usually associated with cool temperatures, our research has shown that seedling disease can occur across a wide range of temperatures typical of the long planting season in Arkansas. The main control for seedling disease is to use a seed treatment; however, there are number of seed treatments available to growers containing one or more fungicides and some with insecticides. The effectiveness of these treatments can vary by location and with time. In our initial work, Allegiance®, which contains only the fungicide metalaxyl, was the most cost effective treatment in our study (Poag et al., 2005), but a later study showed that seed treatments containing more than one fungicide were much more cost effective than Allegiance alone (Popp et al., 2009). Arkansas soybean growers need to know how effective these seed treatments are under our planting conditions.

PROCEDURES

Seeds of the soybean cultivar HBK RY 5221 were treated with nine seed treatments or treated with water for the untreated control and planted on a Sharkey clay at the Northeast Research and Extension Center (NEREC), Keiser, Ark. on a DeWitt silt loam at the Rice Research and Extension Center (RREC), Stuttgart, Ark. and on a Gallion silt loam at the Rohwer Research Station (RRS), Rohwer, Ark. Planting dates were 17 June at NEREC, 29 May and 17 June at RREC, and 21 April, 12 May, and 19 June at RRS. Wet weather prevented the April and May plantings at NEREC, and the April planting at RREC. The seed treatments' products, active ingredients, and application rates are listed in Table 1. The untreated check was treated with water in a similar manner to the other treatments. Each treatment was planted in four row plots, 20 ft long at a seeding rate of 90,000 seed/A, or 65% of the recommended rate. This seeding rate was chosen to enhance the likelihood of getting a yield response to seed treatments and to simulate those growers that may be reducing their planting rates due to the high cost of seed. To enhance seedling disease, one half of the plots were furrow irrigated 24 hours after planting. After that, all tests were furrow irrigated as needed for optimum yield. Tests planted at RRS in April and May, and RREC in May did not receive an irrigation 24 hours after planting due to rain shortly after planting. The center two rows of each plot were evaluated for two and four week stands (only the four week stand results will be presented) and yields taken at the end of the season.

RESULTS AND DISCUSSION

Wet weather prevented the April and May plantings at NEREC, but in the June planting, the Vibrance and Trilex 2000 treatments had significantly greater stands than the untreated control (Table 2). Across irrigation treatments, Trilex 2000 + Gaucho was the only treatment with significantly greater yield than the untreated check. Stands for this treatment were numerically greater, but not statistically different than the untreated check. At RREC, the lowest May stands were with PCNB+Vitavax and with Trilex 2000 + Gaucho and the highest stands were with Maxim, but none of these were significantly different than the untreated check (Table 3). Stands were not significantly different in the June planting (data not shown). Yields were significantly higher than the untreated check with the ApronMaxxRTAMoly+Dynasty+Cruiser seed treatment in both May and June. Yields were 5 to 10 bu/a higher when the test was planted in May compared with June. Both stands and yields were

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higher in the June plots irrigated 24 h after planting than the plots that did not receive the early irrigation (data not shown). At RRS, there were no significant seed treatment effects on stands or yields at any planting date, but in the June planting, stands were significantly higher in the plots that received the early irrigation than those that did not (63,241 vs 60,998 plants/a, respectively). Yields were highest when the tests were planted in April, followed by May, and then June (77, 60, and 50 bu/a, respectively). An economic analysis is underway to evaluate the cost effectiveness of seed treatment across three different planting months.

PRACTICAL APPLICATIONS

Seed treatments can lead to better stands and higher yields. This response to seed treatments occurs at any planting date and is especially important in late-planted soybeans, because there is less time for the soybean plant to compensate for low stands or for the grower to replant. The broad spectrum fungicides appear to be the most effective. While the addition of an insecticide did improve yields slightly, an economic analysis of the potential yield increase resulting from the addition of an insecticide is needed to determine the actual benefit to growers.

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Table 1. Seed treatment products, active ingredients, and application rates (oz/cwt).

Seed treatment product	Active ingredient (s)	Application rate
Allegiance FL®	Metalaxyl	1.5
PCNB+Vitavax®	PCNB, carboxin	4.0
Maxim®	Fludioxonil	0.08
ApronMaxx®RFCMoly	Fludioxonil, metalaxyl	1.5
ApronMaxxRFCMoly+Dynasty®	Fludioxonil, metalaxyl, azoxystrobin	1.5 (ApronMaxx) 0.3 (Dynasty)
ApronMaxxRFCMoly+Dynasty+Cruiser	Fludioxonil, metalaxyl, azoxystrobin, thiamethoxam	1.5 (ApronMaxx) 0.3 (Dynasty) 1.3 (Cruiser)
Trilex® 2000	Trifloxystrobin, metalaxyl	1.0
Trilex 2000+Gaucho® 600	Trifloxystrobin, metalaxyl, imidacloprid	1.0 (Trilex 2000) 1.6 (Gaucho 600)
Vibrance®	Sedaxane	1.0

Table 2. Effect of seed treatment on stand (plants/ac) of June planted soybean, with and without irrigation 24 hours after planting and yield (bu/a) across irrigation treatments at Northeast Research and Extension Center, Keiser, Ark. 2014.

Seed Treatment	June stand	June yield
Allegiance FL	47,583 c	52.8 bc
PCNB+Vitavax	49,061 bc	49.9 bc
Maxim	47,376 c	52.8 bc
ApronMaxxRFCMoly	51,089 ab	52.5 bc
ApronMaxxRFCMoly+Dynasty	51,476 ab	51.9 bc
ApronMaxxRFCMoly+Dynasty+Cruiser	51,296 ab	54.0 ab
Trilex 2000	52,155 a	51.7 bc
Trilex 2000+Gaucho 600	51,743 ab	58.9 a
Vibrance	52,086 a	48.6 c
Untreated Check	49,817 bc	53.4 bc

Table 3. Effect of seed treatment on stands (plants/ac) and yields (bu/ac) of May planted soybean and on yields of June planted soybean at the Rice Research and Extension Center, Stuttgart, Ark. 2014.

Seed Treatment	May stand	May yield	June yield
Allegiance FL	72,397 ab	59.7 bc	54.5 ab
PCNB+Vitavax	68,738 c	60.1 abc	53.6 ab
Maxim	73,181 a	60.4 abc	53.3 ab
ApronMaxxRTAMoly	72,832 ab	61.2 a	51.3 bc
ApronMaxxRTAMoly+Dynasty	72,310 ab	62.4 a	53.7 ab
ApronMaxxRTAMoly+Dynasty+Cruiser	71,787 abc	61.6 ab	55.4 a
Trilex 2000	71,177 abc	60.9 abc	53.4 ab
Trilex 2000 + Gaucho 600	68,781 c	61.8 ab	53.5 ab
Vibrance	69,827 bc	59.7 bc	52.3 bc
Untreated Check	70,524 abc	58.8 c	50.6 bc

Role of Soil and Soil Temperature on Soybean Seedling Disease

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ABSTRACT

High and low vigor Hutcheson seed, treated with ApronMaxx® or untreated, was planted into unpasteurized soil from the Arkansas Agricultural Research and Extension Center, Fayetteville (AAREC), Ark., or from the Pine Tree Research Station (PTRS), near Colt, Ark., and incubated in growth chambers at 77 and 90 ˚F (25 and 32 ˚C, respectively). Stands and root discoloration were determined two weeks after planting. In the second run of the experiment, stands were significantly higher at 77 than 90 ˚F in AAREC soil, but higher at 90 than 77 ˚F in PTRS soil. Treated seed generally had greater stands than untreated seed. High vigor seed produced greater stands than low vigor seed in both soils and at both temperatures. Isolation of *Pythium* spp. from seed was greater when seed were planted in PTRS than AAREC soil at 77 ˚F, but higher in AAREC than PTRS soil at 90 ˚F. In both soils, isolation of *Fusarium* spp. was greater at 77 than 90 ˚F.

INTRODUCTION

Seedling disease is a major problem in Arkansas and is favored by wet soils. This is a particular problem here due to our soils' poor internal and surface drainage resulting in frequent periods of saturated soil conditions. Seedling diseases are caused by a number of *Pythium* species, *Fusarium* species, *Phytophthora sojae* and *Rhizoctonia solani* that usually occur in soils together. The composition of these pathogens in the soil depends on a number of poorly understood factors, but soil texture, cropping history, and latitude appear to be important. Differences in the composition of these seedling pathogens in the soil could influence how environmental conditions affect seedling disease. The primary control for seedling disease is the use of fungicide seed treatments. Our previous research has shown that seed treatments can be effective at any planting date. To better understand the effect of temperature and the effect of soil on seedling disease, tests need to be conducted in growth chambers where soil temperature and moisture are controlled.

PROCEDURES

A Pickwick silt loam (fine-silty, mixed, semi-active, thermic Typic Paleudults) was collected from the University of Arkansas System Division of Agriculture's Agricultural Research and Extension Center (AAREC) and a Calhoun silt loam (fine-silty, mixed, active, thermic Typic Glossaqualfs) from Pine Tree Research Station (PTRS), near Colt and brought to Fayetteville. The soil was placed in 13.38 × 11.02 × 5.51 in. (134 × 28 × 14 cm) tubs and then placed in growth chambers at 77 or 90 ˚F (25 or 32 ˚C, respectively). These are temperatures typical of a May and June planting in Arkansas. The soil was watered to saturation, allowed to drain overnight, and planted with Hutcheson seed that was either treated with water (untreated check) or treated with the broad spectrum fungicide seed treatment ApronMaxx® (metalaxyl + fludioxonil) (1.5 ctw). Soil was held at field capacity. After two weeks, stands and root discoloration were rated. In separate tests, untreated Hutcheson seed was planted in the same soils at the same temperatures and soil moistures. Seed were sampled three days after planting and roots two weeks after planting. The seed and roots were plated on water agar and the percent roots with *Pythium* spp., *Fusarium* spp, or *Macrophomina phaseolina* (the charcoal rot pathogen) were determined. All tests were conducted twice and the results statistically analyzed with SAS using PROC GLM (SAS Institute, Inc., Cary, N.C.).

RESULTS AND DISCUSSION

In the first run of the experiment, stands ranged from 65% to 70% and were not significantly different between soils or temperatures (Fig. 1). However, in the second run, stands were significantly higher in the AAREC soil at 77 than 90 ˚F and significantly higher at 90 than 77 ˚F in the PTRS soil. This suggests that differences in the composition of seedling pathogens in the soils affected the overall response to temperature. Seed treatment increased stands with both soils in the first run of the experiment and in the PTRS soil in the second run. Since there was not an interaction with temperature, these results show that seedling disease was occurring at both 77 and 90 ˚F and in both soils (Fig. 2). Low seed quality resulted in lower stands in both soils and with treated and untreated seed indicating that seed treatment benefits both high and low quality seed. Root discoloration was greater at 90 than 77 ˚F for the AAREC soil, especially in the second run, but not for the PTRS soil (data not shown). Isolation of *Pythium* spp. from seed was higher at 77 ºF in PTRS than AAREC soils, but lower in PTRS soils than AAREC soils at 90 ˚F (Fig. 3). There was higher recovery of *Fusarium* spp. from seed in both soils at 77 than 90 ˚F. There was no recovery of *M. phaseolina* from seed (data not shown). Isolation of *Pythium* spp. from roots was similar in both soils at 77 ˚F,

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but higher in AAREC than PTRS soil at 90 ˚F (Fig. 4). In both soils, recovery of *Fusarium* spp. was higher at 77 than 90 ˚F and *M. phaseolina* was higher at 90 than 77 ˚F especially in PTRS soil. The higher recovery of *Pythium* spp. at 90 ˚F in AAREC than PTRS soils was associated with lower stands in AAREC than PTRS soils at that temperature and implies that the composition of pathogens differs between the two soils. The broad spectrum fungicide seed treatment, ApronMaxx, was effective in both soils and at both temperatures and supports previous findings that seedling disease is a problem whenever we plant soybean.

PRACTICAL APPLICATIONS

This research shows the importance of seed treatments even in late plantings. It also demonstrates that there are differences between soils in the severity of seedling disease and that these differences may be due to differences in the types of seedling pathogens present in the soil. While the broad spectrum fungicide seed treatment appeared to be effective across soils and temperatures, it may not be the best treatment in all situations, because of differences in the seedling pathogens present in the soil.

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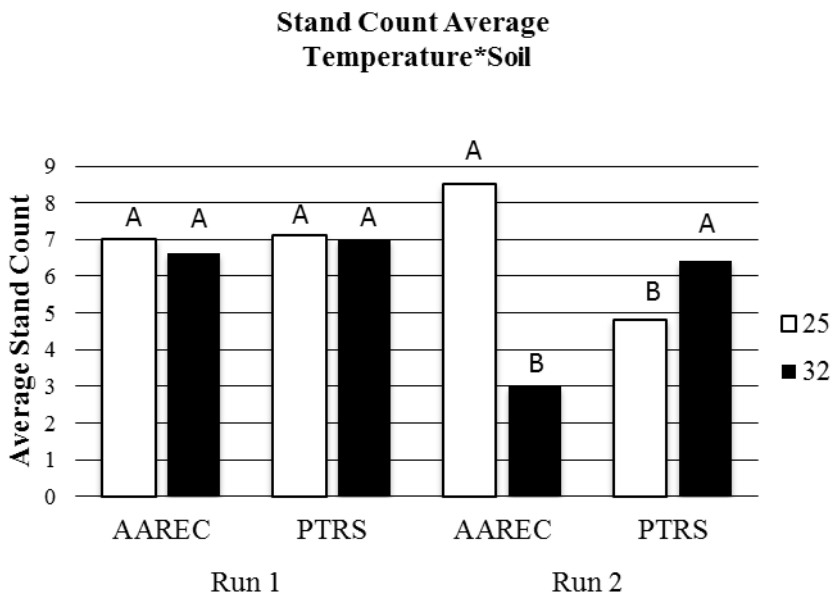

Fig. 1. Stand of Hutcheson soybean seed planted in unpasteurized soil from the Arkansas Agricultural Research Extension Center, Fayetteville (AAREC), Ark. or from the Pine Tree Research Station (PTRS), near Colt, Ark., and incubated at either 77 or 90 ºF (25 or 32 ºC, respectively). Bars within a run and soil with the same letter are not significantly different (*P* > 0.05).

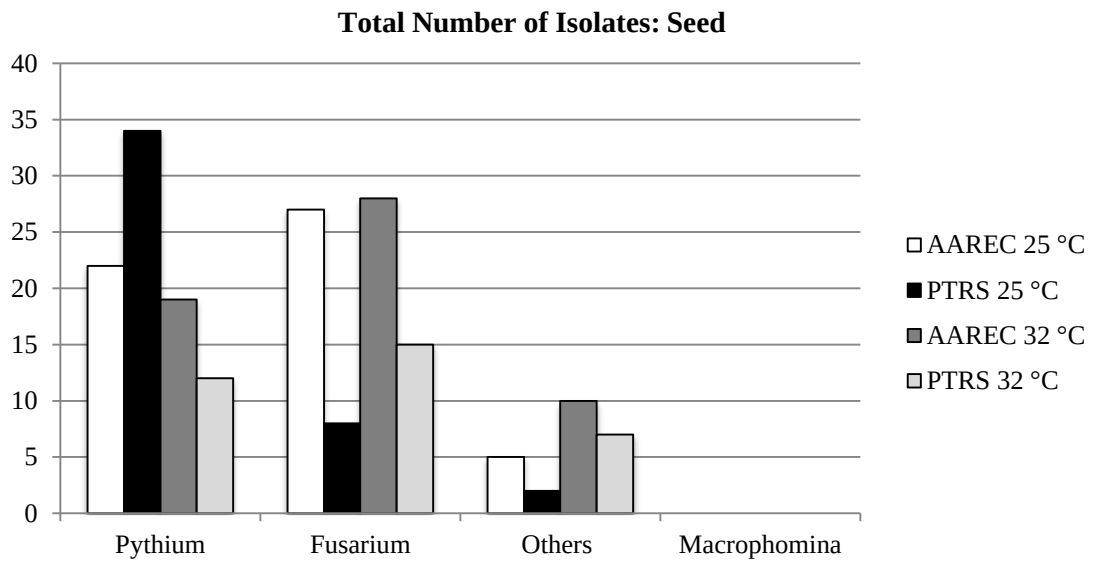

Fig. 2. Stand of Hutcheson soybean seed treated with ApronMaxx® (AMM) or untreated (UTC) planted in unpasteurized soil from Arkansas Agricultural Research Extension Center, Fayetteville (AAREC), Ark. or from the Pine Tree Research Station (PTRS), near Colt, Ark. Data was analyzed across incubation temperatures of 77 and 90 ºF (25 and 32 ºC, respectively). Bars with in a run and soil with the same letter are not significantly different (*P* > 0.05).

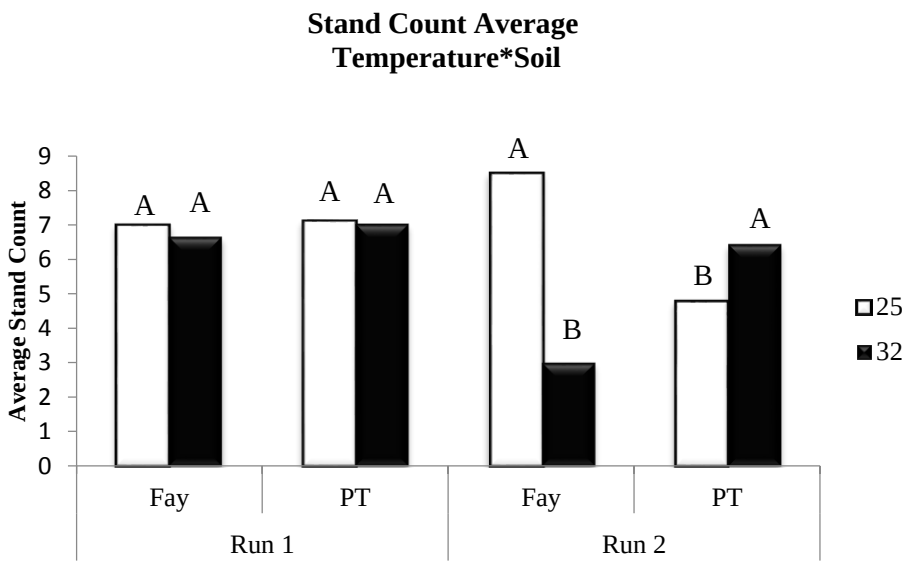

Fig. 3. Number of isolates of *Pythium* spp., *Fusarium* spp., other fungi, and *Macrophomina phaseolina* collected from seed incubated in unpasteurized soil from Arkansas Agricultural Research Extension Center, Fayetteville (AAREC), Ark. or from the Pine Tree Research Station (PTRS), near Colt, Ark. and incubated at 77 or 90 ºF (25 or 32 ºC, respectively).

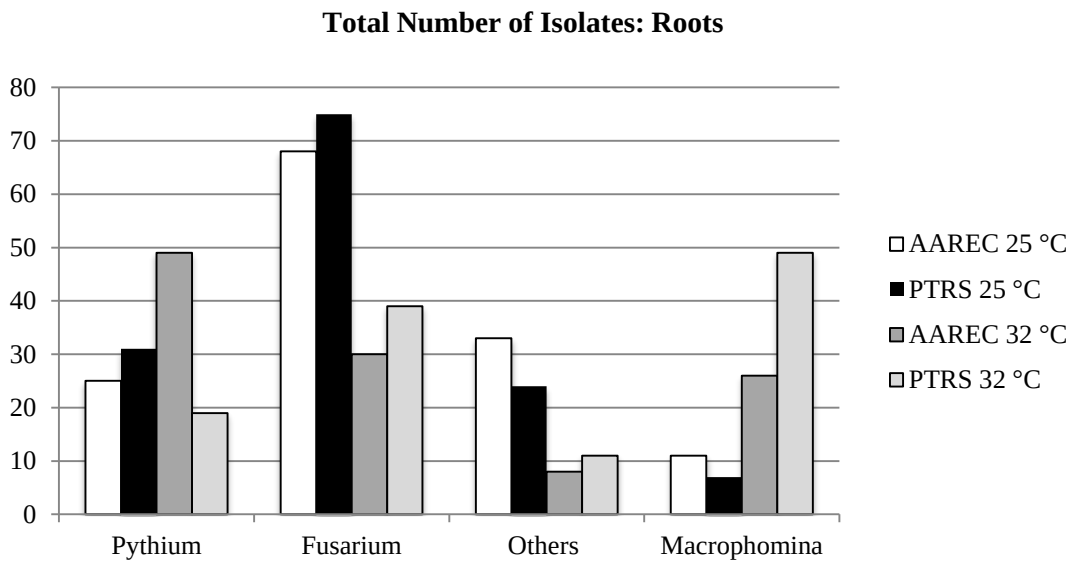

Fig. 4. Number of isolates of *Pythium* spp., *Fusarium* spp., other fungi, and *Macrophomina phaseolina* collected from seedling roots incubated in unpasteurized soil from Arkansas Agricultural Research Extension Center, Fayetteville (AAREC), Ark. or from the Pine Tree Research Station (PTRS), near Colt, Ark. and incubated at 77 or 90 ºF (25 or 32 ºC, respectively).

Phenotypic and Genetic Characterization of *Pythium aphanidermatum* Resistance in Soybean

K. Urrea[1]., J.C. Rupe[1], C.S. Rothrock[1], and P. Chen[2]

ABSTRACT

Resistance to the seedling disease caused by *Pythium aphanidermatum* was characterized in 84 $F_{2:6}$ soybean lines derived from a cross of 'Archer' (resistant parent) and 'Hutcheson' (susceptible parent). In addition to the hypocotyl inoculation method previously used, resistance was characterized with a seed plate assay and an infested vermiculite method. Each inoculation method resulted in a range of reactions to *P. aphanidermatum*. Hutcheson was always among the most susceptible, but some lines were more resistant than Archer. The lines were then assayed with 5403 single nucleotide polymorphism (SNP) molecular markers and the results compared to the resistance data. Nine quantitative trait loci (QTL) were identified on six chromosomes. These results will aid in breeding for resistance to *Pythium* spp.

INTRODUCTION

Seedling diseases are an important problem of soybean production. The primary group of pathogens causing seedling disease are a number of Pythium species (Rosso, 2007; Avanzato, 2011; and Urrea, 2010). The main control for seedling disease is the use of fungicide seed treatments, however, resistance to *Pythium* spp. has been found. In previous research, a single gene for resistance was found in the cultivar 'Archer' using a hypocotyl inoculation method with *P. aphanidermatum* (Rosso, 2007). Recently, using different resistant and susceptible parents, five quantitative trait loci (QTL) were identified using a potting medium infestation method (Ellis et al., 2013). In light of the development of new inoculation techniques and more advanced molecular tools, the soybean population derived from the Archer × Hutcheson cross was reexamined and characterized with SNP molecular markers.

PROCEDURES

The 84 $F_{2:6}$ lines derived from a Archer × Hutcheson cross developed by Dr. P. Chen were evaluated for resistance to *P. aphanidermatum* using a seed plate assay (Broders, 2007 and Avanzato, 2011) and infested vermiculate greenhouse assay (Rosso, 2007). With each assay, there were four replications and each test was repeated. In the seed plate assay, ten seeds of each line were placed on a water agar, petri plate with *P. aphanidermatum;* seven days later the percent germinated seed was determined. With the infestation method, four-inch pots were filled with infested vermiculite (611 cfu/g), ten seeds planted per pot and the pots placed in a greenhouse. Stands were then determined after two wks.

Total genomic DNA of the 84 ($F_{2:6}$) lines and the parents was extracted using the hexadecyltrimethylamonium bromide (CTAB) method (Kisha et al., 1997) and genotyped with 5403 SNP markers (National Library of Medicine, 2012) using the BARC MSU Soy6k Ilumina Infunium Genotyping HD Beadchip (652K) on Ilumina iScan (Ilumina, San Diego, Calif.) at the Michigan State University genotyping core facility, East Lansing, Mich. With each inoculation method (hypocotyl, seed plate, and infestation) linkage maps were constructed using JoinMap 4. (JoinMap, Wageningen, Netherlands). Pythium resistance QTL detection single marker analysis (SMA) and composite interval mapping (CIM) were carried out by WinQTL Cartographer 2.5 (N.C. State University Bioinformatics Research Center, Raleigh, N.C.).

RESULTS AND DISCUSSIOM

There were significant differences ($P \leq 0.0001$) in disease reactions among 84 $F_{2:6}$ lines with each inoculation method (Table 1). With each assay, there was a range of reactions from very susceptible to very resistant (Fig. 1a, b, and c). With all three assays, Hutcheson was among the most susceptible lines, while Archer was among the most resistant; however there were lines that were more resistant than Archer. Resistance was quantitative. The heritability estimates using the infestation assay and the seed plate assay were 0.6955 and 0.8534 respectively, indicating several genes or QTLs.

Of the 5403 SNP markers distributed among the 20 soybean chromosomes, 23.5 % of the loci were polymorphic between Archer and Hutcheson, the parental genotypes. The linkages maps were constructed with 889 markers, representing 695 unique loci. The linkage map covered 3,956.33 cM and the average distance of each loci was about 6.0 cM loci. Composite interval mapping detected a total of 9 QTLs for resistance to *P. aphanidermatum* on chromosomes 4, 7, 8, 9, 11, and 12 with the three phenotyping methods (Table 2). Two resistance QTL were found on chromosomes 4 and 7 using the seed plate assay, three

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on chromosomes 4, 7, and 12 using the infestation assay, and four on chromosomes 8, 9, and 11 using the hypocotyl assay conducted by previously (Rosso et al, 2008).

These results confirm that there is resistance to *P. aphanidermatum* in Archer and that this resistance can be inherited. This resistance was demonstrated across multiple screening methods. Combining the results of the screening assays with the SNP analysis revealed QTL on six chromosomes. Quantitative trait loci on chromosomes 4 and 7 were identified at similar locations using the seed plate and the infestation assays making them strong candidates for further research. The QTL identified in our research are different than those identified with *P. irregulare*, but that study used a different source of resistance and based disease data on root discoloration not stand (Ellis et al., 2013). Our research has found the primary damage from *Pythium* spp. is in reduced stands and not root rot (Avanzato, 2011). Our results make it easier for breeders to incorporate Pythium resistance as they develop new cultivars.

PRACTICAL APPLICATIONS

Disease resistance is often the most cost effective way of controlling plant disease, but has not been used to control seedling diseases in soybean, because the inheritance of this resistance was not understood. By identifying and locating QTL associated with resistance to one of the most important groups of seedling pathogens, *Pythium* spp., this research lays the foundation for further research developing Pythium-resistant cultivars with either conventional or molecular techniques.

ACKNOWLEDGMENTS

The authors want to thank the Arkansas Soybean Board for the funding, the Plant Pathology Department and the University of Arkansas System Division of Agriculture in particular Adele Steger and John Guerber for their assistance. Also, thanks to Dr. Esten Mason and his laboratory and Dr. Chen and his laboratory for the help with the QTL analysis data.

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Table 1. Analysis of variance for seed germination and plant stands of the 84 $F_{2:6}$ lines and parents evaluated for the resistance to *Pythium aphanidermatum* with the seed plate assay and infested vermiculite assay.

	Degrees of Freedom		*P*-value	
Source	**Seed germination**	**Plant stands**	**Seed germination**	**Plant stands**
Model	343	429	<0.0001	<0.0001
Run	1	1	<0.0001	<0.0001
Line	85	85	<0.0001	<0.0001
Rep	2	3	0.3944	0.006
Error	149	258		

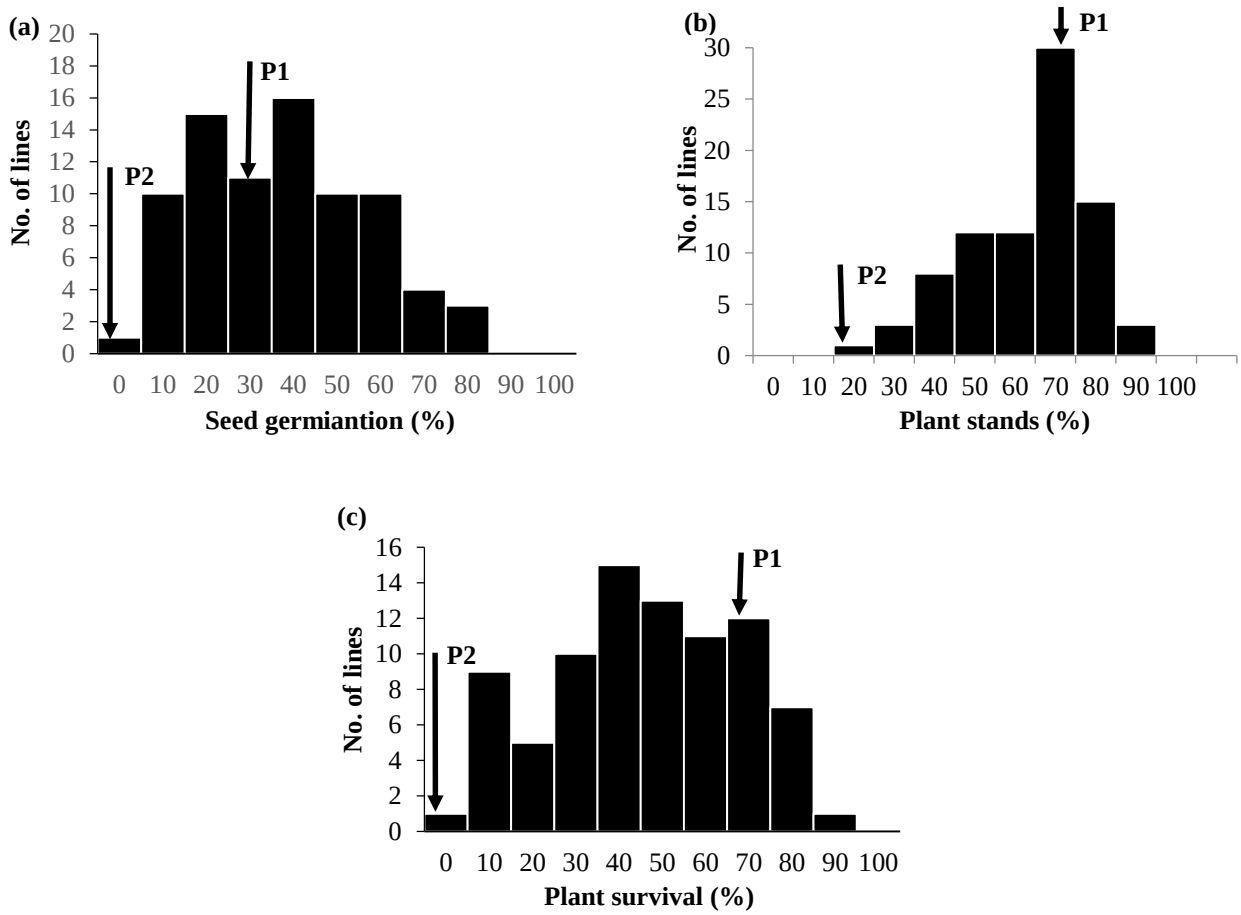

Fig. 1. **Frequency distribution of Pythium resistance in a population derived from 'Archer' (P1) × 'Hutcheson' (P2) cross evaluated in three assays: a) Seed plate assay; b) Infested vermiculite and c) Hypocotyl inoculation.**

Table 2. Quantitative trait loci for partial resistance to *Pythium aphanidermatum* from 84 $F_{2:6}$ lines derived from 'Archer' × 'Hutcheson cross that were mapped using composite interval mapping (CIM) with results from the three phenotyping methods.

Chromosome	Estimated Intervals (cM)	Position (cM)	Nearest marker	CIM LOD	Explained variation (%)	Trait
4	24.98 - 90.98	51.00	ss715589319	4.13	8.29	SA[a]
4	24.98 - 90.98	49.00	ss715589319	6.13	13.76	IV[b]
7	83.19 - 142.18	118.20	ss715598762	5.50	13.85	IV
7	116.18 - 127.18	121.2	ss715598762	3.12	4.5	SA
8	157.57 - 164.57	157.60	ss715599734	4.56	12.57	HI[c]
9	112.82 - 127.82	115.80	ss715605256	4.35	14.45	HI
9	139.97 - 145.97	140.00	ss715605104	5.07	1.14	HI
11	15.54 - 25.54	16.50	ss715610355	4.92	8.20	HI
12	117.42 – 123.42	120.40	ss715612244	6.35	0.34	IV

[a] Seed assay (SA).
[b]Infested vermiculite (IV).
[c]Hypocotyl inoculation (HI).

Effects of Seed Quality, Seed Treatment and Soil Temperature on Stand

J.C. Rupe[1], R.T. Holland[1], A.J. Steger[1], S.C. Goeke[1], C.S. Rothrock[1], and M.P. Popp[1]

ABSTRACT

High and low quality seed, untreated or treated with ApronMaxx® of the cultivars 'Hutcheson' and 'Osage' were planted every two weeks at the Vegetable Research Station, near Kibler, Ark., from 17 April until 9 September. Every two weeks following planting, stands were recorded as well as soil temperature and soil moisture. In general, at most planting dates, treated seed had greater stands than untreated seed and high quality seed had greater stands than untreated seed. Stands for all treatments were very low in the August and September plantings and were associated with daily low temperatures above 77 ˚F (25 ˚C) and high temperatures above 86 ˚F (30 ˚C).

INTRODUCTION

Stand establishment is a major problem for Arkansas soybean growers, especially with late-season plantings. In our previous research, we have shown that both seedling disease and poor seed quality can lead to lower stands (Avanzato et al., 2007). Seed treatment with a broad spectrum fungicide can improve stands and yields at most planting dates unless soil temperatures exceed a certain limit. In a seed storage study, when daily air temperatures were above 95 ˚F (35 ˚C), plantings were associated with extremely low emergence irrespective of seed treatment or seed quality (Rupe et al., 2012). Soil temperatures were not taken in those studies and seed quality changed during the test, so the role of temperature on soybean emergence was not clear. The objective of this study was to determine the effect of air and soil temperature at planting on the emergence of high and low quality seed with and without a fungicide seed treatment across a range of planting environments.

PROCEDURES

In 2013, Osage and Hutcheson seed were stored in a greenhouse from 18 June until 5 August to produce a low quality seed. Additional seed of each cultivar was stored under controlled environmental conditions (65 ˚F and 50% relative humidity). After the greenhouse storage, all seed were stored under the controlled environmental conditions. Half of the seed were treated with ApronMaxx® (1.5 Cwt) and the other half left untreated resulting in eight treatments. From mid-April through mid-September, 400 seed of each treatment were planted every two weeks at the Vegetable Research Station, near Kibler, Ark., into two 20-ft. row plots with four replications. Stands were determined two weeks after planting. Daily soil temperature and moisture, and air temperature and relative humidity were recorded using a data logger. Standard germination and the seed vigor imaging system (SVIS) were measured at the start, the midpoint and the end of the experiment.

RESULTS AND DISCUSSION

Greenhouse storage did not affect standard germination which ranged from 88% to 96%, but did reduce SVIS (a seed vigor test) from 861-956 before aging in the greenhouse to 562-599 after aging. Accelerated aging, another vigor test was reduced from 39%-40% down to 8%-12% after aging. However, by April, all three measurements were lower: standard germ ranged from 41% to 91%, SVIS from 262 to 458 and AA from 0 to 1%. With both cultivars, germination and SVIS fell during the season but tended to remain higher for treated than untreated seed (data not shown). This was unexpected since fungicide seed treatments generally do not improve germination or seed vigor.

Of the 400 seed planted per treatment, stands varied from 25 to 263 and 51 to 308 seedlings for Hutcheson and Osage, respectively (Figs. 1 and 2). However in the final three plantings, stands declined sharply, especially with the untreated seed. The lowest stand occurred with the 25 August planting and increased somewhat with the 9 September planting. For the most part, treated seed had greater stands than untreated seed, and high vigor seed had higher emergence than low vigor seed. It should be noted that while the high vigor seed, generally had higher germination and SVIS ratings than the low vigor seed, all seed lots in this study would be considered low vigor seed lots for commercial seed.

Low emergence late in the season, 14 August forward, were associated with daily low temperatures above 77 ˚F (25 ˚C) and daily high temperatures above 95 ˚F (35 ˚C). Weather conditions in 2014 were generally cooler than in recent years where daily high temperatures were often above 100 ˚F (38 ˚C) making stand failures due to excessive heat more likely than what was experienced in 2014 (Fig. 3).

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PRACTICAL APPLICATIONS

This research shows that stand establishment problems in late-planted soybean can be due to a combination of seedling pathogens, a loss in seed vigor due to prolonging seed storage into the summer, and high soil temperatures at planting. Growers should strive to plant high-vigor seed with a broad spectrum seed treatment and avoid, if possible, planting during extremely hot weather. Increasing seeding rate, especially in fields prone to soil crusting, will also help ensure an adequate stand.

ACKNOWLEDGMENTS

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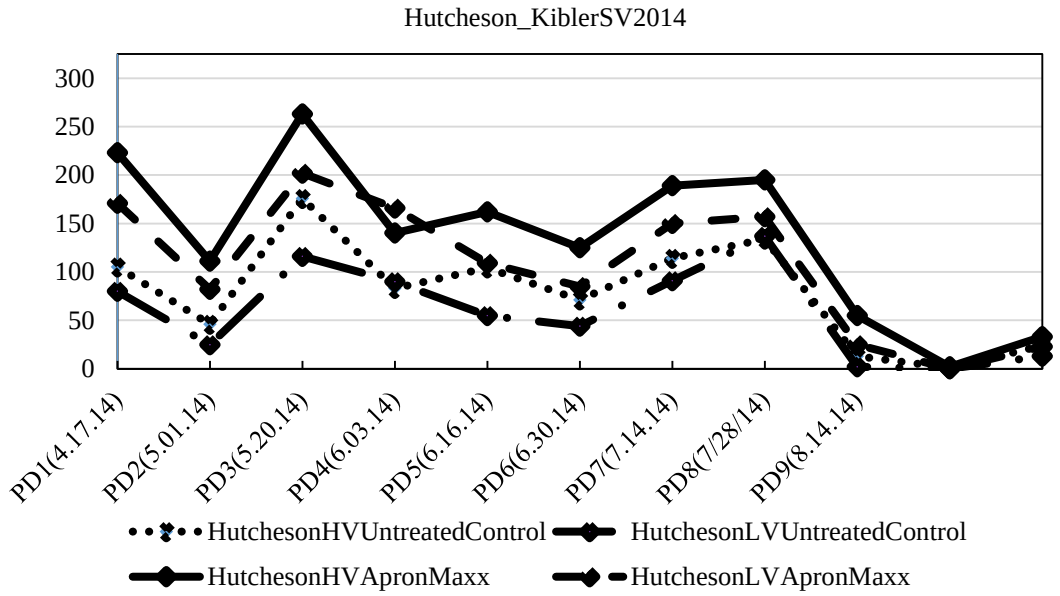

Fig. 1. Two-week stands of high and low vigor Hutcheson soybean seed treated with ApronMaxx® or not treated planted at two-week intervals from 17 April until 9 September 2014 at the Vegetable Research Station, near Kibler, Ark.

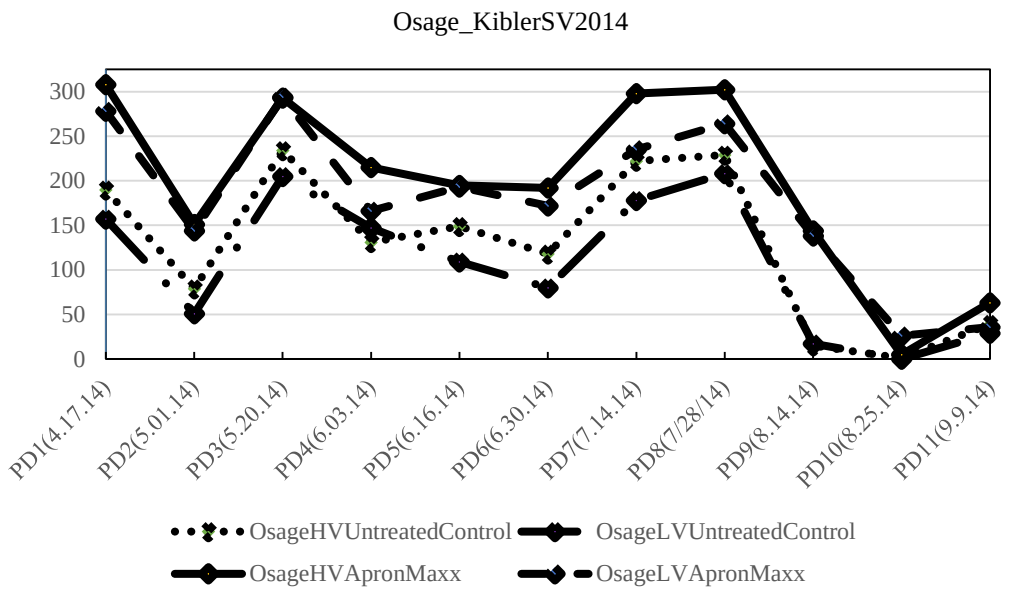

Fig. 2. Two-week stands of high and low vigor Osage soybean seed treated with ApronMaxx or not treated, planted at two-week intervals from 17 April until 9 September 2014 at the Vegetable Research Station, near Kibler, Ark.

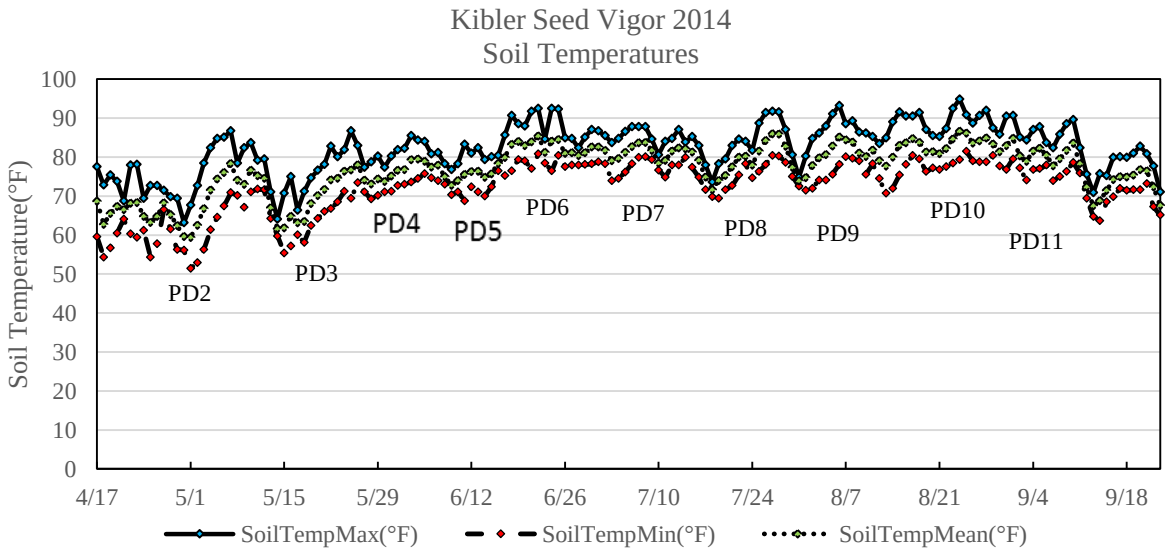

Fig. 3. Maximum, minimum and average daily soil temperatures (°F) and planting dates (PD) from 17 April until 23 September 2014 at the Vegetable Research Station, near Kibler, Ark.

Understanding *Neocosmospora*, *Thielaviopsis*, and *Fusarium virguliforme* in Early-Season Production Systems

T. Spurlock[1], T.L. Kirkpatrick[2], and T. Faske[3]

ABSTRACT

A disease with similar symptoms as black root rot caused by *Thielaviopsis basicola* and sudden death syndrome (SDS) caused by *Fusarium virguliforme* occurred in a number of soybean fields in Arkansas in 2014. Two fields were chosen, one in Drew Co., and one near Yancopin, Ark. for studies. The field in Drew Co. had symptoms previously described for black root rot while the field near Yancopin had severe SDS. Plants in the Drew Co. field were also positive for *Neocosmospora vasinfecta*, with only signs of the pathogen present (perithecia) and no noticeable disease. Yield loss from black root rot was minimal largely due to the relatively small number of plants affected. However, yield loss on affected plants was approximately 30%. Yield loss from SDS was approximately 30 bu/ac according to yield data collected from the combine at harvest. In Drew Co., black root rot symptoms were significantly aggregated with characteristic symptoms of yellow foliage correlating spatially to elevated levels of sodium and reduced levels of calcium (Ca) and *N. vasinfecta* distributed uniformly with correlations of elevated phosphorus (P), iron (Fe) and boron (B). Aerial imagery indicated SDS was found to be aggregated and associated with soil texture. Disease was most severe in areas with the lowest electrical conductivity (EC) values (<35 decis/m, (P = 0.002)). Further, the most damage was located nearest the irrigation source. The distributions of all three pathogens/diseases indicate that they are likely influenced by measurable soil physical and biological factors and each has the potential to be managed site-specifically.

INTRODUCTION

Recently, Neocosmospora stem rot (Greer et al., 2015) and Black root rot (Monfort et al., 2010) were identified as causing disease on soybeans in Arkansas. Sudden death syndrome was first identified in Arkansas in 1971 (Westphal et al., 2008). Yield loss has been variable but can be substantial depending on year for all three diseases. Neocosmospora stem rot is caused by the fungus *Neocosmospora vasinfecta* and causes lower stem deterioration with reddish-orange perithecia present on the crown of the plant. Black root rot has been reportedly caused by *Thielaviopsis basicola* and disease symptoms are described as having a black rotted taproot with yellow foliar symptoms developing during the reproductive stages of soybean development. Sudden death syndrome causes a deterioration of the root system and brown streaking in the cortical tissue. When severely affected plants reach the reproductive stages of development, yellow-orange "flashing" lesions appear on the leaves and the plant defoliates. Because all three of these pathogens appear to be primarily early-season (cool soil temperature) pathogens, there is a need to understand their impact on soybeans in an early-season production system. Strategies have not been developed for managing Neocosmospora stem rot or black root rot and varietal resistance could provide the most effective means of control for all three of these diseases. However, due to the complex nature of soil borne disease, identification of field locations with disease and field conditions favoring disease development will be necessary prior to development of variety tests and management plans.

PROCEDURES

Two fields were chosen for spatial distribution studies, one in Drew Co. (-91.62 longitude, 33.729 latitude), and one near Yancopin, Ark (-91.241 longitude, 33.927 latitude). In the Drew Co. field, 100 GPS points were marked, 10 points in a row, 30 ft. between points and 5 beds between rows of points. The entire sampling area encompassed approximately one acre. On 5 June 2014, 10 plants were collected by GPS location and placed in plastic storage bags by position. Additionally, at each point, soil samples were taken with a standard soil probe and marked by GPS location. Soil samples were sent to the soil testing laboratory in Marianna, Ark. and analyzed by location. The plants were trimmed just above the soil line and washed for 20 min. in tap water and surface disinfested with a 10% solution of 0.5% sodium hypochlorite. Plants were placed on Petri dishes filled with solidified TBCEN medium (Specht and Griffin, 1985) and incubated in complete darkness for approximately 4 weeks at room temperature (approximately 26 °C). After incubation, the number of dishes with *N. vasinfectum* and/or *T. basicola* were counted and recorded by GPS location. On 30 July 2014, the soybean plants with foliar symptoms were counted within a 3-meter circle around each GPS location twice (once by two different raters on the same day) and averaged. Results from the plant sampling assays, fertility analysis, and foliar disease ratings were stored according to position in a .dbf file associated with a .shp file representing the 100 GPS locations projected to WGS 1984 Web Mercator Auxiliary Sphere and analyzed using *Moran's I* to determine spatial

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autocorrelation and distribution and spatial regression to determine spatial dependence and relationships in GeoDa 1.6.6. (Anselin et al., 2006) A subsample of 50 diseased and fifty healthy soybean plants were harvested at maturity to determine disease losses. Pods were hand harvested from each plant, dried at 60 °C for 48 hours and weighed.

In the field near Yancopin, aerial imagery was obtained by flying a Cessna 172 (Cessna Aircraft Company, Wichita, Kan.) with a Geoscanner sensor package having a 4-band multispectral unit utilizing blue, green and red light wavelengths in the visible part of the spectrum and near-infrared (NIR) beyond the red visible light bands (Geovantage, Inc., Swampscott, Mass.). The near-infrared imagery was georeferenced and added as a layer to a .mxd file in ArcGIS 10.2. Yield data was collected on a John Deere 9870 combine (Deere and Company, Moline, Ill.) with a factory-installed yield monitor and stored as a georeferenced .shp file. Soil electrical conductivity (EC) was collected on 4 December 2014 with a Veris 3150 soil EC mapping system on 12-ft centers and stored as a georeferenced .shp file. The yield and soil EC data were added to the same .mxd file as the NIR aerial imagery. A field boundary was digitized in ARCMap and 500 random points assigned using the random points tool in ArcToolbox. The NIR, yield, and soil EC were sampled at each position using the sample tool in ArcToolbox and stored as a new .dbf associated with a .shp file projected to WGS 1984 Web Mercator Auxiliary Sphere. Data were then analyzed using *Moran's I* to determine spatial autocorrelation and distribution and spatial regression to determine spatial dependence and relationships in GeoDa 1.6.6.

RESULTS AND DISCUSSION

Black Root Rot. Symptoms of black root rot were observed in most soybean fields in southeast Arkansas by August of 2014 (Fig 1.). The disease has been reported to be caused by *T. basicola* and occurs on soybean grown in fields that were once planted with cotton. However, after sampling 1000 individual soybean plants in a field in Drew, Co., Ark. no *T. basicola* chlamydospores could be found on the soybean plants. The distribution of disease was aggregated in the field (P = 0.002) with affected plants ranging from 0 to 28 plants with foliar symptoms in the 3-meter area around each GPS location (Fig 2.). Soil samples indicated fertility levels across the grid were aggregated (Table 1) with a spatial correlation of black root rot disease and the highest levels of Na and lowest levels of Ca in the sampled area, P = 0.02, and P = 0.08 respectively. Plants with yellow foliar symptoms were selected arbitrarily and re-sampled. A fungus, with white hyphae and black stroma was isolated from the inside of the lower stems of many of the plants. The black stroma produced in culture is similar to the black mycelial mat found on the rotted tap roots of affected soybean plants. This isolate is currently being used in laboratory pathogenicity assays and has caused disease on soybean seedlings.

Neocosmospora Stem Rot. The disease Neocosmospora stem rot was not reported to be a problem in 2014. Signs of the pathogen were observed on plants arbitrarily sampled from all 100 GPS locations in the field in Drew, Co., Ark. Affected plants ranged from 0-7 plants per position positive for the pathogen. The presence of the pathogen was confirmed by the production of orange perithecia on and around the root in culture. The distribution of the pathogen was uniform (P = 0.027) and was associated spatially with elevated levels of phosphorus, iron, and boron. The uniform distribution of the fungus is likely due to continued soybean monoculture in the field (Fig 3).

Sudden Death Syndrome. This disease was identified in a number of soybean fields in southeast Arkansas in 2014. Sudden death syndrome produced foliar flashing and defoliation with deterioration of the root cortical tissue, typical of the disease, in a field near Yancopin, Ark. While the variety was rated moderately resistant, approximately 30 bu/ac were lost in severely affected areas of the field (approximately 86 bu/ac maximum). Based on near-infrared imagery and randomly assigned point data the distribution of defoliation caused by SDS was significantly aggregated (P = 0.001) as was yield (P = 0.001), and soil EC values (P = 0.001). Spatial regression analysis indicated that SDS was spatially dependent on soil texture as was yield and the three correlated (P = 0.002). Of interest is the fact that SDS was most severe in the lighter textured (sandier) areas of the field (Fig 4).

PRACTICAL APPLICATIONS

The price of seed and inputs have been increasing while the price of soybeans have been decreasing. The efficiency with which we grow soybeans must be increased. Further, advancing equipment technology allows us to collect yield data and apply inputs with geographic reference, or site-specifically, if so desired. As we understand soil borne pathogens, the yield loss that they actually cause, and where they are most likely to occur or cause yield loss in a field, control measures can be more targeted, improve efficiency, and potentially lower wasted application.

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Table 1. Correlations of fertility, yellow foliar symptoms associated with symptoms of black root rot, and presence of *Neocosmospora vasinfecta* on soybeans in Drew Co., Ark.

Parameter	***Moran's I*[a]**	***Neocosmospora vasinfecta*[b]**	**Yellow foliar symptoms[c]**
Elevation	0.001	NS	NS
Ph	0.001	NS	NS
Phosphorus	0.001	0.006	NS
Potassium	0.001	NS	NS
Calcium	0.001	NS	-0.08
Magnesium	0.001	NS	NS
Sodium	0.002	NS	0.02
Sulfur	0.001	NS	NS
Iron	0.001	0.0004	NS
Manganese	0.001	0.01	NS
Copper	0.001	NS	NS
Zinc	0.036	NS	NS
Nitrogen	0.003	NS	NS
Boron	0.001	0.008	NS
ECEC	0.001	NS	NS
Neocosmospora *vasinfecta*†	-(0.027)	*	NS
Yellow foliar symptoms‡	0.002	NS	*

[a] Moran's I indicates the level of spatial autocorrelation or the variables' similarity with itself across space (distribution). A *P*-value < 0.05 is considered significantly aggregated while significantly uniform distributions are represented with a *P*-value < 0.05 and a preceding (-).

[b] Plants with red-orange perithecia of *N. vasinfecta*.

[c] Yellow foliar symptoms associated with root disease.

Fig 1. Diseased plants from a field in Drew Co., Ark. The soybean plants had yellow foliar symptoms during the reproductive stage of development. Once extracted from the soil, the taproots were rotted and slender, corky, and covered with black stromatic hyphae.

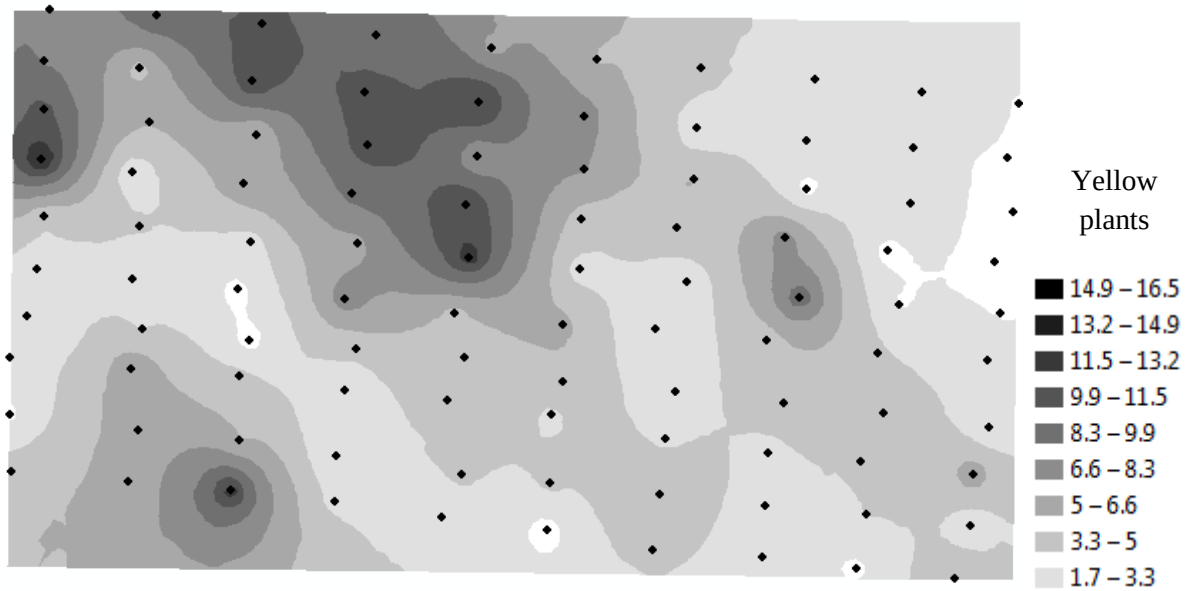

Fig 2. The spatial representation (using ordinary kriging) of yellow foliar symptoms associated with soybeans in a field located in Drew, Co., Ark. The foliar symptoms were counted within a 3-meter circle around each of 100 GPS locations representing approximately an acre. The distribution was aggregated (clustered).

Fig 3. The spatial representation (using ordinary kriging) of plants with perithecia of *Neocosmospora vasinfecta* on 10 plants sampled from a 3-meter circle around each of 100 GPS locations representing approximately an acre. The distribution was uniform.

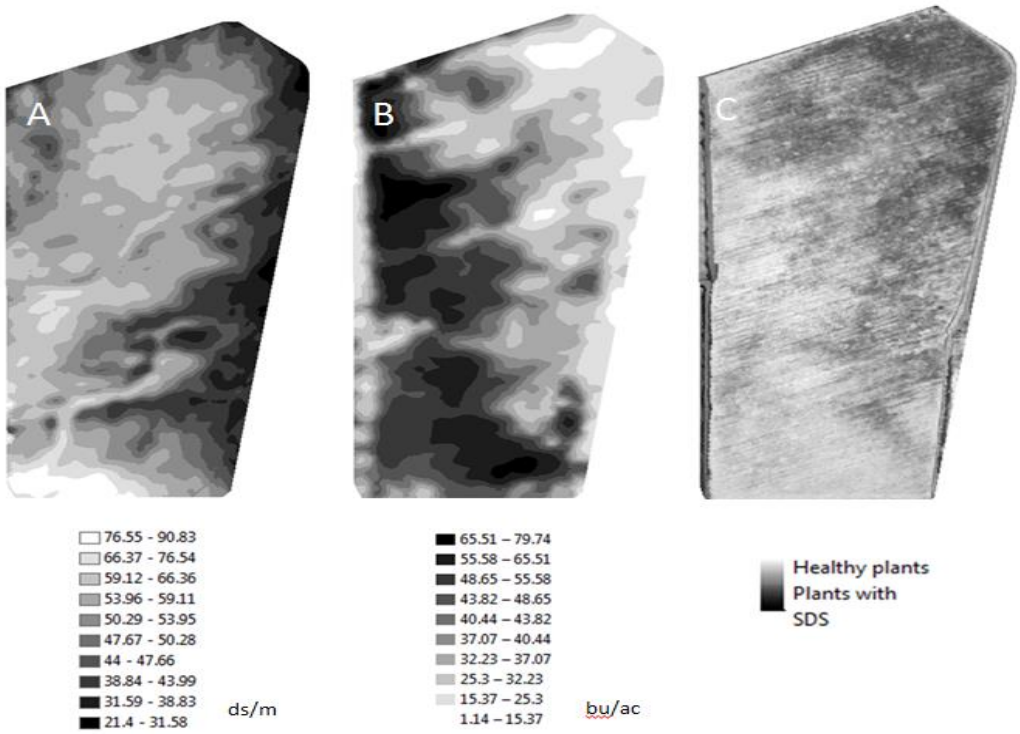

Fig 4. A) Soil electrical conductivity (EC) (texture), B) yield, and C) defoliation from sudden death syndrome in a soybean field near Yancopin, Ark. All three data layers correlated spatially indicating sudden death syndrome (SDS) was most destructive and reduced yield in an aggregated pattern correlating to the lower soil EC values in the field.

Foliar Fungicide Efficacy at Five Timings on Frogeye Leaf Spot in Maturity Group IV and V Soybean

T.N. Spurlock[1], A. Greer[1], and A.C. Tolbert[1]

ABSTRACT

Field trials were conducted to determine the best timings and chemistries for foliar fungicides to manage frogeye leaf spot (FLS) on soybean. Chemistries included strobilurins, triazoles, and mixed modes of action to account for growing strobilurin-resistant populations. Two separate plantings were made, a maturity group (MG) IV cultivar as a full-season production system and a MG V cultivar planted at a later date to simulate a double cropping system. In the MG IV timing trial, with the exception of the R1 treatment alone, Headline® (strobilurin) did not provide as much control as Domark® (triazole) or Quilt Excel® (strobilurin + triazole). In the MG V timing trial, although some timings x fungicide did improve disease control over the untreated check, no statistical significances in yield were shown. Fungicide performance trials for both MG IV and MG V indicated both singular and mixed modes of action that were effective in reducing FLS severity, however, yield was not statistically significant.

INTRODUCTION

Cercospora sojina, a fungal pathogen, that causes a foliar disease commonly referred to as frogeye leaf spot (FLS), can be found anywhere soybeans are grown and cause yield reductions up to 30% in susceptible cultivars. Symptoms appear on leaves as purple water-soaked spots, developing into circular to angular brown lesions surrounded by dark reddish-brown margins. The fungus survives in infected seeds and infested soybean residue (Phillips, 2008). Due to the increasing acreage of soybean in Arkansas, and more fields growing soybean in successive years, disease pressure from FLS is likely to be high each year. Therefore, making the best management choices such as resistant cultivars, high-quality seed selection, deep tillage of residues, crop rotation, and foliar fungicides is essential to proper control and limiting yield loss. Using foliar fungicides to control FLS has been complicated by a population of *C. sojina* that is largely resistant to strobilurin fungicide and recent data indicates strobilurin fungicides do not provide adequate control alone. Further, fungicides are most often effective when applied at the proper timing. The objective of this work is to determine chemistries most effective against the current population of *C. sojina* in Arkansas as well as determine if growth stage can be used to indicate proper timing for fungicide application.

PROCEDURES

Fungicide Timing Trials. Two separate trials were conducted in a silt loam field at the Rohwer Research Station, near Rohwer, Ark. and arranged in a randomized complete block design. Each trial contained 3 fungicide treatments in 5 replications, differing only in maturity group. The MG IV test was planted 20 May, in AgVenture49C9RR, a full-season soybean production system, and the MG V test was planted 23 June, in AgVenture52B2RR, simulating a double-crop soybean production system. Both tests were planted on 38-in. row spacing and divided into 4 row plots 20 ft long. The center two rows of each plot were sprayed at 5 different timings: beginning flowering (R1 on MG IV) or 4th trifoliate (V4 on MG V), beginning pod (R3), beginning seed (R5), R1+R3, and R3+R5. Plots were sprayed using a MudMaster (Bowman Manufacturing, Newport, Ark.) sprayer with a compressed air driven custom multi boom (R&D Sprayers, Opelousas, La.) with 19 in. nozzle spacing. Fungicides were applied at 10 gallons per acre using Teejet 11002VS tips at 3.5 mph. Disease ratings were based on percent of disease coverage in the upper one-third of the canopy and were taken pre-application, and at intervals post-application. The center two rows were harvested 26 Sep (MG IV) and 22 Oct (MG V) with a Wintersteiger Delta plot combine. Data were analyzed using analysis of variance followed by means separation of fixed effects (fungicide treatments) using Fisher's protected least significant difference (LSD) test $P = 0.05$.

Fungicide Performance Trials. The MG IV test was planted 20 May 14 and the MG V trial was planted 23 June 14 both on 38-in. row spacing and divided into 4 row plots 20 ft long. The center two rows of each plot were sprayed at beginning pod (R3) on 8 June 14 and 22 Aug 14 for MG IV and MG V, respectively. Fungicides were applied with a MudMaster using the same settings as mentioned previously. Disease ratings were based on percent of disease coverage in the upper one-third of the canopy and were taken pre-application, and at 8, 15, 22, and 36 days post application (DPA) for MG IV and 12 and 21 days post application for MG V. The center two rows were harvested 26 Sept 14 and 22 Oct 14 for MG IV and MG V, respectively. Data were subjected to analysis of variance followed by means separation of fixed effects using Fisher's protected least significant difference (LSD) test $P = 0.05$.

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RESULTS AND DISCUSSION

Maturity group IV data is shown in Table 1, where average severity of FLS at the R1, R3, and R5 timings was 0%, 1%, and 3.1%, respectively. Ratings taken on 30 July were the only rating to show significant differences. All treatments had been applied on 30 July, except the R5 sprays. The 30 July ratings show, with the exception of the R1 treatment alone, Headline® (strobilurin) did not provide as much control as Domark® (triazole) or Quilt Excel® (strobilurin + triazole).

Maturity group V data is shown in Table 2, where average severity of FLS at the V4, R3, and R5 timings was 0%, 2%, and 5.8%, respectively. Data prior to 3 Sept. lacked significant differences (not shown). All treatments had been applied on 22 Sept. although some timings × fungicide did improve disease control over the untreated check, no statistical significances were shown in yield.

Fungicide Performance Trials. The MG IV trial did not have FLS at application. However, disease was rated at an average of 8 and 15 DPA. By 22 DPA, FLS was in the 2-2.5% coverage range, and differences were observed among treatments. The best performing triazole treatments were Topguard®, Domark®, Alto®, Muscle®, and Proline®. The top strobilurin treatments were Equation® and Aproach®, while Priaxor® and Quilt Excel® were the most efficacious of the mixed chemistries. Among the treatments listed previously, there were no statistical differences between or within chemistries. By 36 DPA, no significant differences were observed among any treatments, nor were any differences observed in yield data (Table 3.).

In the MG V fungicide performance trial, FLS was rated 2% at application. At 12 DPA only two treatments were not statistically significant compared to the untreated check. At 21 DPA all treatments were significantly different than the untreated check; however, none of the treatments had any effect on yield (Table 4).

PRACTICAL APPLICATIONS

In both tests, some fungicides controlled FLS compared to the untreated check; however, no significant differences were shown in yield indicating a fungicide application based on timing alone is probably not reliable. Future testing will include a scout and spray treatment to compare the efficacy of traditional methods against automatic spray methods.

ACKNOWLEDGMENTS

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Table 1. Maturity group IV frogeye leaf spot (FLS) ratings and yield.

Treatment and rate/ac	Timing	30 Jul 14	25 Aug 14	Yield (bu/ac)
Untreated Check	R1	2.1 cd†	39.0	51.9
Headline 6 fl oz	R1	2.1 cd	32.2	48.7
Domark 4 fl oz	R1	2.1 cd	39.0	49.5
Quilt Excel 14 fl oz	R1	2.5 ab	42.2	49.2
Headline 6 fl oz	R1+R3	2.5 ab	38.0	49.3
Domark 4 fl oz	R1+R3	2.1 cd	31.0	54.0
Quilt Excel 14 fl oz	R1+R3	2.0 d	32.0	50.3
Headline 6 fl oz	R3	2.6 a	45.0	48.0
Domark 4 fl oz	R3	2.2 cd	37.0	50.2
Quilt Excel 14 fl oz	R3	2.1 cd	37.0	49.5
Headline 6 fl oz	R3+R5	2.6 a	39.0	50.8
Domark 4 fl oz	R3+R5	2.2 cd	30.0	49.4
Quilt Excel 14 fl oz	R3+R5	2.3 cd	36.0	52.6
Headline 6 fl oz	R5	2.3 bc	38.0	52.3
Domark 4 fl oz	R5	2.2 cd	42.0	50.8
Quilt Excel 14 fl oz	R5	2.2 cd	38.0	52.1
LSD (P=0.05)		0.275	9.16	4.718
Standard Deviation		0.217	7.24	3.730
CV		9.62	19.46	7.38
Treatment Prob(F)		0.0001	0.5146	0.4811
Mean Squared Error (MSE)		0.05	52.42	13.91

†Column numbers followed by the same letter are not significantly different at P = 0.05 as determined by Fisher's protected least significant difference test.

Table 2. Maturity group V Frogeye leaf spot (FLS) ratings and yield.

Treatment and rate/ac	Timing	3 Sep 14	12 Sep 14	22 Sep 14	29 Sep 14	Yield (bu/ac)
Untreated Check		4.6 abc†	7.8 a	8.4 a-e	8.6 ab	52.3
Headline 6 fl oz	V4	5.4 ab	7.4 a	9.3 a	9.2 a	54.1
Domark 4 fl oz	V4	5.6 a	7.6 a	9.0 ab	8.9 ab	51.4
Quilt Excel 14 fl oz	V4	5.0 ab	7.4 a	8.5 a-d	9.1 a	50.6
Headline 6 fl oz	R1+R3	4.1 b-e	5.2 bcd	6.6 d-g	5.9 cde	52.7
Domark 4 fl oz	R1+R3	2.4 f	4.0 de	5.2 g	5.2 de	54.5
Quilt Excel 14 fl oz	R1+R3	2.5 f	4.0 de	5.2 g	5.0 e	54.0
Headline 6 fl oz	R3	4.2 bcd	5.0 cde	6.9 b-g	7.5 abc	52.1
Domark 4 fl oz	R3	2.9 def	4.2 de	6.31 efg	5.2 de	55.7
Quilt Excel 14 fl oz	R3	3.0 def	4.0 de	6.8 c-g	5.8 cde	54.2
Headline 6 fl oz	R3+R5	5.4 ab	6.8 ab	8.8 abc	7.1 bcd	52.6
Domark 4 fl oz	R3+R5	3.6 c-f	4.6 cde	6.6 d-g	5.5 de	50.3
Quilt Excel 14 fl oz	R3+R5	2.8 ef	3.4 e	6.0 fg	4.9 e	55.7
Headline 6 fl oz	R5	5.0 ab	7.2 a	8.0 a-f	8.7 ab	50.9
Domark 4 fl oz	R5	5.2 ab	7.2 a	8.4 a-e	9.4 a	55.4
Quilt Excel 14 fl oz	R5	4.4 abc	6.2 abc	7.4 a-f	7.9 ab	52.2
LSD (P=0.05)		1.334	1.63	2.185	1.950	5.876
Standard Deviation		1.054	1.29	1.709	1.525	4.507
CV		25.52	22.31	23.28	21.45	8.67
Treatment Prob(F)		0.0001	0.0001	0.0017	0.0001	0.6748
Mean Squared Error (MSE)		1.11	1.65	9.92	2.33	0.76

† Column numbers followed by the same letter are not significantly different at P = 0.05 as determined by Fisher's protected least significant difference test.

Table 3. Fungicide performance on Frogeye leaf spot (FLS) on MG IV soybeans applied at R3.

Treatment and rate/ac	22 DPA	36 DPA	Yield (bu/ac)
Untreated Check	2.5 a†	4.9	51.7
Topguard 7 fl oz	2.1 c	4.4	53.5
Domark 4 fl oz	2.1 c	4.0	55.5
Fortix 5 fl oz	2.4 ab	4.7	51.9
Stratego YLD 4 fl oz	2.4 ab	4.7	51.8
Equation 6 fl oz	2.0 c	4.3	52.8
Priaxor 4 fl oz	2.2 bc	4.5	53.6
Quilt Xcel 10.5 fl oz	2.1 c	4.5	53.8
Aproach 6 fl oz	2.1 c	4.2	53.9
Alto 4 fl oz	2.0 c	4.5	52.5
Muscle 4 fl oz	2.2 bc	4.7	50.2
Proline 2.5 fl oz	2.0 c	4.4	56.8
LSD (P=0.05)	0.248	0.747	3.929
Standard Deviation	0.194	0.585	3.074
CV	8.93	13.4	5.78
Treatment Prob(F)	0.0006	0.5477	0.1100
Mean Squared Error (MSE)	0.04	0.34	9.45

†Column numbers followed by the same letter are not significantly different at P = 0.05 as determined by Fisher's protected least significant difference test.
DPA = days post application.

Table 4. Fungicide performance on Frogeye leaf spot (FLS) on MG V soybeans applied at R3.

Treatment and rate/ac	12 DPA	21 DPA	Yield (bu/ac)
Untreated Check	4.5 a†	7.6 a	48.2
Topguard 7 fl oz	2.5 bc	3.6 bcd	53.0
Domark 4 fl oz	2.9 bc	4.4 bcd	51.0
Fortix 5 fl oz	2.4 bc	2.8 d	52.4
Stratego YLD 4 fl oz	3.4 ab	5.2 bc	49.0
Equation 6 fl oz	3.0 bc	5.4 b	50.2
Priaxor 4 fl oz	3.1 bc	4.4 bcd	48.5
Quilt Xcel 10.5 fl oz	2.7 bc	5.0 bc	49.9
Aproach 6 fl oz	3.4 ab	4.6 bcd	47.4
Alto 4 fl oz	3.0 bc	4.4 bcd	49.5
Topsin XTR 20 fl oz	2.1 c	3.4 cd	49.9
Proline 2.5 fl oz	2.2 c	4.0 bcd	50.3
LSD (P=0.05)	1.107	1.86	4.585
Standard Deviation	0.866	1.45	3.587
CV	29.53	31.8	7.18
Treatment Prob(F)	0.0068	0.0014	0.4151
Mean Squared Error (MSE)	0.75	2.11	12.87

†Column numbers followed by the same letter are not significantly different at P = 0.05 as determined by Fisher's protected least significant difference test.
DPA = days post application.

Dissecting the Epidemiology of Soybean Vein Necrosis Virus: A Study on Transmission and Alternative Hosts

I. Tzanetakis[1] and J. Zhou[1]

ABSTRACT

Soybean vein necrosis disease (SVND), a disorder caused by soybean vein necrosis virus (SVNV), is the most prevalent soybean virus disease in North America. Despite its importance, little is known about the host range and alternative hosts of the virus. Other than the soybean thrip, no other species have been tested for their ability to transmit SVNV. In this study, 31 common weed species in soybean fields were tested as potential alternative hosts of the virus and the western flower thrip, the most important vector of tospoviruses, was evaluated for its ability to transmit SVNV.

INTRODUCTION

Soybean vein necrosis disease (SVND) was first found in Arkansas and Tennessee in 2008 (Zhou et al., 2011). Since its discovery, SVND has expanded from the south-central United States to all major soybean-producing areas of North America. The vast majority of soybean pathologists listed this disease as the most prevalent problem in their individual states in 2012. Soybean vein necrosis disease is caused by soybean vein necrosis virus (SVNV), a thrips-transmitted tospovirus (Zhou and Tzanetakis, 2013). Typical symptoms of SVNV start as vein clearing along the main veins, with veins yellowing and turn into necrosis as the season progresses. Clearing or lesions may occur on one of multiple areas of the affected leaves and severely affected leaves die off. Disease symptoms are more evident higher in the canopy because newly emerged leaves are preferential feeding sites of the virus vector, the soybean thrip (*Neohydatothrips variabilis* (Beach)) (Faske et al., 2014).

Tospoviruses are some of the most devastating pathogens affecting global agriculture. They are transmitted by 15 thrips species (Whitfield et al., 2005; Pappu et al., 2009; Zhou and Tzanetakis, 2013). Other than soybean thrips, a species newly categorized as a virus vector due to its ability to vector SVNV, it is still unknnown whether other thrips species play a role in virus transmission. The western flower thrip (WFT, *Frankliniella occidentalis*) is an efficient vector of at least five tospoviruses, among which two, *Tomato spotted wilt virus* (TSWV) and *Groundnut ringspot virus* (GRSV) naturally infect soybean (Pappu et al., 2009). It is therefore important to explore whether this species can function as a SVNV vector. As there is a soybean-free period in North America, vector and virus need to find feeding grounds to overwinter. The identification of alternative hosts in the field is helpful for minimizing movement of the virus to soybeans early in the season, and therefore is critical for virus control and disease management. Soybean vein necrosis disease is prevalent in dry, warm years and given the predictions that this will be more common in the future, it is imperative to study the epidemiology of the disease in more depth and minimize its impact to all soybean production systems.

PROCEDURES

A WFT colony was maintained on green bean pods as described by Rotenberg et al., 2009. Larvae were collected within 24 hours of hatching and used in transmission studies as described by Zhou and Tzanetakis (2013). Three replicates were used in transmission studies. The presence of SVNV was determined using the detection protocol of Zhou and Tzanetakis (2013). Briefly, total nucleic acids were isolated from leaves exhibiting feeding scars and treated with RNase-free DnaseI before converted to cDNA. The synthesized cDNA was then used as template in polymerase chain reaction (PCR) to amplify a 348-nucleotide fragment of SVNV NP gene using primer set SVNV-NPF/SVNV-NPR (Zhou and Tzanetakis, 2013).

Overwinter hosts are critical for the survival of vector and virus during the soybean-free period in the field, for this reason weed species were tested for SVNV infection. A total of 31 species (Table 1) were collected from different soybean fields that were heavily infested by SVNV during 2012 and 2014, and tested using dot blot immunoassay using polyclonal antibodies generated against the recombinant SVNV nucleoprotein. Positive and negative controls were included in each reaction. Seeds from virus-positive species were collected and inoculated with the virus. Given that no information can be found from the literature on whether the soybean thrips feed on target weeds, seeds of several legume species and some of the most common weed species (Table 2) in the field were planted in the greenhouse to test their susceptibility to SVNV and soybean thrips. Thrips larvae hatched within 24 h of feeding or without feeding on SVNV symptomatic region, were transferred to seedlings at the rate of 20-30/plant, and kept in growth chamber for symptom development. The survival rate of thrips were assessed and the presence of SVNV were tested using reverse transcription-polymerase chain reaction (RT-PCR) four to six weeks post inoculation. Negative control was also included for each species.

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RESULTS AND DISCUSSION

None of the soybean seedlings with WFT larvae which fed on infected materils exhibited SVND symptoms or any other virus-like symptoms; RT-PCR detection did not reveal any SVNV positive samples suggesting WFT is unable to transmit SVNV and therefore they are not the potential vector. Possible explanation for this result could be the inability of WFT to acquire the virus or the failure of the virus being replicated within thrips or both. To unravel this question, the replication rate of SVNV within thrips after acquisition period needs to be assessed using quantative detection methods.

Over 1700 plants from 31 species were tested for SVNV using dot blot, including hemp sesbania, sicklepod, alfafa, white clover, and red clover that belong to the family Fabaceae. However, none of them tested positive for SVNV in our study. We also tested more than 200 individual broadleaf signalgrass, a common monocotyledon weed in the field, and two of them were positive for the virus. To confirm this result, seeds of broadleaf signalgrass were collected from the corresponding fields and planted under the greenhouse conditions. Larvae and adults of soybean thrips were transferred to the seedlings. Only minor feeding scars were observed on broadleaf signalgrass compared with white clover six weeks post inoculation. This result combined with the low infection rate in dot blot assay for field samples suggests this monocot species is less likely to play a major role in the epidemiology of SVND. Another greenhouse transmission study focusing on legume species, sweet potato, and ivy leaf morning glory revealed two new hosts for SVNV: medicago and pigon pea. Ivy leaf morning glory can sustain the replication of the vector and is a systemic host for the virus whereas SVNV failed to move out of the local lesion on cowpea.

PRACTICAL APPLICATIONS

The current research is a further exploration of epidemiology of SVND providing important information for virus control and disease management. The fact that WFT are not vectors for SVNV excludes the possibility of mixed infection between SVNV and TSWV as well as GRSV in nature. As a systemic host for SVNV, ivy leaf morning glory exhibits lesions on both inoculated and systemic leaves, suggesting this widely spread weed species in soybean fields probably plays an important role in disease dissemination, which validates the hypotheses of previous studies (Zhou and Tzanetakis, 2013). Our experiment also expands the host range of SVNV to other legume species. So far, other than soybean, where the virus was first isolated, another four legumes including cowpea, mungbean, medicago and pigeon pea can also sustain the replication of the virus, indicating SVNV may be a new concern for growers. Whereas cowpea and mungbean are local lesion hosts, it still needs to be determined whether the virus can move out of the inoculated leaves on medicago and pigeon pea.

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Table 1. **Weed species tested for alternative hosts.**

Weed species	Number of tested samples	Number of SVNV[a] positive samples
Palmer amaranth	28	-
Barnyardgrass	32	-
Horseweed	37	-
Prickly sida	32	-
Hemp sesbania	30	-
Italian ryegrass	49	-
Yellow nutsedge	60	-
Sicklepod	44	-
Giant ragweed	34	-
Broadleaf singalgrass	210	2
Common waterhemp	26	-
Crabgrass	43	-
Henbit	36	-
Horsenettle	38	-
Spreading dayflower	35	-
Smartweed	36	-
Hophornbeam copperleaf	34	-
Cutleaf evening primrose	41	-
Spotted spurge	28	-
Common ragweed	62	-
Eclipta	43	-
Curly dock	30	-
Chickweed	27	-
Common purslane	24	-
Shepherd's purse	33	-
Spurred anoda	45	-
Alfafa	94	-
Johnsongrass	65	-
White clover	316	-
Red clover	65	-
Wild onion	50	-

[a] SVNV = soybean vein necrosis virus.

Table 2. Weed and legume species tested in the greenhouse study.

Plant species	Number of plants tested	Number of positive plants	Type of infection
Ivy leaf morning glory	6	2	Systemic
Medicago	6	2	Not determined
Cowpea	5	2	Local lesion
Chickpea	10	-	-
Pigeon pea	6	1	Not determined
Sweet potato	15	-	-

Utilization of Tank Mixtures and Nozzle Selection to Improve Liberty®, Roundup PowerMax®, and Engenia™ Efficacy

C.J. Meyer[1], J.K. Norsworthy[1], G.R. Kruger[1], L.T. Barber[2], and R.C. Scott[2]

ABSTRACT

Nozzle selection and spray volume will become important variables for making labeled postemergence applications of dicamba in next-generation cropping systems. It appears likely that soybean cultivars will be available within the next four to five years that permit over-the-top applications of glyphosate, glufosinate, and dicamba. Hence, a field experiment was conducted in 2013 and 2014 at the Northeast Research and Extension Center in Keiser, Ark. to evaluate interactions between dicamba (formulated as Engenia™), glyphosate (Roundup PowerMax®), and glufosinate (Liberty®) applied with three different nozzle types (TeeJet 11004 TT, AIXR, and TTI nozzles). To supplement the field data, droplet spectra for each nozzle and tank-mix combination were determined at the West Central Research and Extension Center in North Platte, Neb. For most treatments, as droplet size decreased, efficacy on Palmer amaranth and barnyardgrass increased. When treatments were made to larger barnyardgrass in 2014, an antagonistic effect was observed when Engenia was added to Roundup PowerMax. This research illustrates that steps taken to reduce off-target herbicide movement through use of coarser nozzles are likely to be detrimental to control of some weeds with these products, especially on larger weeds.

INTRODUCTION

Managing droplet size in auxin-type, herbicide-resistant crops is a critical component of minimizing off-target movement. Nozzle selection requirements are stated on new herbicide labels registered for use in new technologies such as Enlist™ Soybean. In the coming years, it is expected that soybean varieties with stacked resistance to glyphosate, glufosinate, and dicamba will be released. Two weeds that pose serious management concerns in current agricultural systems are Palmer amaranth (*Amaranthus palmeri*) and barnyardgrass (*Echinochloa crus-galli*). Both of these weeds have extensive documentation of herbicide resistance and even multiple resistance to many different herbicides. In order to protect emerging technologies, a full understanding of the effects of manipulating application parameters on the control of irrepressible and resistant-prone species is needed.

Prior research suggests that manipulating droplet size is more important for contact herbicides such as glufosinate as opposed to systemic herbicides such as glyphosate and 2,4-D (Etheridge et al., 2001; Feng et al., 2003; McKinlay et al., 1974). However, the effect of droplet size on efficacy appears to depend on the specific species being investigated.

The objective of this research was to evaluate the effect of nozzle type on weed control and droplet spectra of herbicide tank-mixtures of glufosinate, glyphosate, and dicamba alone and in all combinations with dicamba. Herbicide formulation can impact droplet spectra; hence, the specific products evaluated in this research included Liberty® (glufosinate), Roundup PowerMax® (glyphosate), and Engenia™ (dicamba).

PROCEDURES

A field experiment was conducted in 2013 and 2014 in Keiser, Ark. to evaluate applications of dicamba tank-mixtures using various spray nozzles. Plots 12.7 ft by 50 ft in size were assigned to a specific herbicide-nozzle combination in each experiment. To supplement the field data, droplet spectra for each nozzle and tank-mix combination were determined at the West Central Research and Extension Center in North Platte, Neb.

The experimental design was a randomized complete block factorial with four replications and two factors: nozzle type and herbicide solution. The herbicide treatments were Liberty at 29 fl oz/ac, Roundup PowerMax at 22 fl oz/ac, Engenia at 12.8 fl oz/ac, Liberty + Engenia, Roundup PowerMax + Engenia, and Liberty + Roundup PowerMax + Engenia. Teejet 11004 TT, AIXR, and TTI nozzles were used to apply each herbicide treatment and alter the droplet size of the spray. Applications were

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made with a MudMaster multiboom sprayer (Bowman Manufacturing Co., Inc. Newport, Ark.) at 40 psi, 15 gallons/ac spray volume, and ground speed of at 8.3 mph to actively growing weeds. Percent weed control was evaluated four weeks after application for Palmer amaranth and barnyardgrass.

All data were analyzed in JMP Pro 11 using the MIXED procedure. In the field experiment, years were analyzed separately and replication was included as a random variable. Means were separated using Fisher's protected least significant difference test (0.05) and, for the particle size analysis, a Tukey's adjustment was used to separate means.

RESULTS AND DISCUSSION

For all treatments and nozzle combinations, Palmer amaranth control was greater than 90% in both years, except for Roundup PowerMax alone (Table 1). Glyphosate-resistant Palmer amaranth was present at the site location and control of the population by Roundup PowerMax alone was around 50%. In 2013, TT nozzles provided 96% control and TTI nozzles provided 89% control of barnyardgrass averaged across all herbicides except for Engenia alone (control of barnyardgrass by Engenia alone was 0%). A similar effect of nozzle selection was observed in 2014 (Table 2). When treatments were applied to 8- to 12-in. tall barnyardgrass in 2014, compared to 3- to 6-in. tall plants in 2013, an antagonistic effect was observed when Engenia was added to Roundup PowerMax. The weed control data correlated with the droplet spectra analysis in that as volume median diameter (D_{v50}) increased from TT nozzles to the TTI nozzles, efficacy tended to decrease. Changing nozzle size or mixing herbicides in solution can have a dramatic effect on the droplet spectrum and volume median diameter. For example, Liberty alone tends to decrease Dv_{50} relative to pure water but when tank-mixed with Engenia or Roundup PowerMax, a reduction in droplet size is not observed (Table 3).

PRACTICAL APPLICATIONS

Changing nozzle size, nozzle type, or addition of another herbicide into the tank-mix can have a dramatic effect on the droplet spectrum and even efficacy on both barnyardgrass and Palmer amaranth. These results suggest that nozzle selection will play a key role in maximizing efficacy of postemergence applications in dicamba-resistant crops. Additionally, evaluating droplet spectra of potential dicamba-containing tank-mixtures is critical for producing the desired droplet size to minimize off-target movement. Managing all of the parameters of the spray application will be an integral component of using new technologies safely and preserving their efficacy.

ACKNOWLEDGMENTS

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Table 1. Post-emergence Palmer amaranth control 2 and 4 weeks after treatment (WAT) as influenced by the interaction of herbicide treatment and nozzle selection in 2013 and 2014.

			Weed control							
			2013				2014			
Treatments	**Rate**	**Nozzle**	**2 WAT**		**4 WAT**		**2 WAT**		**4 WAT**	
	fl oz/A		%	SE[†]	%	SE	%	SE	%	SE
Liberty	29	TT[‡]	98	1	96	2	100	0	100	0
		AIXR[§]	99	1	96	1	97	2	99	1
		TTI[¶]	94	2	91	2	100	0	99	1
Engenia	12.8	TT	99	1	98	1	93	1	98	2
		AIXR	100	0	99	0	93	1	99	1
		TTI	97	1	98	1	93	1	100	0
Roundup PowerMax	22	TT	59	1	58	1	61	2	59	1
		AIXR	56	1	63	1	66	2	51	2
		TTI	63	1	61	1	58	1	50	2
Engenia + Liberty	12.8 + 29	TT	100	0	99	0	98	1	100	0
		AIXR	99	1	99	0	100	0	100	0
		TTI	100	0	100	0	99	1	99	1
Engenia + Roundup PowerMax	12.8 + 22	TT	100	0	100	0	96	3	96	2
		AIXR	100	0	100	0	95	2	97	2
		TTI	100	0	99	0	90	4	94	1
Engenia + Liberty + Roundup PowerMax	12.8 + 29 + 22	TT	100	0	100	0	100	0	100	0
		AIXR	100	0	100	0	100	0	100	0
		TTI	100	0	100	0	100	0	100	0

[†] Timings that did not meet the assumptions of analysis of variance are reported as means followed by the standard error (SE) of the mean.
[‡] Refers to the TeeJet Turbo TeeJet (TT) 11004 nozzle.
[§] Refers to the TeeJet Air Induction Extended Range (AIXR) 11004 nozzle.
[¶] Refers to the TeeJet Turbo TeeJet Induction (TTI) 11004 nozzle.

Table 2. Post-emergence barnyardgrass control 2 and 4 weeks after treatment (WAT) as influenced by herbicide treatment and nozzle selection in 2013 and 2014.

			Weed control[§]			
			2013		2014	
Main Effect	**Treatments**	**Rate**	**2 WAT**	**4 WAT**	**2 WAT**	**4 WAT**
Herbicide[‡]		fl oz/A	---------%-------		----------%---------	
	Liberty	29	95 ab[†]	89 b	97 a	96 bc
	Engenia	12.8	0	0	0	0
	Roundup PowerMax	22	94 bc	94 a	97 a	98 a
	Engenia + Liberty	12.8 + 29	93 c	89 b	96 a	94 c
	Engenia + Roundup PowerMax	12.8 + 22	97 a	94 a	92 b	94 c
	Engenia + Liberty + Roundup PowerMax	12.8 + 29 + 22	97 a	94 a	97 a	97 ab
Nozzle[§]						
	TT[¶]		99 a	96 a	97 a	97 a
	AIXR[#]		97 b	94 a	96 a	96 a
	TTI[††]		91 c	87 b	95 b	94 b

[†]Means followed by the same letter within a column are not statistically different according to Fisher's protected least significant difference test ($\alpha = 0.05$).
[‡]Control values are for the main effect of herbicide, averaged across nozzle type.
[§]Control values are for the main effect of nozzle type, averaged across herbicide.
[¶]Refers to the TeeJet Turbo TeeJet (TT) 11004 nozzle.
[#]Refers to the TeeJet Air Induction Extended Range (AIXR) 11004 nozzle.
[††] Refers to the TeeJet Turbo TeeJet Induction (TTI) 11004 nozzle.

Table 3. Volume median diameter D_{v50} and percentage of the volume containing droplets with diameters less than 141 µm for nozzle and herbicide combinations.

Treatments	Rate	Nozzle	D_{v50}	<141 µm
	fl oz/A			
Water	-	TT‡	359 fg†	7.44 bcd
		AIXR§	482 de	2.22 g
		TTI¶	742 b	0.41 i
Liberty	29	TT	346 fg	10.71 a
		AIXR	389 f	7.36 cd
		TTI	617 c	1.54 h
Engenia	12.8	TT	340 g	7.14 de
		AIXR	483 de	2.26 g
		TTI	756 b	0.39 i
Roundup PowerMax	22	TT	378 fg	7.49 bcd
		AIXR	465 e	3.40 f
		TTI	788 b	0.37 i
Engenia + Liberty	12.8 + 29	TT	385 f	7.67 bc
		AIXR	468 e	3.82 f
		TTI	781 b	0.41 i
Engenia + Roundup PowerMax	12.8 + 22	TT	373 fg	8.03 b
		AIXR	461 e	3.44 f
		TTI	764 b	0.44 i
Engenia + Liberty + Roundup PowerMax	12.8 + 29 + 22	TT	402 f	6.63 e
		AIXR	530 d	2.43 g
		TTI	877 a	0.24 i

† Means followed by the same letter within a column are not statistically different according to Fisher's protected least significant difference test with a Tukey adjustment ($\alpha = 0.05$).

‡ Refers to the TeeJet Turbo TeeJet (TT) 11004 nozzle.

§ Refers to the TeeJet Air Induction Extended Range (AIXR) 11004 nozzle.

¶ Refers to the TeeJet Turbo TeeJet Induction (TTI) 11004 nozzle.

Influence of Spray Tips and Spray Volumes on Efficacy of Engenia™ Tank-Mixtures

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ABSTRACT

Nozzle selection and spray volume will become highly important variables for making labeled postemergence applications of dicamba in next-generation cropping systems. A field experiment was conducted in 2013 and 2014 at the Northeast Research and Extension Center in Keiser, Ark. to evaluate tank mixtures of Engenia™ (dicamba), Roundup PowerMax®, Liberty®, and Dual Magnum® applied with TeeJet AIXR, AITTJ60, and TTI nozzles. Two nozzle sizes, 11003 and 11006, were used to vary spray volume from 10 gal/A to 20 gal/A, respectively. For barnyardgrass and Palmer amaranth, control was greater at 20 gal/A for some treatment combinations. The addition of Dual Magnum significantly and dramatically reduced the size of the droplets in the spray pattern for all nozzle types. The results from this research demonstrate that using low spray volume and coarser nozzles could reduce weed control of some species and demonstrate the importance of understanding how additional tank-mix partners influence the droplet spectra.

INTRODUCTION

Parameters of herbicide applications, such as nozzle selection and spray volume, will become more important as auxin-resistant crop varieties become commercially available and as herbicide-resistance continues to threaten agricultural production. Palmer amaranth (*Amaranthus palmeri*) and barnyardgrass (*Echinochloa crus-galli*) are two weeds that have evolved resistance to many different modes of action and remain hard to control across Arkansas. Along with the auxin-resistant crop varieties, BASF Corporation is developing a new formulation (N,N-bis-[aminopropyl]methylamine) of dicamba that will be marketed as Engenia™ herbicide for use in dicamba-resistant crops. To better control these problematic weeds, a full understanding of the effects of manipulating application parameters on the control of irrepressible and resistant-prone species using tank-mixtures of Engenia is needed.

Herbicide efficacy is related to droplet size and spray volume (gal/A), but the relationship differs widely among herbicides and species. Even so, it is still helpful to identify common trends related to the interactions between droplet size, spray volume, herbicide, and weed species. At equal spray volumes, smaller droplets tend to be more effective than larger droplets. Small droplet size is more important for retention on upright, grass weeds than broadleaf weeds with horizontal structure (McKinlay et al. 1974; Etheridge et al. 2001). Also, the importance of adequate coverage, typically achieved with smaller droplets, is more important with contact herbicides. Reducing spray volumes near rates typical for commercial ground applicators (15 gal/A) decreases herbicide performance (Knoche, 1994). The objective of this study was to evaluate the influence of nozzle selection and spray volume on the efficacy of potential dicamba tank-mix combinations that could be used in dicamba-resistant crops.

PROCEDURES

A field experiment was conducted in 2013 and 2014 in Keiser, Ark. to evaluate applications of dicamba tank-mixtures using various spray nozzles. Plots 12.7 ft by 50 ft in size were assigned to a specific herbicide-nozzle combination in each experiment. To supplement the field data, droplet spectra for each nozzle and tank-mix combination were determined at the West Central Research and Extension Center in North Platte, Neb.

The experimental design was a randomized complete block factorial with four replications and three factors: nozzle type, spray volume, and herbicide solution. The herbicide treatments were Liberty® at 29 fl oz/A + Engenia™ at 12.8 fl oz/A, Roundup PowerMax® 22 fl oz/A + Engenia, Liberty + Roundup PowerMax + Engenia, and Liberty + Roundup PowerMax + Engenia, + Dual Magnum® at 16 fl oz/A.

Teejet AIXR, AITTJ60 and TTI nozzles were used to apply each herbicide treatment. Two spray volumes, 10 and 20 gal/A, were investigated. Spray volumes were achieved by changing the nozzle size for each nozzle type from 11003 to 11006, rated at 0.3 gal/min and 0.6 gal/min, respectively. Applications were made with a MudMaster multiboom sprayer (Bowman Manufacturing Co., Inc. Newport, Ark.) at 40 PSI and traveling at 9.4 mph to actively growing weeds. Percent weed control was evaluated four weeks after application for Palmer amaranth and barnyardgrass.

All data were analyzed in JMP Pro 11 using the MIXED procedure (SAS Institute, Inc., Cary, N.C.). In the field experiment, years were analyzed separately and replication was included as a random variable. Means were separated using

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Fisher's protected least significant difference test (0.05) and, for the particle size analysis a Tukey's adjustment was used to separate means.

RESULTS AND DISCUSSION

Data for Palmer amaranth control had low variability within and between treatments and were not suitable for statistical analysis. Therefore, the data are presented as means followed by standard deviations (Table 1). In general, Palmer amaranth control was very high and no large differences in control between nozzles or spray volumes were observed. However, for Roundup PowerMax + Engenia applied using the TTI nozzle, Palmer amaranth control at 20 gal/A was 5% lower than 20 gal/ac in 2013 (94% compared to 99%) and 7% lower in 2014 (87% compared to 94%). A similar reduction in barnyardgrass control was observed in 2013, and for the interaction between nozzle type and spray volume, control with the TTI nozzle at 10 gal/ac was significantly less than at 20 gal/ac (Table 2).

The weed control data correlated with the droplet spectra analysis in that as volume median diameter (D_{v50}) increased from TT nozzles to the TTI nozzles, efficacy tended to decrease. Changing nozzle size, nozzle type, or the addition of another herbicide into the tank-mix can have a dramatic effect on the droplet spectrum and D_{v50}. For example, the addition of Dual Magnum to Engenia + Liberty + Roundup PowerMax decreased the D_{v50} for the TTI 11006 nozzle from 789 µm to 570 µm (Table 3).

PRACTICAL APPLICATIONS

The results from the weed control data indicate that at large droplet sizes (using the TTI nozzle), reducing spray volume from 20 gal/A to 10 gal/A can result in a reduction in weed control. As sprayer applicators begin to use larger droplets to reduce drift of auxinic herbicides combined with lower spray volumes to cover more acres per sprayer load, a reduction in weed control could negatively affect herbicide-resistance management. Nozzle selection will play a key role in maximizing efficacy of postemergence applications in dicamba-resistant crops. Additionally, evaluating droplet spectra of potential dicamba-containing tank-mixtures is critical for producing the desired droplet size to minimize off-target movement.

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McKinlay, K.S., R. Ashford, and R.J. Ford. (1974) Effects of drop size, spray volume, and dosage onparaquat toxicity. Weed Sci. 22:31-34.

Table 1. Post-emergence Palmer amaranth control 4 weeks after treatment as influenced by the interaction between herbicide treatment nozzle type and spray volume in 2013 and 2014.

Treatments	Rate	Nozzle	Spray Volume	Weed Control[a] 2013		2014	
	fl oz/A		gal/A	-%-	SE	-%-	SE
Engenia + Liberty	12.8+ 29	AIXR[b]	10	100	0	100	0
			20	99	1	100	0
		AITTJ60[c]	10	100	0	100	0
			20	96	1	100	0
		TTI[d]	10	97	1	98	3
			20	98	2	100	0
Engenia + RoundUp PowerMax	12.8+ 22	AIXR	10	99	1	92	2
			20	97	1	94	2
		AITTJ60	10	98	1	91	1
			20	95	2	91	2
		TTI	10	94	1	87	2
			20	99	1	94	2
Engenia + Liberty + RoundUp PowerMax	12.8 + 29 + 22	AIXR	10	100	0	98	1
			20	100	1	100	0
		AITTJ60	10	98	1	100	1
			20	99	1	100	0
		TTI	10	97	1	100	0
			20	97	1	100	0
Engenia + Liberty + Roundup PowerMax + Dual Magnum	12.8 + 29 + 22 + 16	AIXR	10	100	0	100	0
			20	100	0	98	2
		AITTJ60	10	98	1	98	1
			20	100	1	100	0
		TTI	10	99	1	100	1
			20	96	2	100	0

[a] Data did not meet the assumptions of analysis of variance and are reported as means followed by the standard error (SE) of the mean.
[b] Refers to the TeeJet Air Induction Extended Range (AIXR) nozzle.
[c] Refers to the TeeJet Air Induction Turbo TwinJet (AITTJ60) nozzle.
[d] Refers to the TeeJet Turbo TeeJet Induction (TTI) nozzle.

Table 2. Post-emergence barnyardgrass control 4 weeks after treatment as influenced by interactions between herbicide, nozzle type, and spray volume in 2013 and 2014.

				Weed Control	
Treatments	**Rate**	**Nozzle**	**Spray Volume**	**2013**	**2014[a]**
	fl oz/A		gal/A	--%--	--%--
Engenia + Liberty	12.8+ 29	AIXR[b]	10	97	94
			20	97	
		AITTJ60[c]	10	97	
			20	95	
		TTI[d]	10	90	
			20	93	
Engenia + Roundup PowerMax	12.8+ 22	AIXR	10	97	94
			20	97	
		AITTJ60	10	88	
			20	90	
		TTI	10	83	
			20	94	
Engenia + Liberty + Roundup PowerMax	12.8 + 29 + 22	AIXR	10	94	95
			20	95	
		AITTJ60	10	89	
			20	92	
		TTI	10	86	
			20	86	
Engenia + Liberty + Roundup PowerMax + Dual Magnum	12.8 + 29 + 22 + 16	AIXR	10	98	97
			20	98	
		AITTJ60	10	96	
			20	97	
		TTI	10	95	
			20	94	
			LSD[e]	4	2
Type*Size		AIXR	10	-	96
			20	-	96
		AITTJ60	10	-	95
			20	-	96
		TTI	10	-	91
			20	-	94
			LSD		3

[a] In 2014, only the main effect of herbicide and interaction between nozzle type and size were significant in the model.
[b] Refers to the TeeJet Air Induction Extended Range (AIXR) nozzle.
[c] Refers to the TeeJet Air Induction Turbo TwinJet (AITTJ60) nozzle.
[d] Refers to the TeeJet Turbo TeeJet Induction (TTI) nozzle.
[e] Least significant difference according to Fisher's protected least significant difference test ($\alpha = 0.05$).

Table 3. Volume median diameter, D_{v50}, and percentage of the volume containing droplets with diameters less than 141 µm.

Treatments	Rate	Nozzle	Spray Volume	D_{v50}	<141 µm
	fl oz/A		gal/A	---µm---	-----$\%_{vol}$----
Engenia + Liberty	12.8+ 29	AIXR[a]	10	459	3.55
			20	515	2.45
		AITTJ60[b]	10	629	0.86
			20	620	1.02
		TTI[c]	10	743	0.33
			20	757	0.7
Engenia + Roundup PowerMax	12.8+ 22	AIXR	10	385	6.24
			20	487	3.16
		AITTJ60	10	570	1.3
			20	611	1.24
		TTI	10	665	0.76
			20	746	0.57
Engenia + Liberty + Roundup PowerMax	12.8 + 29 + 22	AIXR	10	560	1.54
			20	501	3.01
		AITTJ60	10	629	0.98
			20	653	1.05
		TTI	10	800	0.23
			20	789	0.51
Engenia + Liberty + Roundup PowerMax + Dual Magnum	12.8 + 29 + 22 + 16	AIXR	10	399	4.17
			20	490	1.99
		AITTJ60	10	469	2.28
			20	499	1.96
		TTI	10	589	0.92
			20	568	1.6
			LSD[d]	43	0.54

[a] Refers to the TeeJet Air Induction Extended Range (AIXR) nozzle.
[b] Refers to the TeeJet Air Induction Turbo TwinJet (AITTJ60) nozzle.
[c] Refers to the TeeJet Turbo TeeJet Induction (TTI) nozzle.
[d] Least significant difference according to Fisher's protected least significant difference test with a Tukey adjustment ($\alpha = 0.05$).

Broadleaf Weed Control Programs for Edamame

R.A. Salas[1], N.R. Burgos[1], R.C. Scott[2], L. Estorninos[1] and S. Abugho[1]

ABSTRACT

Edamame is a specialty soybean harvested as a vegetable. Few herbicides are registered for use on edamame, which constrains expanded commercial production in the U.S. A field study was conducted in 2014 at Fayetteville and Kibler, Ark. to evaluate the effectiveness of different herbicide programs and the tolerance of edamame to different herbicides. The experimental design was a randomized complete block with 15 treatments and four replications. Herbicide programs included various combinations and sequences of PRE and POST emergence herbicides. The field was overseeded with morningglory, hemp sesbania, prickly sida, and Palmer amaranth. All herbicide treatments were safe to edamame 'AVS-4002'. Prefix® and Flexstar® herbicides caused 35-45% injury 1 wk after POST treatment; however, the crop recovered. Season-long control of morningglory (>89%) can be achieved with Spartan® Charge + Dual® PRE, BroadAxe® PRE followed by (fb) Pursuit® POST, and Valor® XLT PRE fb Pursuit POST. Hemp sesbania was controlled >88% with treatments containing Flexstar, Prefix, or Blazer® + Basagran® POST. All herbicide treatments effectively controlled Palmer amaranth and prickly sida except for Dual PRE fb Flexstar POST, which controlled prickly sida only 73%. The best herbicide programs include Valor XLT PRE fb Pursuit POST and Linex® + Sencor® PRE fb Prefix POST.

INTRODUCTION

Edamame is a specialty soybean harvested as a vegetable when the seeds are immature. There is a growing demand for edamame, especially in Arkansas, where a dedicated processing plant was built to handle production and shipment of the product. There are very few herbicides labeled for edamame because vegetable soybean has different residue tolerances from conventional soybean. Limited herbicide options constrain the expanded commercial production of edamame in the U.S. Thus, this study was conducted to evaluate the effectiveness of various herbicide programs in controlling major weed problems in edamame soybean production and to examine the tolerance of edamame to different herbicides.

PROCEDURES

Field studies were conducted in 2014 at the Arkansas Agricultural Research and Extension Center, Fayetteville, Ark. on Leaf silt loam soil and the Vegetable Research Station, near Kibler, Ark. on Dardanelle silt loam soils. The design was a randomized complete block with 15 treatments and four replications. Herbicide programs included various combinations and sequences of preemergence (PRE) and postemergence (POST) herbicides. Treatment, rates, and timings are shown in Table 1.

Edamame 'AVS-4002' was planted on 7 May and 4 June 2014 in Fayetteville and Kibler, respectively. The field was overseeded with morningglory, hemp sesbania, prickly sida, and Palmer amaranth. Preemergence herbicides were applied immediately after planting and POST treatments were sprayed to V3 soybean and to 2- to 3-inch Palmer amaranth. Herbicide treatments were applied using a CO_2-backpack sprayer delivering 20 gallons per acre (GPA) of spray volume at 38 psi. Crop stand at 3 wk after planting was recorded. Weed control and crop injury were also evaluated at 3 wk after PRE treatment (WAT-PRE), and at 1, 2, and 4 wk after POST treatment (WAT-POST). Weed control ratings were based on a scale of 0 (no control) to 100% (complete control). Mature pods were harvested from the 20-ft middle row to estimate yield. Four plants were selected from each plot to estimate the number of pods and weight of grain per plant. Data was subjected to analysis of variance using JMP Pro v. 11 (SAS Institute, Inc., Cary, N.C.). Significant means were separated using Fisher's protected least significant difference test.

RESULTS AND DISCUSSION

Location was a significant factor influencing crop response and weed control, thus the data from each location was analyzed separately.

Crop Response. In Fayetteville, minimal crop injury was observed from the PRE treatment (0 to 4%) except with Valor® XLT which caused 16% crop injury (Table 2). Soybean injury (stunting, bronzing, and speckling of leaves) was highest at 1 WAT POST with Prefix® (45%) followed by (fb) Flexstar® (41%) treatments. However, the crop recovered at 4 WAT POST

[1] University of Arkansas System Division of Agriculture, Department of Crop, Soil and Environmental Sciences, Fayetteville, Ark.

(4% injury). Temporary soybean injury from Flexstar has been previously reported without affecting crop yield (Wilson, 2005). All treatments produced similar grain yield ranging from 1683 to 3206 lb/A with an average of 19 g seed weight per plant (Table 2). Valor XLT PRE fb Pursuit POST had the lowest plant population of 35,000 plants/A, but produced the highest number of pods per plant. Soybean has the ability to adjust yield components at low plant densities to maintain yield levels (Epler and Staggenborg, 2008).

The test in Kibler showed slightly different results from that of Fayetteville. Plant population was generally less in Kibler than in Fayetteville, probably due to late planting. Injury with fomesafen (15% to 24%) was apparent at 1 WAT POST but declined at 4 WAT POST (Table 2). Each plant produced 76 pods on average, with 29 g seed weight per plant. Crops treated with herbicides produced 2.3 to 4.3× more grain yield than the weedy plots.

Weed Control. Morningglory was controlled >89% with Spartan® Charge + Dual® PRE, BroadAxe® PRE fb Pursuit® POST, and Valor XLT PRE fb Pursuit POST across all evaluation times (Tables 3 and 4). Season-long control of hemp sesbania was achieved (>88%) with treatments containing Flexstar, Prefix, or Blazer® + Basagran®. Hemp sesbania was poorly controlled (55%) with Zidua® PRE fb Pursuit POST as is expected of these herbicides. All herbicide treatments controlled prickly sida (≥88%) except for Dual PRE fb Flexstar POST. In the same manner, all herbicide treatments controlled Palmer amaranth ≥88%. Overall, the highest weed control was achieved with Valor XLT PRE fb Pursuit POST, followed by Linex® + Sencor® PRE fb Prefix POST in both locations (Tables 3 and 4). Other herbicide treatments consistently controlled weeds ≥85% in both locations, except for Dual PRE fb Blazer + Bentazon POST (79%).

PRACTICAL APPLICATIONS

Herbicide treatments used in the study are safe for use on edamame 'AVS-4002'. Prefix and Flexstar can cause temporary injury, but did not impact yield. Effective overall broadleaf weed control (≥93%) can be achieved with Valor XLT PRE fb Pursuit POST, Linex + Sencor PRE fb Prefix/Flexstar POST, Dual + Sencor PRE fb Flexstar POST, Broadaxe PRE fb Pursuit PRE, Zidua + Linex PRE fb Pursuit POST, and Zidua PRE fb Flexstar POST. Labeling of Valor, Sencor, and Zidua can be pursued to diversify the modes of action used and broaden the overall weed control spectrum.

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Table 1. Treatment list for edamame 'AVS-4002'[a] response to various herbicide programs, Arkansas Agricultural Research and Extension Center, Fayetteville and Vegetable Research Station, Kibler, Ark., 2014.

Trade Name	Active Ingredient	Rate	Timing
		lb ai/A	
Dual Magnum fb Flexstar[b]	*S*-metolachlor fb fomesafen	1 fb 0.29	PRE fb POST[c]
Dual Magnum + Sencor fb Flexstar	*S*-metolachlor + metribuzin fb fomesafen	1 + 0.38 fb 0.29	PRE fb POST
Linex + Sencor fb Flexstar	Linex + metribuzin fb fomesafen	1 + 0.38 fb 0.29	PRE fb POST
Dual Magnum fb Blazer + Basagran	*S*-metolachlor fb acifluorfen + bentazon	1 fb 0.25 + 0.50	PRE fb POST
Linex fb Blazer + Basagran	Linex fb acifluorfen + bentazon	1 fb 0.25 + 0.50	PRE fb POST
Linex fb Prefix	Linex fb fomesafen + *S*-metolachlor	1 fb 0.24 + 1.09	PRE fb POST
Linex + Sencor fb Prefix	Linex + metribuzin fb fomesafen + S-metolachlor	1 + 0.38 fb 0.24 + 1.09	PRE fb POST
Linex + Dual Magnum fb Blazer + Basagran	Linex + S-metolachlor fb acifluorfen + bentazon	1 + 1 fb 0.25 + 0.50	PRE fb POST
Spartan Charge + Dual Magnum	carfentrazone + sulfentrazone + S-metolachlor	0.027 + 0.24 + 1	PRE
Broadaxe fb Pursuit	sulfentrazone + S-metolachlor fb imazethapyr	0.137 + 1.23 fb 0.06	PRE fb POST
Valor XLT fb Pursuit	flumiozaxin + chlorimuron fb imazethapyr	0.097 + 0.034 fb 0.06	PRE fb POST
Zidua + Linex fb Pursuit	pyroxasulfone + Linex fb imazethapyr	0.11 + 0.75 fb 0.06	PRE fb POST
Zidua fb Pursuit	pyroxasulfone fb imazethapyr	0.11 fb 0.06	PRE fb POST
Zidua fb Flexstar	pyroxasulfone fb fomesafen	0.11 fb 0.38	PRE fb POST
Nontreated check	-	-	-

[a]Edamame 'AVS-4002' variety planted on 7 May 2014 in Fayetteville and on 4 June 2014 in Kibler, Ark.
[b]fb = followed by; plus (+) = tank-mixed.
[c]PRE = 1 d after planting; POST = 28 d after planting.

Table 2. Edamame 'AVS-4002' response to various herbicide programs in Fayetteville and Kibler, Ark., 2014.

	Fayetteville				Kibler			
			Crop Injury				Crop Injury	
Herbicide treatments[a]	**Plant Population**	**Grain Yield**	**1 WAT[c] POST[d]**	**4 WAT POST**	**Plant Population**	**Grain Yield**	**1 WAT POST**	**4 WAT POST**
	x 1000/A	lb/A	--------%--------		x 1000/A	lb/A	--------%--------	
Dual Magnum fb Flexstar	50	3206	36	4	26	1974	19	1
Dual Magnum + Sencor fb Flexstar	58	2927	34	1	34	2172	20	0
Linex + Sencor fb Flexstar	53	2796	36	1	32	2164	23	1
Dual Magnum fb Blazer + Basagran	58	2655	20	1	28	1704	21	1
Linex fb Blazer + Basagran	58	3065	24	3	25	2051	16	1
Linex fb Prefix	61	2654	44	3	21	2143	15	0
Linex + Sencor fb Prefix	60	2864	45	4	39	2139	24	0
Linex + Dual Magnum fb Blazer + Basagran	59	2503	23	2	35	1741	17	3
Spartan Charge + Dual Magnum	57	2244	9	1	34	2003	0	0
Broadaxe fb Pursuit	59	2373	16	4	29	2167	3	0
Valor XLT fb Pursuit	35	1997	24	13	23	2405	8	3
Zidua + Linex fb Pursuit	57	2612	16	6	18	1980	3	1
Zidua fb Pursuit	57	2664	13	4	18	1310	0	1
Zidua fb Flexstar	51	2349	41	4	28	1857	23	3
Nontreated check	54	1683	0	0	34	565	0	0
$LSD_{0.05}$[b]	8	NS	5	7	NS	629	6	NS

[a]fb = followed by; plus (+) = tank-mixed.
[b]Fisher's protected least significant test used to compare treatment means within each column; NS = not significant.
[c]WAT = weeks after treatment.
[d]POST = post-emergence herbicide application.

Table 3. Weed control, 4 WAT POST, by various herbicide programs for edamame soybean[a], Fayetteville, Ark., 2014.

Herbicide Treatment[b]	Weed control, 4 WAT[c] POST[d]					
	Morningglory	Hemp Sesbania	Prickly Sida	Palmer Amaranth	Others[e]	Overall
	----------%----------					
Dual Magnum fb Flexstar	93	99	73	96	91	90
Dual Magnum + Sencor fb Flexstar	93	97	91	94	91	93
Linex + Sencor fb Flexstar	91	100	96	94	84	93
Dual Magnum fb Blazer + Basagran	81	96	88	84	86	87
Linex fb Blazer + Basagran	91	99	95	88	90	93
Linex fb Prefix	92	96	95	97	90	94
Linex + Sencor fb Prefix	92	98	98	97	93	96
Linex + Dual Magnum fb Blazer + Basagran	92	97	93	89	90	92
Spartan Charge + Dual Magnum	89	91	77	90	83	86
Broadaxe fb Pursuit	95	89	98	90	96	93
Valor XLT fb Pursuit	97	98	100	92	97	97
Zidua + Linex fb Pursuit	92	98	100	87	96	94
Zidua fb Pursuit	92	55	99	85	93	85
Zidua fb Flexstar	94	97	96	97	84	94
$LSD_{0.05}$[f]	7	12	12	8	8	NS

[a] Edamame 'AVS-4002' variety planted on 7 May 2014.
[b] fb = followed by; plus (+) = tank-mixed.
[c] WAT = weeks after treatment.
[d] POST = post-emergence herbicide application.
[e] Others = sedges, broadleaf signalgrass, common lambsquarters, and sicklepod.
[f] Fisher's protected least significant difference test used to compare treatment means within each column; NS = not significant.

Table 4. Weed control, 4 WAT POST, by various herbicide programs for edamame soybean[a], Kibler, Ark. 2014.

Herbicide Treatment[b]	Weed control at 4 WAT[c] POST[d]					
	Morningglory	Hemp Sesbania	Prickly Sida	Palmer Amaranth	Others[e]	Overall
	----------%----------					
Dual Magnum fb Flexstar	58	89	83	98	100	85
Dual Magnum + Sencor fb Flexstar	73	100	100	99	100	94
Linex + Sencor fb Flexstar	88	100	100	100	100	98
Dual Magnum fb Blazer + Basagran	35	69	90	100	100	79
Linex fb Blazer + Basagran	61	98	100	100	95	91
Linex fb Prefix	61	100	100	100	95	91
Linex + Sencor fb Prefix	87	100	100	100	98	97
Linex + Dual Magnum fb Blazer + Basagran	48	99	100	98	98	88
Spartan Charge + Dual Magnum	100	78	100	100	100	96
Broadaxe fb Pursuit	100	89	98	100	100	97
Valor XLT fb Pursuit	100	97	100	100	98	99
Zidua + Linex fb Pursuit	78	96	100	100	100	95
Zidua fb Pursuit	81	55	100	100	100	87
Zidua fb Flexstar	79	88	100	100	98	93
$LSD_{0.05}$[f]	15	9	6	NA	NA	4

[a] Edamame 'AVS-4002' variety planted on 4 June 2014.
[b] fb = followed by; plus (+) = tank-mixed.
[c] WAT = weeks after treatment.
[d] POST = post-emergence herbicide application.
[e] Others = sedges, broadleaf signalgrass, common lambsquarters, and sicklepod.
[f] Fisher's protected least significant difference test used to compare treatment means within each column; NS = not significant.

Efficacy and Crop Safety of Pre-emergence and Post-emergence Herbicides on AVS-4002 Edamame in Arkansas

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ABSTRACT

Edamame (*Glycine max* L.) is becoming a popular crop in Ark. The AVS-4002 variety is the first commercial variety from the University of Arkansas System Division of Agriculture. Limitations in herbicide options are the primary concern for this crop. Field studies were conducted in 2014 at the Vegetable Research Station in Kibler, Ark. to determine AVS-4002 response to different rates and time of application of soil- and foliar- herbicides labeled for field soybean. The study was conducted in a randomized complete block design consisting of 26 herbicide treatments with three replications. Stand count, crop injury, weed control, and yield were recorded. Overall weed control with pre-plant (PPL) and pre-emergence (PRE) herbicides was 92%-100% at 21 d after planting. Overall post-emergence (POST) weed control was 89%-93% at 35 DAP. Spartan® applied at a higher rate (0.375 lb ai/ac) caused the highest crop injury (30%). Highest yield was recorded in plots treated with Zidua ® (1909 lb/ac). This study shows that the productivity of AVS-4002 is affected by different rates and time of application of herbicides. Proper choice of herbicide treatments is critical.

INTRODUCTION

Edamame soybean (*Glycine max* L.) is becoming a popular crop in the U.S. Due to its increasing popularity, several states such as Washington, Mississippi, Illinois and Arkansas started to grow edamame with the latter recently known as a large-scale producer in the country (Ross, 2013; Boydston, 2011, Williams and Nelson, 2014, Zhang and Kyei-Boahen, 2007). Two commercialized edamame varieties grown in Arkansas, the traditional Asian variety and AVS-4002 developed through the University of Arkansas System Division of Agriculture's Soybean Breeding program (UAEX, 2014). Herbicide is the main limitation of growing edamame because it is consumed directly as a vegetable crop, which requires retesting for pesticide residue in the fresh, immature, edamame seed. Its tolerance margin to herbicides registered for use in field soybean also needs to be verified. Recently, Williams and Nelson (2014) noted that several edamame varieties are tolerant to pre-emergence (PRE) herbicides such sulfentrazone and linuron, which offers growers additional herbicide options. To support the use of these herbicides in Arkansas, an experiment was conducted to determine the response of AVS-4002 edamame to different herbicides and application timings.

PROCEDURES

A field experiment was conducted on Roxana silt loam (coarse, mixed, superactive, nonacid, thermic Typic Udifluvents) soil. The study was oriented in a randomized complete block design with 26 treatments and three replications (Table 1). Edamame seeds were drill-seeded on 24 May 2014 in four-row plots (20-ft long with 3-ft spacing between rows). Three herbicide treatments were applied 12 d before planting (PPL) and fifteen herbicide treatments were applied PRE, 1 d after planting (DAP). Six herbicide treatments alone or in combination were applied on 13 July 2014 at 2-3 trifoliate leaf stage (POST) of the soybean. A weed-free check (hoe-weeded) was included as reference for evaluating the potential phytotoxicity of herbicides on edamame soybeans and a weedy check as a reference for the efficacy of herbicides on weeds.

Herbicide treatments were applied using a CO_2-backpack sprayer with a handheld boom fitted with 4 flat fan nozzles (Tee Jet XR11003) spaced 18 in. apart, delivering 20 gallons per acre of spray volume at 20 PSI. The weed-free check plots were hoe-weeded as needed. The crop was irrigated as needed. Stand count and visual ratings for injury and weed control was recorded 21 DAP. Additional visual injury and weed control ratings were recorded at 35 DAP for POST- applied herbicides.

Mature pods were harvested from 6.56 ft of the middle row to estimate crop yield. At harvest, four plants were randomly selected for evaluating the total number of pods per plant. All pods were mechanically dehulled after harvest to determine grain weight from each plot. Grain moisture content was adjusted to 13% (correction factor) to calculate grain yield per acre.

RESULTS AND DISCUSSION

Crop Response. Crop stand in the weed-free and weedy plots were 163,400 and 162,000 plants/ac., respectively (Table 2). All PRE herbicide-treated plots had similar crop stand to the check plots. Spartan ® applied at a higher rate (0.375 lb ai/ac) caused the highest crop injury (30%), with the low rate (0.1875 lb ai/ac) causing only 8% crop injury at 21 DAP. Previous research

[1]University of Arkansas System Division of Agriculture, Department of Crop, Soil and Environmental Sciences, Fayetteville, Ark.

showed the same rate response to sulfentrazone on other legumes such as peanuts, cowpea and field soybean (Grichar, 2006; (Burgos et al., 2009; Taylor-Lovell et al., 2001). A recent study comparing grain soybean and edamame response to sulfentrazone, linuron, imazamox and fomesafen showed that both types of soybean respond similarly to these herbicides (Williams and Nelson, 2014). In our test, edamame response to other sulfentrazone-containing treatments (Spartan ® Charge and BroadAxe ®; 0.278 lb ai/ac, 1.37 lb ai/ac) ranged from 0%-8% injury. Metribuzin-containing herbicides, Canopy ® (0.2233 lb ai/ac) and Sencor ® (0.5 lb ai/ac), caused minimal (5%) crop injury. Linex ® (0.7501 lb ai/ac), Reflex ® (0.38 lb ai/ac), Dual Magnum ® (1 lb ai/ac), Prefix ® (1.24 lb ai/ac) applied PRE did not cause any injury. Spartan Charge applied PPL caused no injury and little crop response (5%) when applied PRE. Injury with Valor XLT ® (0.3126 lb ai/ac) was negligible between PPL and PRE application. Verdict ® applied PPL or PRE caused 5%-7% crop injury. Zidua® plots had the highest yield (1909 lbs a/ac) followed by weed-free (1883 lbs a/ac) and Valor XLT applied PPL (1758 lbs a/ac).

Efficacy. Overall weed control at 21 DAP for all PPL and PRE herbicides was 92%-100%. Weeds recorded at 21 DAP were red sprangletop (*Leptochloa panicia* Retz.), Palmer amaranth (*Amaranthus palmeri* L.), and barnyardgrass (*Echinochloa* spp.) (Table 3). At 35 DAP, overall POST herbicide efficacy on weeds such as Palmer amaranth and red sprangletop ranged from 89% to 94% (Table 4).

PRACTICAL APPLICATIONS

Several herbicides labeled for field soybean can be used for edamame. With proper residue tolerance, the label of such herbicides can be expanded to include vegetable soybean.

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Table 1. Herbicide list for edamame soybean, AVS-4002, Vegetable Research Station, Kibler, Ark., 2014[a].

Common name	Trade name	Formulation	Rate lb ai/ac	Timing
S-metolachlor	Dual Magnum	7.62EC	1.00	PRE
S-metolachlor + fomesafen	Prefix	5.3EC	1.24	PRE
sulfentrazone	Spartan	4F	0.1875	PRE
sulfentrazone	Spartan	4F	0.3750	PRE
S-metolachlor + fomesafen	Prefix	5.3EC	1.39	POST
fomesafen	Reflex	2LC	0.38	PRE
fomesafen	Flexstar	1.88SL	0.38	POST
imazethapyr	Pursuit	2SL	0.06	POST
(imazamox + bentazon)	Raptor + Basagran	1AS; 4SL	0.047+0.5	POST
saflufenacil	Sharpen	2.85SC	0.0625	PRE
saflufenacil + dimethenamid	Verdict	5.5EC	0.3126	PRE
saflufenacil + dimethenamid	Verdict	5.5EC	0.4733	PPL
sulfentrazone + carfentrazone	Spartan Charge	3.5L	0.2768	PPL
sulfentrazone + carfentrazone	Spartan Charge	3.5L	0.2768	PRE
pyroxasulfone	Zidua	85WDG	0.1250	PRE
acifluorfen	Ultra Blazer	2SL	0.5	POST
(acifluorfen + bentazon)	Ultra Blazer + Basagran	2SL; 4SL	0.25+0.5	POST
flumioxazin + chlorimuron	Valor XLT	40.3WDG	0.3126	PPL
flumioxazin + chlorimuron	Valor XLT	40.3WDG	0.3126	PRE
linuron	Linex	4L	0.7501	PRE
linuron	Linex	4L	1.5	PRE
metribuzin	Sencor	75DF	0.5	PRE
metribuzin + chlorimuron	Canopy	75DF	0.2233	PRE
S-metolachlor + sulfentrazone	Broadaxe	7EC	1.24 + 0.13	PRE

[a]Herbicide rate in lb ai/ac; Plus (+), = proprietary mixture; Parenthesis () = tank-mixed; PPL-applied 12 d before planting; PRE-applied 1 d after planting; POST = applied at 2-3 trifoliate of the edamame soybean.

Table 2. Efficacy and crop safety of herbicides for 'AVS-4002'edamame soybean, Vegetable Research Station, Kibler, Ark., 2014.

Herbicide Treatment[a]					Injury[d]			Yield[e]	
					21	7	14		
Trade name	Rate lb ai/ac	Timing	Plant height[b] in.	Stand[c] Plants/ac ×1000	----------%----------			Pod no./plant	Grain lb/ac
Weedy Check			26	162.0	--	--	--	138	625
Weed free			31	163.4	--	--	--	167	1883
Dual Magnum	1.00	PRE	30	93.4	0	--	0	206	1410
Prefix	1.24	PRE	30	119.4	0	--	0	219	1561
Spartan	0.1875	PRE	27	111.2	8	--	5	156	964
Spartan	0.3750	PRE	23	85.1	30	--	10	186	553
Prefix	1.39	POST	2	129.0	--	22	13	213	1445
Reflex	0.38	PRE	28	131.9	0	--	0	193	1740
Flexstar	0.38	POST	31	144.1	--	23	8	211	1517
Pursuit	0.06	POST	26	148.3	--	0	0	169	1499
Raptor + Basagran	0.047+0.5	POST	30	148.3	--	0	0	207	1642
Sharpen	0.0625	PRE	27	108.5	8	--	5	139	1097
Verdict	0.3126	PRE	28	115.3	7	--	5	187	1365
Verdict	0.4733	PPL	30	119.4	5	--	0	226	1552
Spartan Charge	0.2768	PPL	27	142.9	0	--	0	179	1160
Spartan Charge	0.2768	PRE	28	112.6	5	--	0	188	1410
Zidua	0.1250	PRE	29	118.1	5	--	5	280	1909
Ultra Blazer	0.5	POST	30	120.8	--	25	10	184	1677
Ultra Blazer + Bentazon	0.25+0.5	POST	28	124.9	--	13	2	173	1401
Valor XLT	0.3126	PPL	28	129.0	0	--	7	194	1758
Valor XLT	0.3126	PRE	27	122.2	5	--	5	247	1392
Linex	0.7501	PRE	29	126.3	0	--	0	218	1552
Linex	1.5	PRE	30	108.5	5	--	5	216	1231
Sencor	0.5	PRE	30	105.7	5	--	5	212	1615
Canopy	0.2233	PRE	31	82.4	5	--	5	221	1615
Broadaxe	1.37	PRE	28	108.5	8	--	5	211	1535
LSD $_{0.05}$[f]			NS	33.9	4	6	3	NS	607

[a] Plus (+) = tank-mixed; PPL = pre-plant applied 12 d before planting, 10 May 2014; PRE = pre-emergence applied 1 d after planting, 23 May 2014; POST = post-emergence application at 2-3 trifoliate leaf stage of edamame, 13 June 2014.
[b] Plant height = inches.
[c] Stand count = plants per acre.
[d] DAP = 21 days after planting; DAT = 7 d after POST treatments or 14 d after POST (= 35 DAP); dashes (--) = no data collected.
[e] lb = pounds per acre.
[f] Fisher's protected least significant difference test used to compare treatment means within each column; NS = not significant.

Table 3. Efficacy of soil-applied soybean herbicides, 21 d after planting, Vegetable Research Center, Kibler, Ark., 2014.

Herbicide Treatment[a]			Weed Control at 21 DAP[b]				
Trade name	**Rate lb ai/ac**	**Timing**	**RSGL**	**PA**	**BYG**	**Others**	**Overall**
			----------%----------				
Dual Magnum	1.00	PRE	100	100	100	100	100
Prefix	1.24	PRE	100	100	100	100	100
Spartan	0.1875	PRE	98	100	98	100	99
Spartan	0.3750	PRE	100	100	100	100	100
Prefix	1.39	POST	--	--	--	--	--
Reflex	0.38	PRE	100	100	100	100	100
Flexstar	0.38	POST	--	--	--	--	--
Pursuit	0.06	POST	--	--	--	--	--
Raptor + Basagran	0.047+0.5	POST	--	--	--	--	--
Sharpen	0.0625	PRE	82	98	93	97	92
Verdict	0.3126	PRE	93	100	100	100	99
Verdict	0.4733	PPL	97	87	98	98	95
Spartan Charge	0.2768	PPL	88	93	98	98	95
Spartan Charge	0.2768	PRE	95	100	98	100	98
Zidua	0.1250	PRE	100	100	100	100	100
Ultra Blazer	0.5	POST	--	--	--	--	--
Ultra Blazer + Bentazon	0.25+0.5	POST	--	--	--	--	--
Valor XLT	0.3126	PPL	100	100	100	100	100
Valor XLT	0.3126	PRE	100	100	100	100	100
Linex	0.7501	PRE	100	100	100	100	100
Linex	1.5	PRE	100	100	100	100	100
Sencor	0.5	PRE	100	100	100	100	100
Canopy	0.2233	PRE	100	100	100	100	100
Broadaxe	1.37	PRE	100	100	100	100	100
LSD[c]			6	6	2	NS	2

[a] Plus (+) = tank-mixed; PPL = pre-plant applied 12 d before planting, 10 May 2014; PRE = pre-emergence applied 1 d after planting, 23 May 2014; POST = post-emergence application at 2-3 trifoliate leaf stage of edamame, 13 June 2014.
[b] DAP = days after planting; Mean weed control: RSGL = red sprangleto, PA = Palmer Amaranth, BYG = barnyardgrass; Others = eclipta, goosegrass, carpetweed dashes (--) = no data collected from POST herbicide treatments.
[c] Fisher's protected least significant difference test used to compare treatment means within each column; NS = not significant.

Table 4. Efficacy of soil-applied soybean herbicides, 35 d after planting, Vegetable Research Center, Kibler, Ark., 2014

Herbicide treatment[a]			Weed control at 35 DAP[b]			
Trade name	**Rate lb ai/ac**	**Timing**	**RSGL**	**PA**	**Others**	**Overall**
			----------%----------			
Dual Magnum	1.00	PRE	98	97	98	98
Prefix	1.24	PRE	98	98	100	99
Spartan	0.1875	PRE	81	95	93	90
Spartan	0.3750	PRE	88	98	95	94
Prefix	1.39	POST	88	97	97	94
Reflex	0.38	PRE	91	97	95	94
Flexstar	0.38	POST	82	93	93	89
Pursuit	0.06	POST	92	93	95	93
Raptor + Basagran	0.047+0.5	POST	90	88	92	90
Sharpen	0.0625	PRE	63	92	95	83
Verdict	0.3126	PRE	83	88	90	87
Verdict	0.4733	PPL	93	82	92	89
Spartan Charge	0.2768	PPL	85	92	92	89
Spartan Charge	0.2768	PRE	85	95	95	92
Zidua	0.1250	PRE	100	100	100	100
Ultra Blazer	0.5	POST	90	95	93	93
Ultra Blazer + Bentazon	0.25+0.5	POST	85	95	95	92
Valor XLT	0.3126	PPL	97	98	93	98
Valor XLT	0.3126	PRE	100	100	100	100
Linex	0.7501	PRE	85	90	95	90
Linex	1.5	PRE	90	95	93	93
Sencor	0.5	PRE	92	93	93	93
Canopy	0.2233	PRE	100	100	100	100
Broadaxe	1.37	PRE	100	100	100	100
LSD[c]			8	5	4	4

[a] Plus (+) = tank-mixed; PPL = pre-plant applied 12 d before planting, 10 May 2014; PRE = pre-emergence applied 1 d after planting, 23 May 2014; POST = post-emergence application at 2-3 trifoliate leaf stage of edamame, 13 June 2014

[b] DAP = days after planting; RSGL = red sprangletop, PA = Palmer Amaranth.

[c] Fisher's protected least significant difference test used to compare treatment means within each column.

Differential Tolerance of Palmer Amaranth to Sublethal Doses of Dicamba and Fomesafen

R.A. Salas[1], S. Singh[1], and N.R. Burgos[1]

ABSTRACT

Palmer amaranth is one of the most problematic weeds in field crops in the southern U.S. The occurrence of glyphosate-resistant Palmer amaranth has prompted a shift in weed management strategies. Fomesafen is an alternative tool for controlling glyphosate-resistant pigweeds. Commercialization of Dicamba-tolerant crops will expand the crop acres sprayed with dicamba. This research was conducted to examine the differential response to sublethal doses of dicamba and fomesafen in 35 *Amaranthus* populations from Arkansas. Whole-plant bioassays were conducted in the greenhouse. One-hundred plants were grown in cellular trays, at 1 plant/cell, and sprayed with 0.25 lb ae/acre dicamba or 0.12 lb ai/acre fomesafen when seedlings were three- to four-inches tall. All populations were controlled 84% to 100% with dicamba; the survivors showed 61% to 95% injury. Plant mortality and injury of the fomesafen survivors were variable, ranging from 59% to 100% and 30% to 95%, respectively. Within a population, injury levels ranged from 30% to 100%. Populations treated with fomesafen differentiated into two groups, with one group showing the lowest control and most variable response to fomesafen. The other group showed higher mortality with survivors showing >80% injury. Inadvertent exposure to sublethal doses of herbicides can occur in the field due to a combination of several factors. This study showed that 5 populations were harder to kill with sublethal doses than others. This highlights the value of implementing season-long, integrated weed management programs.

INTRODUCTION

Palmer amaranth (*Amaranthus palmeri* S. Watson) is one of the most common, troublesome, and economically damaging weeds in the U.S. In soybean, densities of 8 Palmer amaranth plants/m^2 can reduce crop yield by 78% (Bensch et al., 2003). The widespread occurrence of glyphosate-resistant Palmer amaranth has prompted a shift in weed management strategies. Currently, fomesafen is a major tool used to control glyphosate-resistant Palmer amaranth. With the upcoming dicamba-tolerant soybean technology, dicamba will soon be used to control broadleaf weeds in soybean. This study is conducted to investigate the differential response of *Amaranthus* populations from Arkansas to sublethal doses of dicamba and fomesafen herbicides.

PROCEDURE

Whole-plant bioassays were conducted in the greenhouse using samples collected between 2008 and 2013. The experiment was conducted in a randomized complete block design with two replications. Each replication consisted of 1 tray with 50 seedlings. Seeds of 10 to 20 plants per field (each field is considered one population) were tested. Composite seed sample from each population was used for the bioassays. From each composite seed sample, 100 seedlings were grown in cellular trays at 1 plant/cell. Populations were treated with 0.5× of the recommended doses equivalent to 0.25 lb ae/acre dicamba and 0.12 lb ai/acre fomesafen when the seedlings were three- to four-inches tall. Thirty-three Palmer amaranth and two tall waterhemp populations were treated with dicamba. Sixteen Palmer amaranth populations were sprayed with fomesafen. Herbicide treatments were applied using a laboratory sprayer equipped with a flat-fan nozzle delivering 20 gallons per acre at 46 psi. Injury and mortality were recorded 21 days after treatment. The overall effects of the herbicide were visually assessed relative to the nontreated control, using a scale of 0 (no visible injury) to 100 (complete desiccation). Data was analyzed using JMP Pro v. 11 (SAS Institute, Inc., Cary, N.C.). Hierarchal clustering was done using injury and mortality data.

RESULTS AND DISCUSSION

Differential Response to Low Dose of Dicamba. All thirty-five *Amaranthus* populations were controlled 84% to 100% with dicamba (Table 1). Mortality and injury differed within and among populations. Most of the survivors showed >80% injury but a few individuals (up to 9 in some populations) showed lesser injury (61-80%). Some of these least injured plants were able to grow healthy up to reproductive stage. The populations differentiated into 3 clusters based on mortality and levels of injury of the survivors (Fig. 1 and Table 1). The first cluster, consisted of 22 populations, showed ≥94% mortality with the least number of survivors that were injured >80%. These populations were highly sensitive. The second cluster, composed of 10 populations, showed 84% to 93% control with higher frequency of survivors, but were also injured >80%. These populations were less sensitive but these survivors are not likely to reproduce. The third cluster had three populations with 91% to 94% mortality, but

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had 8 survivors that were less injured (61% to 80%) than those in the other clusters. These few survivors are more likely to reproduce. The two tall waterhemp populations were sensitive. Dicamba at 0.25 lb ae/acre left few survivors that are likely to reproduce. Even so, control measures need to be implemented to prevent these survivors from producing seeds and replenishing the seedbank with increasing numbers of tolerant plants and eventually selecting for a resistant biotype (Botha, 2012).

Differential Response to Sublethal Dose of Fomesafen. It is expected that a sublethal dose of any herbicide will reveal recalcitrant populations that are more likely to have escapes under suboptimal field conditions. Five populations (≤80% mortality) were harder to kill with sublethal doses of fomesafen than others (Table 2). The frequency of survivors from a sublethal dose of fomesafen ranged from 59% to 100%. The survivors also showed a wide range of injury, from 30% to 95%. Within a population, injury levels varied from 30% to 100%. In the greenhouse, survivors with 70% injury were still able to reproduce. Fifteen survivors (≤70% injury) are likely to produce seed. The populations differentiated into 2 clusters, largely according to mortality and level of injury of survivors (Fig. 2 and Table 3). Cluster one, which is composed of 3 populations, had the lowest control and most variable response to fomesafen (30-95% injury). These are recalcitrant populations. The second cluster, comprised of 13 populations, showed higher mortality with survivors showing >80% injury and were healthy enough to produce seeds. These populations are very sensitive to fomesafen. While it has been reported by Patzoldt et al. (2002) that a full dose of fomesafen showed consistent superior *Amaranthus* control; the problem starts when some individual plants in the field receive a sublethal dose and produce seed. Herbicide use at sublethal dose allows the selection of minor gene(s) that minimize herbicide injury and thus endow plant survival. However, the use of recommended dose may eliminate plants possessing those weakly endowing resistance gene traits. Recurrent exposure to sublethal dose of herbicide especially in a cross-pollinated species like Palmer amaranth increases the risk of accumulation of minor genes traits leading to herbicide resistance (Norsworthy, 2012; Busi et al., 2013; Vila-Aiub and Ghersa, 2005).

PRACTICAL APPLICATIONS

A few *Amaranthus* populations from Arkansas show a higher risk for escapes and, by extension, selection of tolerant plants. This underscores the importance of monitoring for survivors and implementing holistic weed management programs so that not any one tool is at risk of becoming ineffective.

ACKNOWLEDGMENTS

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Table 1. Population cluster analysis of *Amarathus* populations tested with 0.25 lb ae/ac dicamba.

		Mortality (%)			Mean frequency of survivors				
Cluster	**No. of Populations**	**Mean**	**Min**	**Max**	**0-10% Injury**	**11-30% Injury**	**31-60% Injury**	**61-80% Injury**	**81-99% Injury**
1	22	98	94	100	0	0	0	0	4
2	10	89	84	93	0	0	0	1	22
3	3	92	91	94	0	0	0	8	15

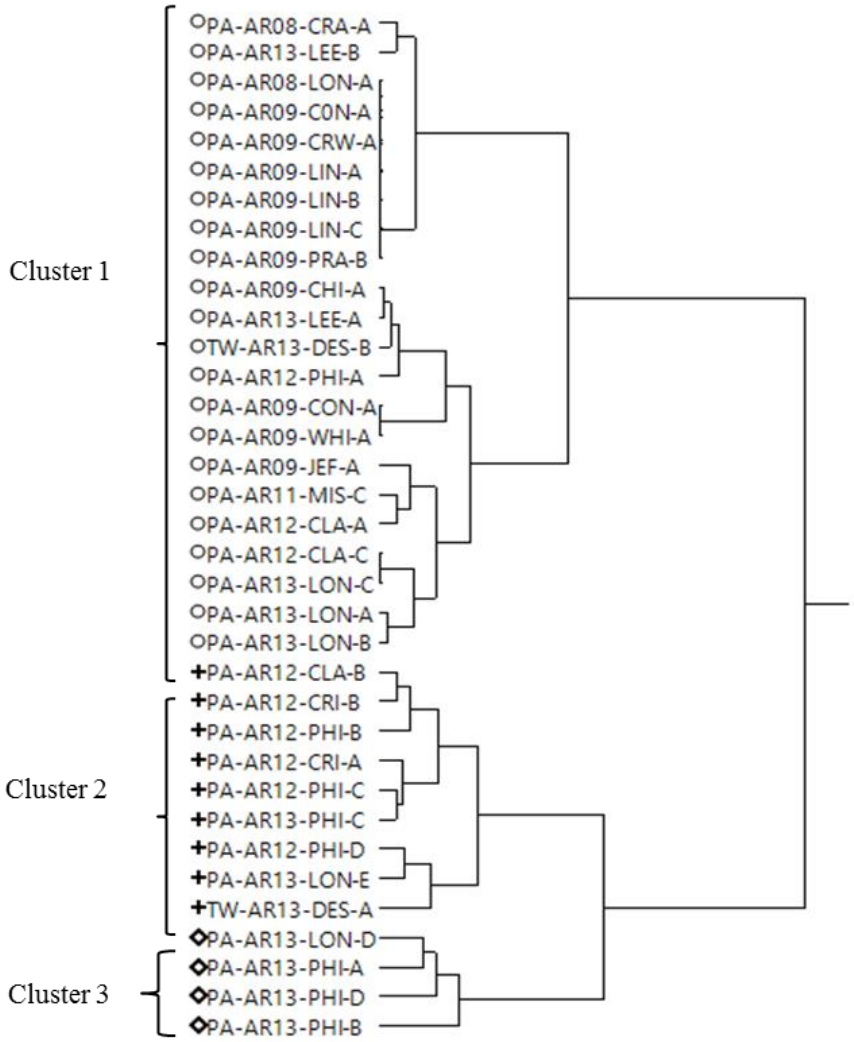

Fig. 1. Hierarchal cluster analysis of *Amaranthus* populations tested with 0.25 lb ae/ac dicamba.

Table 2. Differential response to 0.12 lb ai/acre fomesafen in Palmer amaranth populations from Arkansas.

			Frequency of the survivors			
Population	**Mortality (%)**	**Minimum Injury (%)**	**11-30% Injury**	**31-60% Injury**	**61-80% Injury**	**81-99% Injury**
PA-AR08-CRA-A	87	80	0	0	2	11
PA-AR08-CRA-B	94	80	0	0	1	5
PA-AR08-CRI-A	96	80	0	0	1	3
PA-AR08-CRW-B	87	90	0	0	0	13
PA-AR08-JAC-A	85	60	0	1	8	6
PA-AR08-LON-A	94	95	0	0	0	6
PA-AR08-MIS-A	89	80	0	0	1	10
PA-AR09-CON-A	92	80	0	0	2	6
PA-AR09-CRW-A	100	100	0	0	0	0
PA-AR09-JEF-B	80	75	0	0	7	13
PA-AR09-WHI-A	99	80	0	0	1	0
PA-AR12-CLA-A	59	30	1	0	12	28
PA-AR12-CLA-B	67	80	0	0	1	32
PA-AR12-CRI-A	50	60	0	1	13	36
PA-AR12-CRI-B	96	90	0	0	0	4
PA-AR12-PHI-A	70	85	0	0	0	30
LSD	9	-	-	-	-	-

Table 3. Population cluster analysis of Palmer amaranth populations tested with 0.12 lb ai/acre fomesafen.

		Mortality (%)			Mean frequency of survivors				
Cluster	**No. of populations**	**Mean**	**Min**	**Max**	**0-10% Injury**	**11-30% Injury**	**31-60% Injury**	**61-80% Injury**	**81-99% Injury**
1	3	65	50	85	0	1	1	11	23
2	13	86	67	100	0	0	0	0	10

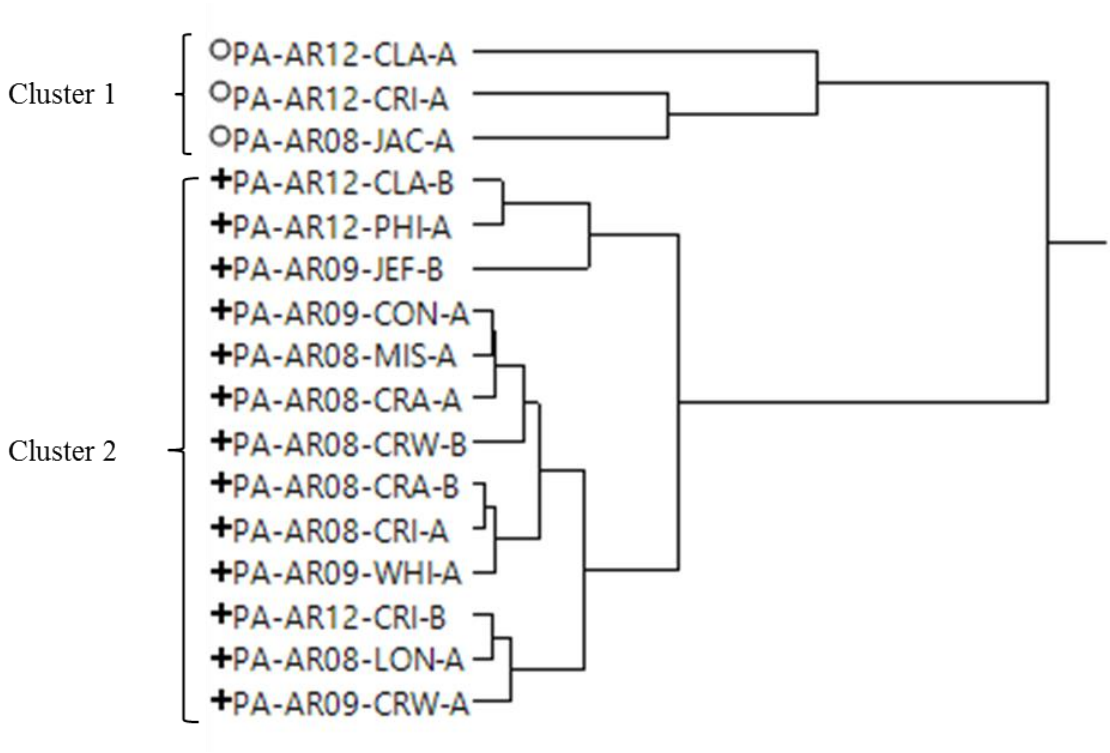

Fig. 2. Hierarchal cluster analysis of Palmer amaranth population tested with 0.12 lb ai/ac fomesafen.

Fall Management Practices and Herbicide Programs for Controlling *Palmer amaranth* Population and Seed Production in Soybean

N.E. Korres[1], J.K. Norsworthy[1], and R.C. Scott[2]

ABSTRACT

A large-plot field experiment was conducted at Keiser, Ark. from fall of 2010 through spring of 2014 to understand to what extent fall management practices after soybean harvest (i.e., spreading or incorporating crop residues into the soil, use of cover crops, windrowing and/or not burning, and removing crop residues) and herbicide programs (i.e., use of post-emergence (POST)-only (Roundup® -only) or pre-emergence (PRE) followed by POST (Roundup or Liberty®) + residual herbicides in soybean) would impact Palmer amaranth density, seed production, and soil seedbank over three growing seasons. Significant differences were observed between fall management practices on Palmer amaranth populations for each year. The incorporation of crop residues into the soil during the formation of beds in the fall, the use of cover crops, and residue windrowing and burning were the most effective practices in lessening the Palmer amaranth population. On the contrary, the effects of fall management practices on Palmer amaranth seed production were not consistent among years. The inclusion of a PRE herbicide application into the herbicide program showed significant reductions on Palmer amaranth density and subsequent seed production each year compared to the Roundup-only program, and the Liberty-containing residual program was superior to the Roundup-containing program in reducing Palmer amaranth seed production and the number of Palmer amaranth plants that emerged in the spring from the soil seedbank. This study demonstrated that crop residue management such as chaff removal from the combine, narrow-windrow burning, or the use of cover crops in combination with an effective PRE + POST residual herbicide program is important for optimizing in-season management of Palmer amaranth. Reducing the soil seedbank has a profound impact on lessening the risk for herbicide resistance and the consistency and effectiveness of future weed management efforts.

INTRODUCTION

Palmer amaranth (*Amaranthus palmeri* S. Wats) is one of the most problematic weeds in soybean, cotton, and corn in southern U.S. causing substantial yield losses when not adequately controlled (Massinga et al., 2001; Morgan et al., 2001; Riar et al., 2013). Its high seed production and easy dispersal allow populations to spread across vast acres and quickly overtake most crops and overpower most herbicides through sheer numbers such as glyphosate, pendimethalin and fluometuron due to its high proliferation and number of seeds in the soil seedbank (Norsworthy et al., 2014; Sparks et al., 2003).

Crop residue management has been reported to be an effective preventive control method in reducing inputs into the soil seedbank (Norsworthy et al., 2012). The effects of windrowed crop residue burning or chaff removal on ryegrass and wild radish or wild oat on seed reduction respectively were demonstrated by Walsh and Newman (2007) and Shirtliffe and Entz (2005).

The evolution of herbicide resistance in Palmer amaranth in combination with its substantial yield reductions in soybean necessitates a more united approach to Palmer amaranth control methods. Use of diversified methods that target the weed seed prevents the input of resistant seeds into the seedbank; whereas the use of pre-emergence (PRE) and post-emergence (POST) herbicides can reduce significantly its current and future population and subsequent seed production. The objective of this work was to examine the effects of various fall management practices and herbicide programs in soybean on Palmer amaranth population and seed production.

PROCEDURES

A split-plot experiment in a randomized complete block design with three replications was conducted at Keiser, Ark. from fall of 2010 through spring of 2014. Main plot treatments consisted of six soybean residue management practices; whereas subplot treatments consisted of three herbicide programs. A straw spreader was attached to the combine in the first and second residue management practice (Fall 1 and 2, respectively). In Fall 1, crop residues were spread across the plot but not bedded; whereas in Fall 2, crop residues were incorporated into the soil as beds were reformed in the fall. In the third management practice (Fall 3), a straw spreader was attached to a combine and a winter rye cover crop was used prior to soybean planting. The straw chopper was removed in the fourth and fifth practices (Fall 4 and 5) and the residues were windrowed but were burned only in the fifth. Finally, in the sixth fall management practice (Fall 6), the straw and chaff were collected in a cart attached to the combine and removed from the field.

The subplot herbicide treatments consisted of Roundup PowerMax® (hereafter Roundup) applied at V2 and V7 soybean growth stages at 22 fl oz/ac (Herb 1); a PRE application of Valor® at 2 oz/ac followed by (fb) Roundup at 22 fl oz/ac + Prefix® at 32 fl oz/ac (V2) fb Roundup at 22 fl oz/ac (V7) (Herb 2). The third herbicide program (Herb3) was similar to the second with

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Liberty® at 29 fl oz/ac substituting for Roundup. Palmer amaranth density was recorded prior to harvesting and expressed as plants/m^2. Six female mature plants per plot were randomly selected and harvested for the determination of Palmer amaranth seed production as described by Sellers et al. (2003). A mixed model using JMP 11.2 PRO (SAS Institute, Cary, N.C.) was fitted on the seed counts which were Box-Cox transformed to ensure that the usual regression assumptions of normality and homogeneity are satisfied. Data of Palmer amaranth population were transformed based on natural logarithms and the same model was applied for their analysis. However, the original and transformed data analyses gave similar results, thus non-transformed Palmer amaranth population data are presented.

RESULTS AND DISCUSSION

Significant differences were observed between fall management practices on Palmer amaranth population for each year with Fall 3, Fall 5, and Fall 6 management practices being most effective in lessening the Palmer amaranth population. On the contrary, the effects of residue management on Palmer amaranth seed production were not consistent among years (results not shown). The inclusion of a PRE herbicide application into the herbicide program showed significant reductions on Palmer amaranth and subsequent seed production each year compared to the Roundup-only program (Fig. 1). The presence of Liberty strengthened the herbicidal control on both Palmer amaranth population and seed production. The incorporation of PRE fb POST residual herbicide application significantly reduced Palmer amaranth population and seed production compared to the Roundup-only program in all crop residue programs investigated. This study demonstrated that crop residue management such as chaff removal from the combine, the use of cover crops, or burning windrowed crop residues in combination with an effective PRE+POST residual herbicide program is an important management tool in reducing the Palmer amaranth population and seed production (Tables 1 and 2) and subsequently soil seedbank.

PRACTICAL APPLICATIONS

Fall management practices are a useful preventive tool against weeds. Farmers should broaden and diversify their weed control options by incorporating harvest weed seed control strategies that target Palmer amaranth escapes at crop harvest or integrating a fall planted cover crop into their current production systems, ultimately reducing the soil seedbank and the risk for new cases of herbicide resistance developing. This research also points to the strength of the Liberty-based weed control program on glyphosate-resistant Palmer amaranth and the fact that integration with a strategy such as narrow-windrow burning will go a long way towards driving the soil's seedbank towards extinction. Use of narrow-windrow burning in soybean is a cheap and efficient means of protecting against further development of herbicide resistance.

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Table 1. Effects of fall management practices × herbicide program on Palmer amaranth density at soybean harvest.[a]

	Palmer amaranth density (plants m^{-2})								
	2011			**2012**			**2013**		
	Herb 1	**Herb 2**	**Herb 3**	**Herb 1**	**Herb 2**	**Herb 3**	**Herb 1**	**Herb 2**	**Herb 3**
Fall 1	25	0.9	0.02	43	0.4	0.02	34	0.5	0.01
Fall 2	12	0.2	0.05	19	0.2	0.01	29	0.5	0.03
Fall 3	18	0.4	0.01	25	0.2	0.03	14	0.3	0.03
Fall 4	10	0.2	0.01	39	0.2	0	45	0.3	0.01
Fall 5	7	0.2	0.02	27	0.1	0.01	36	0.3	0
Fall 6	8	0.1	0.01	13	0.2	0	20	0.5	0.01
SEM[b]	1.03			2.38			2.31		

[a] The fall management practices listed here (Fall 1 – Fall 6) and the herbicide programs (Herb 1 – Herb 3) are described in the Procedures.
[b] SEM = Standard error of the mean at 5% significance level.

Table 2. Effects of fall management practices × herbicide program on Palmer amaranth seed production.[a]

	Palmer amaranth seed production (seeds/m^2)								
	2011			**2012**			**2013**		
	Herb 1	**Herb 2**	**Herb 3**	**Herb 1**	**Herb 2**	**Herb 3**	**Herb 1**	**Herb2**	**Herb 3**
Fall 1	407,000	2,800	5.5	189,000	978	1	101,000	515	1
Fall 2	199,000	15,444	10.8	149,000	359	9	150,000	8,480	73.8
Fall 3	300,000	6,010	2.2	65,000	307	1	31,500	131	1
Fall 4	167,000	3,420	6.8	466,000	459	0	14,100	4,180	8.3
Fall 5	104,000	2,512	11.2	101,000	473	1	20,900	4,140	0
Fall 6	122,000	1,850	5.8	126,000	481	0	14,100	989	1.8
SEM[b]	0.43			0.39			0.49		

[a] The fall management practices listed here (Fall 1 – Fall 6) and the herbicide programs (Herb 1 – Herb 3) are described in the Procedures.
[b] SEM=Standard error of the mean at 5% significance level.

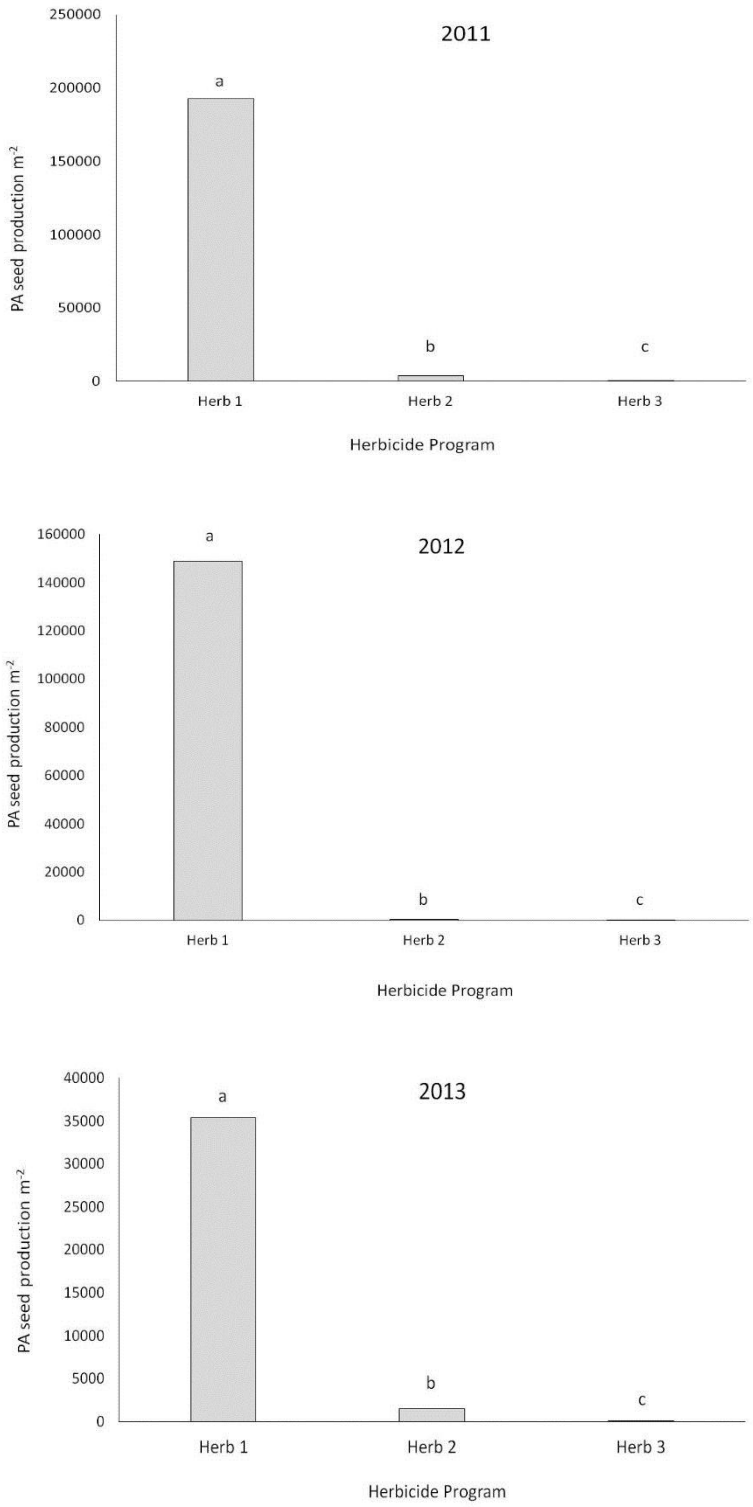

Fig. 1. Effects of herbicide program on Palmer amaranth seed production from 2011 to 2013 averaged over fall management practices. Columns with different numbers are statistically different at 5% significance level. Each herbicide program is fully described in the Procedures.

Narrow-Windrow Burning of Soybean Chaff in an Effort to Decrease the Return of Weed Seed to the Soil Seedbank

J.K. Green[1], J.K. Norsworthy[1], and R.C. Scott[2]

ABSTRACT

The ongoing issue of herbicide-resistance is making a large impact on current weed management practices. In Australia, harvest weed seed control techniques are in practice today as a result of widespread resistance to herbicides. An experiment was conducted in 2014 at the Northeast Research and Extension Center in Keiser, Ark.to determine the relationship between heat intensity in narrow-windrow burning of soybean residue as a function of soybean biomass or yield potential. Temperatures at the soil surface in the windrow were recorded every second over the duration of the burn. Additionally, seeds of Palmer amaranth, barnyardgrass, johnsongrass, and pitted morningglory were placed at the soil surface inside the narrow windrows in 5-cm diameter tins to also evaluate the effectiveness of burning in relation to weed seed survival. At twenty-five sample sites, temperatures during the burn reached more than 300 °C and duration of burns were greater than those reported previously for wheat in Australia. For Palmer amaranth, barnyardgrass, and johnsongrass, all seeds were converted to ash; whereas remnants of pitted morningglory seeds remained intact; albeit, none germinated or were viable. As a result of the effectiveness of narrow-windrow burning on these weeds and the fact that narrow-windrow will not slow harvest efforts, greater use of this practice is needed in soybean to reduce return of weed seed to the soil seedbank and ultimately the risk of herbicide resistance developing to herbicides that are currently effective.

INTRODUCTION

Even with the importance of soybean production today, weed management still remains a challenge. Herbicide-resistance is becoming a larger phenomenon with every passing year. Currently, the most troublesome weeds for soybean in Arkansas are Palmer amaranth, morningglory spp., barnyardgrass, horseweed, hemp sesbania, sicklepod, and prickly sida (Riar et al., 2013). Palmer amaranth is most widely known for its ability to rapidly evolve resistance to herbicides. Glyphosate and acetolactate synthase resistance in Palmer amaranth is widespread in Arkansas and several of the aforementioned weeds also exhibit resistance to glyphosate and other herbicide and/or are difficult to control in current production systems.

At the crux of herbicide resistance management is the need to prevent weed seed return to the soil seedbank and the need to diversify current weed control tactics (Norsworthy et al., 2012) In Australia, producers routinely use harvest weed seed control (HWSC) including narrow-windrow burning, chaff carts, a bale-direct system, and the Harrington Seed Destructor as means of reducing seed returns to the soil seedbank. Of these strategies, narrow-windrow burning is the cheapest to implement and does not slow crop harvesting process; hence, it is likely the most suitable strategy for adoption by Arkansas soybean producers today. For this reason, research was initiated to understand the effectiveness of narrow-windrow burning in killing weed seed from an array of weed species in commercial soybean production.

PROCEDURES

A field experiment was conducted at the University of Arkansas Northeast Research and Extension Center in Keiser, Ark. in 2014. This experiment took place in a production field of soybean grown under furrow irrigated conditions. Five 2-m rows of soybeans were hand harvested to determine the yield potential and amount of biomass available for burning in the field. Different amounts of soybean biomass were crucial to this experiment. In order to achieve different amounts of soybean biomass, the swath harvested with the combine was varied from 5 to 10 soybean rows with each pass of the combine. The five rows simulated a low-yielding environment whereas the 10 rows mimicked a normal yield for irrigated, high-yielding soybean. Additionally, chaff biomass was collected from a 1-m row near where each burn occurred.

One-hundred seeds of Palmer amaranth, barnyardgrass, johnsongrass, and pitted morningglory were placed on the soil surface beneath the narrow-windrow in separate aluminum tins (5-cm diameter). The samples were buried within the row of chaff and chaff was thoroughly mixed with weed seed in the tins. The temperature at the location of the weed seed was recorded every second throughout the burn. Heat intensity was calculated by subtracting the ambient temperature from each recorded temperature and summing the number of degrees above ambient. After burning, germination and viability of remaining seed, including seed remnants, were assessed.

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Using a varying swath width for the header, we were able to evaluate the effectiveness of narrow-windrow burning in a simulated low-yielding (30 bu/A) and high-yielding (60 bu/A) environment. For the twenty-five sampling locations for which temperature and effectiveness of the burns were assessed, most sampling sites reached temperatures in excess of 300 °C. A temperature of 200 °C was maintained for more than 5 minutes in most of the burns. A graph depicting temperatures over the duration of a typical burn of weed-laced soybean chaff in narrow windrows is shown in Fig. 1. All seeds of Palmer amaranth, barnyardgrass, johnsongrass, and pitted morningglory were killed with narrow-windrow burning, regardless of the biomass amount present. Heat indices from the narrow-windrows were 10- to 15-fold greater than those found by Walsh et al. (2007) in Australia for wheat chaff. This difference in heat indices may be attributed to better air circulation in wheat chaff, and hence, a quicker burn (shorter burn) or lower moisture content of the wheat chaff relative to soybean chaff which could impact the duration of the burn. A linear regression analysis was conducted on the relationship between heat indices and biomass and a linear relationship was found (Fig. 2). Based on these results, heat indices should increase as the amount of biomass available for burning increases or ultimately as soybean yield potential increases. The amount of biomass available for burning is most likely related to yield potential since harvest index in soybean is somewhat stable across most varieties and yield environments.

PRACTICAL APPLICATIONS

The chute used for this research was constructed in less than 2 hours and cost approximately $200 in materials. The opening in the chute was 16 inches which was sufficient for forming narrow-windrows in soybean without negatively impacting harvest speed in a high-yielding environment (60 bu/A). Based on the fact that previous research has shown that more than 99% of seed are retained by Palmer amaranth plants through soybean maturity and likely enter the harvester (Norsworthy et al., 2014), this research provides further evidence that producers should be able to easily integrate narrow-windrow burning into current U.S. soybean production as a means of diversifying weed management practices and reducing the number of weeds existing in the subsequent cropping cycle. As a result of narrow-windrow burning reducing the number of viable weed seed entering the soil seedbank, it is our belief that the likelihood for herbicide resistance to develop on farms where this tactic is employed with effective herbicides is much lower than what is currently being experienced in soybean systems where herbicides alone are the means of weed control.

ACKNOWLEDGMENTS

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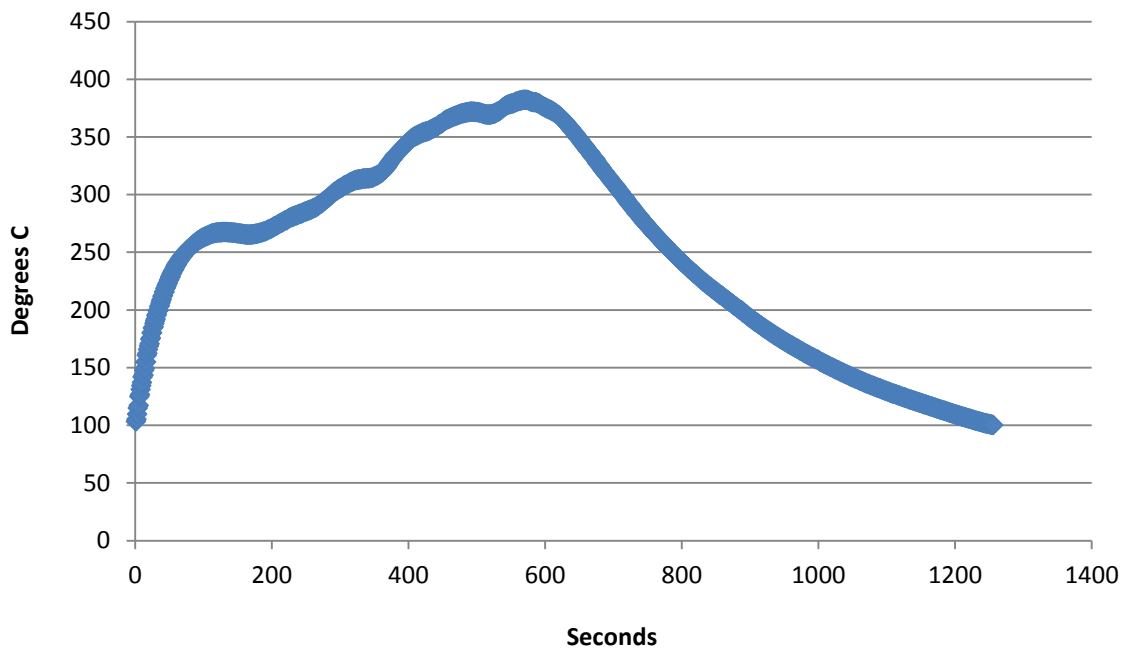

Fig. 1. Typical burn of soybean chaff in narrow-windrow burning.

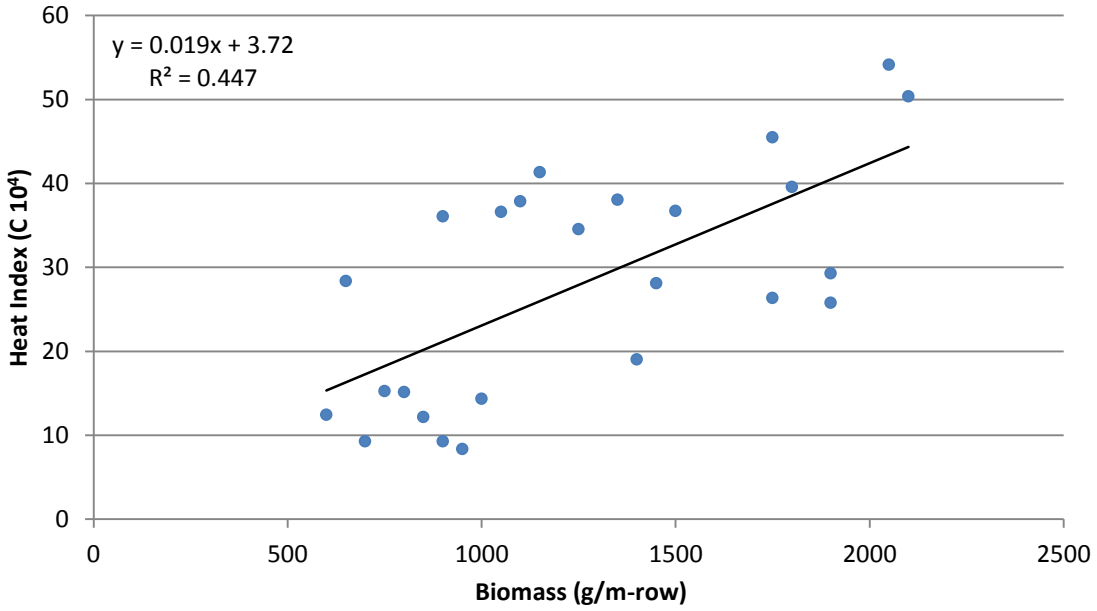

Fig. 2. Relationship between soybean biomass and heat index.

Effect of Soybean Seed Insecticide Treatment on Soybean Tolerance to Herbicides

R.C. Scott[1], W.J. Ross[1], J.K. Norsworthy[2] and T. Barber[1]

ABSTRACT

A trial was conducted in the summer of 2014 to evaluate the effect of a soybean insecticide seed treatment (Cruiser Maxx®) on sensitivity of conventional soybean to various labeled and non-labeled herbicides. Residual treatments all injured soybean < 6% when evaluated 10 days after emergence. Soybean seed treatment did not appear to have any "safening" effect on these herbicides, which included: metribuzin, Dual®, Zidua®, Valor®, and combinations of Valor with Dual and Zidua. Of all the post herbicides evaluated, only slightly less injury was observed on treated versus untreated soybean when a low rate of Liberty® herbicide was applied. Injury from 4 oz. of Liberty was reduced from 45% to 30% and from 30% to 15% with 2 oz. of Liberty per acre. Post injury ranged from 0% to 80% from herbicides including: Roundup®, Permit®, Liberty, dicamba, and 2,4-D at two low rates each. Although injury from some treatments lingered for the rest of the season, no other differences were observed at later timings. This trial was not taken to yield and at no time was any actual injury observed from insects.

INTRODUCTION

The benefits of a seed insecticide treatment in rice have been well documented (Taillon et al., 2014). However less conclusive work has been conducted in soybean. In recent research in rice, the use of a seed insecticide treatment, Cruiser Maxx Rice® and NipSit® Inside, was shown to improve the ability of conventional rice to withstand low rates of the herbicides glyphosate and imazethapyr when applied to 2- to 3-leaf rice (Scott et al., 2014). The effect of drift from these two products to conventional rice can be severe and is well documented (Davis et al., 2011, and Hensley et al., 2012). In that research, insecticide treated rice plants were able to recover from and tolerate these herbicides significantly better than seed treated with only the fungicide components of the various treatments.

Due to the need for pigweed control, many herbicides from a wide range of chemical classes are being used both pre-emergence (PRE) and post-emergence (POST) in soybean for weed control. Many of these herbicides are known to cause crop response under certain conditions. This certainly includes the protoporphyrinogen oxidase (PPO) inhibitors such as: Valor®, Sharpen® and Flexstar®. Injury to soybean can be more severe when these herbicides are tank-mixed with chloroacetamide herbicides such as Dual®. In addition, drift of glyphosate to Liberty Link® soybean and the reverse can also cause injury. Many soybean varieties are non-sulfonylurea-tolerant soybean (STS). Therefore herbicides like Leadoff®, Classic® and Canopy® can result in injury as well as drift of acetolactate synthase (ALS)-inhibiting herbicides not labeled for soybean from adjacent rice and corn crops. For example, Permit® drift to soybean is fairly common.

With this in mind, a study was conducted at the Newport Extension Center, Newport, Ark., to evaluate whether the use of the soybean seed insecticide treatment Cruiser Maxx® could prevent or lessen (safen) the effects of these herbicides on soybean.

PROCEDURES

A field experiment was conducted in the summer of 2014 near Newport, Ark. to evaluate the effect of a soybean insecticide seed treatment, Cruiser Maxx, on herbicide injury to conventional soybean. The conventional soybean variety Ozark was planted on 17 July 2014 in plots measuring 7.5 × 20 feet in size. In each plot, half the drill rows were treated with Cruiser Maxx at 7 oz/cwt, and the other half were treated with only the fungicide portion of that treatment. Seeding rate was 125,000 seeds per acre. Seed were planted to a depth of 0.5 inches. Soil temperature at the time of planting and application of the PRE treatments was 62 °F.

Herbicide treatments consisted of metribuzin (0.671 lb/ac), Dual Magnum (2.0 pints/ac), Zidua (3.5 oz/ac), and Valor applied alone at 2.0 oz/ac or in a tank mix with Zidua and Dual Magnum applied PRE. Post-emergence treatments included Roundup PowerMax (2 and 4 oz/ac), Liberty (2 and 4 oz/ac), dicamba (0.25 and 0.5 oz/ac), 2,4-D (0.75 and 1.5 oz/ac) and Permit at 0.5 and 1.0 oz/ac applied at the third trifoliate stage (V3). Herbicides were applied with a 4-nozzle boom calibrated to deliver 15 GPA using CO_2 as a propellant.

Plots were visually rated for herbicide injury at 10 days after emergence and at 35 days after application of the POST treatments. The rating scale was 0 to 100 where 0 = no injury and 100 = complete death or desiccation of the plant. Means were separated using Fisher's Protected least significant difference test (0.05).

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RESULTS AND DISCUSSION

Residual treatments all injured soybean < 6% when evaluated 10 days after emergence (Table 1). Soybean seed treatment did not appear to have any "safening" effect on these herbicides, which included: metribuzin, Dual, Zidua, Valor, and combinations of Valor with Dual and Zidua; although injury for all these treatments was lower than what is observed from time to time in the field.

Of all the post herbicides evaluated, only slightly less injury was observed on treated versus untreated soybean when a low rate of Liberty herbicide was applied. Injury from 4 oz. of Liberty was reduced from 45% to 30% and from 30% to 15% with 2 oz. of Liberty per acre (Table 2). Post injury ranged from 0 to 80% from herbicides including: Roundup, Permit, Liberty, dicamba, and 2,4-D at two low rates each. There were no differences in rates applied POST for each herbicide with the exception of the Liberty treatments. Although injury from some treatments lingered for the rest of the season, no other differences were observed at later timings. This trial was not taken to yield and at no time was any actual injury observed from insects.

PRACTICAL APPLICATIONS

In rice, seed insecticide treatments have been proven to reduce the effects of drift of certain herbicides and hasten recovery time to injury. This effect, while not 100% effective, does make management of drift and herbicide injury easier in some situations. This soybean trial will be repeated in 2015. It is worth noting that only after a number of trials were conducted in rice did the advantages to a rice seed insecticide treatment fully come to light. Since very little pre-emergence injury was observed to begin with, an effort will be made to increase injury from PRE applied herbicides next year. Although little "safening" effect was observed with the POST treatments, the fact that Liberty was less injurious to treated soybean will be further investigated.

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Table 1. Response of Ozark conventional soybean to various pre-emergence treatments.

		Soybean Injury (%) at 10 and 35 DAT			
Herbicide	**Rate**	**10 DAT**	**10 DAT (T)[a]**	**35 DAT**	**35 DAT (T)**
Metribuzin	0.671 lb/A	0	0	0	0
Dual Magnum	2.0 pts/A	0	0	0	0
Zidua	3.5 oz/A	4	3	0	0
Valor	2.0 oz/A	4	4	0	0
Zidua+Valor	3.5+2.0 oz/A	6	6	0	0
Dual+Valor	2.0pt+2.0 oz/A	3	3	0	0
LSD $_{0.05}$	-	NSD		NSD	

[a] Abbreviations used: (DAT) = days after treatment. (T) = treated soybean. (LSD) = least significant difference test. (NSD) = no significant difference.

Table 2. Response of Ozark conventional soybean to various post-emergence treatments applied at third trifoliate and averaged across two rates, except for the Liberty treatments.

	Soybean Injury (%) at 10 and 35 DAT			
Herbicide	**10 DAT**	**10 DAT (T)[a]**	**35 DAT**	**35 DAT (T)**
Liberty 4oz/A	45	30	4	2
Liberty 2oz/A	30	15	3	2
Roundup	15	15	5	5
Dicamba	60	60	30	30
2,4-D	15	15	5	5
Permit	70	70	40	40
$LSD_{0.05}$	14		NSD	

[a] Abbreviations used: (DAT) = days after treatment. (T) = treated soybean. (LSD) = least significant difference test. (NSD) = no significant difference.

Roundup Ready® Herbicide Systems in Arkansas Soybean (*Glycine max*)

R.C. Doherty[1], L.T. Barber[2] L.M. Collie[2], A.W. Ross[2], and R.C. Scott[2]

ABSTRACT

Soybean growers in Arkansas still struggle to gain complete control of glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) and other weeds in Roundup Ready soybean. Roundup Ready programs must contain overlapping residual herbicides used throughout the growing season. The application timing of the residual herbicides in the system can influence season-long weed control. The objective of this research was to determine the herbicide systems that would provide optimum season-long weed control and optimum yield in Arkansas Roundup Ready soybean.

INTRODUCTION

Glyphosate-resistant Palmer amaranth has forced soybean weed control programs to evolve into full-season systems. These herbicide systems must also provide control of troublesome grass species and other broadleaf weeds such as morningglory (Scott et al., 2015). More information was needed on the timing and herbicides used for control of weeds with overlapping-residual full-season herbicide systems.

PROCEDURES

One trial was established at the Rohwer Research Station, Rohwer, Ark on a Hebert silt loam soil in 2014 to evaluate Palmer amaranth, Morningglory *(Ipomoea sp*.), Southwestern cupgrass (*Eriochloa gracilis*), and Sickle pod (*Senna obtusifolia*) control in soybean. The trial was arranged in a randomized complete block design with four replications. Thirteen herbicide systems were evaluated for season-long weed control and soybean yield. The thirteen systems tested were Envive ® at 0.09 lb ai/ac pre-emergence (PRE) followed by (fb) Roundup WeatherMax ® at 0.95 lb ai/ac plus Prefix ® at 1.32 lb ai/ac mid post (MP), Canopy ® at 0.28 lb ai/ac plus Cinch ® at 0.955 lb ai/ac PRE fb Roundup WeatherMax at 0.95 lb ai/ac plus Prefix ® at 1.32 lb ai/ac MP, Trivence ® at 0.31 lb ai/ac fb Roundup WeatherMax at 0.95 lb ai/ac plus Prefix at 1.32 lb ai/ac MP, Zidua ® at 0.133 lb ai/ac PRE fb Roundup WeatherMax at 0.95 lb ai/ac plus Prefix at 1.32 lb ai/ac MP, Fierce ® at 0.166 lb ai/ac PRE fb Roundup WeatherMax at 0.95 lb ai/ac plus Prefix at 1.32 lb ai/ac MP, Boundary ® at 1.63 lb ai/ac PRE fb Roundup WeatherMax at 0.95 lb ai/ac plus Prefix at 1.32 lb ai/ac MP, Authority ® MTZ at 0.338 lb ai/ac PRE fb Roundup WeatherMax at 0.95 lb ai/ac plus Prefix at 1.32 lb ai/ac MP, Authority ® Elite at 1.75 lb ai/ac PRE fb Roundup WeatherMax at 0.95 lb ai/ac plus Prefix at 1.32 lb ai/ac MP, Valor ® at 0.064 lb ai/ac PRE fb Roundup WeatherMax at 0.95 lb ai/ac plus Prefix at 1.32 lb ai/ac MP, Roundup WeatherMax at 1.38 lb ai/ac early post (EP) fb Roundup WeatherMax at 1.38 lb ai/ac MP, Fierce at 0.143 lb ai/ac PRE fb Roundup WeatherMax at 0.95 lb ai/ac plus Cobra ® at 0.125 lb ai/ac MP, Statement ® at 1.31 lb ai/ac PRE fb Roundup WeatherMax at 0.95 lb ai/ac plus Cobra at 0.125 lb ai/ac plus Ultra Blazer ® at 0.375 lb ai/ac MP, and Prefix at 1.32 lb ai/ac PRE fb Roundup WeatherMax at 0.95 lb ai/ac plus Cobra at 0.125 lb ai/ac plus Ultra Blazer at 0.375 lb ai/ac MP. Weed control was recorded on a 0-100 scale with 0 being no control and 100 being complete control. The center two rows of the four-row plot were harvested for yield.

RESULTS AND DISCUSSION

Boundary at 1.63 lb ai/ac, Fierce at 0.143 lb ai/ac, and Fierce at 0.166 lb ai/ac provided 89%, 84%, and 81% control of Palmer amaranth respectively, while all other treatments provided 75% or less control at 28 days after the pre-emergence application (DAA) (Table 1). Envive at 0.09 lb ai/ac and Authority MTZ at 0.338 lb ai/ac provided 90% control of morningglory, while Authority Elite at 1.75 lb ai/ac provided 88%. All other treatments provided 80% or less control of morningglory 28 DAA (Table 1). Authority Elite at 1.75 lb ai/ac provided 89% control of broadleaf signalgrass, while Boundary at 1.63 lb ai/ac, Prefix at 1.32 lb ai/ac, Statement at 1.31 lb ai/ac, and Zidua at 0.133 lb ai/ac all provided 88% control of broadleaf signalgrass. All other treatments provided 86% or less control 28 DAA (Table 1). Canopy at 0.28 lb/ai/ac plus Cinch at 0.955 lb ai/ac provided 91% control of barnyardgrass, while Boundary at 1.63 lb ai/ac, Prefix at 1.32 lb ai/ac, Statement at 1.31 lb ai/ac, and Zidua at 0.133 lb ai/ac all provided 88% control. All other treatments provided 83% or less control of barnyardgrass 28 DAA (Table 1).

At 77 days after the 3-4 trifoliate (DAC) application, Fierce at 0.166 lb ai/ac fb Roundup WeatherMax at 0.95 lb ai/ac plus Prefix at 1.32 lb ai/ac provided 99% control of palmer amaranth, while Boundary at 1.63 lb ai/ac fb Roundup WeatherMax at

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0.95 lb ai/ac plus Prefix at 1.32 lb ai/ac, Authority Elite at 1.75 lb ai/ac fb Roundup WeatherMax at 0.95 lb ai/ac plus Prefix at 1.32 lb ai/ac, and Fierce at 0.143 lb ai/ac fb Cobra at 0.195lb ai/ac plus Roundup WeatherMax at 0.95 lb ai/ac provided 97% control (Table 2). Authority Elite at 1.75 lb ai/ac fb Roundup WeatherMax at 0.95 lb ai/ac plus Prefix at 1.32 lb ai/ac, and Fierce at 0.143 lb ai/ac fb Cobra at 0.195lb ai/ac plus Roundup WeatherMax at 0.95 lb ai/ac provided 92% control of morningglory 77 DAC (Table 2). Envive at 0.09 lb ai/ac fb Roundup WeatherMax at 0.95 lb ai/ac plus Prefix at 1.32 lb ai/, Canopy at 0.28 lb/ai/ac plus Cinch at 0.955 lb ai/ac fb Roundup WeatherMax at 0.95 lb ai/ac plus Prefix at 1.32 lb ai/ac, and Authority MTZ at 0.338 lb ai/ac fb Roundup WeatherMax at 0.95 lb ai/ac plus Prefix at 1.32 lb ai/ac provided 99% control of Southwestern cupgrass 77 DAC (Table 2). Boundary at 1.63 lb ai/ac fb Roundup WeatherMax at 0.95 lb ai/ac plus Prefix at 1.32 lb ai/, Authority Elite at 1.75 lb ai/ac fb Roundup WeatherMax at 0.95 lb ai/ac plus Prefix at 1.32 lb ai/, and Fierce at 0.143 lb ai/ac fb Cobra at 0.195 lb ai/ac plus Roundup WeatherMax at 0.95 lb ai/ac at provided 99% control of sicklepod (Table 2). Two herbicide systems provided soybean yield over 60 bushels. The two systems were Authority MTZ at 0.338 lb ai/ac fb Roundup WeatherMax at 0.95 lb ai/ac plus Prefix at 1.32 lb ai/ac and Authority Elite at 1.75 lb ai/ac fb Roundup WeatherMax at 0.95 lb ai/ac plus Prefix at 1.32 lb ai/ provided 61 and 62 bushels of soybean per acre (Table 3).

PRACTICAL APPLICATIONS

Palmer amaranth is still the number one weed problem in Arkansas soybean production. Numerous pre-emergence herbicide options are available for residual control. In a Roundup system, Prefix or Flexstar applications should be held until a post-emergence timing if pigweed populations emerge in a crop. Morningglories and sicklepod continue to be problematic in some areas. Producers should adjust pre-emergence and post-emergence herbicide selection, especially for morningglory control. Implementing herbicide systems that optimize weed control and soybean yield are imperative to sustaining Arkansas soybean production.

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Table 1. Weed control 28 days after pre-emergence application at Rohwer Research Station, Rohwer, Ark. in 2014.

			%Weed Control			
Treatment	**lb ai/A**	**Timing**	**Palmer**	**Morningglory**	**Broadleaf**	**Barnyardgrass**
Envive	0.09	PRE[a]	70	90	65	65
Canopy	0.28	PRE	73	80	86	91
Cinch	0.955	PRE				
Trivence	0.31	PRE	70	76	45	68
Zidua	0.133	PRE	75	74	88	88
Fierce	0.143	PRE	84	63	75	83
Fierce	0.166	PRE	81	79	68	83
Boundary	1.63	PRE	89	25	88	88
Authority MTZ	0.338	PRE	63	90	75	80
Authority Elite	1.75	PRE	68	88	89	83
Valor	0.064	PRE	55	69	50	61
Statement	1.31	PRE	55	45	88	88
Prefix	1.32	PRE	65	35	88	88
$LSD_{0.05}$[b]			19	21	13	18

[a] PRE = Pre-emergence.
[b] LSD = Fishers protected least significant difference test.

Table 2. Weed control 77 days after post-emergence application in 2914.

			%Weed Control			
Treatment	**lb ai/ac**	**Timing**	**Palmer amaranth**	**Morning-glory**	**Southwestern cupgrass**	**Barnyard-grass**
Envive Roundup[b] + Prefix	0.09 0.95 + 1.32	PRE[a] POST[c]	91	81	99	95
Canopy + Cinch Roundup + Prefix	0.28 + 0.955 0.95 + 1.32	PRE POST	95	90	99	97
Trivence Roundup + Prefix	0.31 0.95 + 1.32	PRE POST	84	87	97	91
Zidua Roundup + Prefix	0.133 0.95 + 1.32	PRE POST	92	85	95	87
Fierce Roundup + Cobra	0.143 32 + 12.5	PRE POST	97	92	93	99
Fierce Roundup + Prefix	0.166 0.95 + 1.32	PRE POST	99	91	98	95
Boundary Roundup + Prefix	1.63 0.95 + 1.32	PRE POST	97	78	98	99
Authority MTZ Roundup + Prefix	0.338 0.95 + 1.32	PRE POST	91	71	99	94
Authority Elite Roundup+Prefix	1.75 0.95 + 1.32	PRE POST	97	92	98	99
Valor Roundup + Prefix	0.064 0.95 + 1.32	PRE POST	89	72	93	98
Statement Roundup + Ultra Blazer + Cobra	1.31 0.95 + 0.375 + 0.125	PRE POST	86	79	91	92
Prefix Roundup + Ultra Blazer +Cobra	1.32 0.95 + 0.375 + 0.125	PRE POST	95	75	97	91
Roundup Roundup	1.38 1.38	EP[d] POST	20	20	21	25
LSD $_{0.05}$[e]			9	24	4	11

[a] PRE = Pre-emergence.
[b] Roundup = Roundup WeatherMax.
[c] POST = Post-emergence.
[d] EP = Early post-emergence.
[e] LSD = Fisher's protected least significant difference test.

Table 3. Soybean yield at Rohwer Research Station, Rohwer, Ark. in 2014.

Treatment	lb ai/ac	Timing	Yield Bushels/ac
Envive	0.09	PRE[a]	55
Roundup[b] + Prefix	0.95 + 1.32	POST[c]	
Canopy + Cinch	0.28 + 0.955	PRE	58
Roundup + Prefix	0.95 + 1.32	POST	
Trivence	0.31	PRE	59
Roundup + Prefix	0.95 + 1.32	POST	
Zidua	0.133	PRE	57
Roundup + Prefix	0.95 + 1.32	POST	
Fierce	0.143	PRE	58
Roundup + Cobra	32 + 12.5	POST	
Fierce	0.166	PRE	55
Roundup + Prefix	0.95 + 1.32	POST	
Boundary	1.63	PRE	
Roundup + Prefix	0.95 + 1.32	POST	55
Authority MTZ	0.338	PRE	
Roundup + Prefix	0.95 + 1.32	POST	61
Authority Elite	1.75	PRE	
Roundup+Prefix	0.95 + 1.32	POST	62
Valor	0.064	PRE	
Roundup + Prefix	0.95 + 1.32	POST	55
Statement	1.31	PRE	
Roundup + Ultra Blazer + Cobra	0.95 + 0.375 + 0.125	POST	53
Prefix	1.32	PRE	
Roundup + Ultra Blazer +Cobra	.95 + 0.375 + 0.125	POST	58
Roundup	1.38	EP[d]	32
Roundup	1.38	POST	
LSD $_{0.05}$[e]			8

[a] PRE = Pre-emergence.
[b] Roundup = Roundup WeatherMax.
[c] POST = Post-emergence.
[d] EP = Early post-emergence.
[e] LSD = Fisher's protected least significant difference test.

Flag the Technology Cloud (FTTCloud): A Digital Tool for Agricultural Stakeholders for Drift Prevention and Misapplication of Herbicides

D. Saraswat[1], B. Hancock[1], and R.C. Scott[2]

ABSTRACT

The statewide adoption of Flag the Technology program in 2012 brought forth some practical challenges such as how to deal with loss or misplacement of flags due to high winds or mischievous human interventions, how to ensure the visibility of flags to airborne chemical applicators, and how to keep up with the number of different colored flags as newer herbicide-tolerant crop technologies become available in the future. These challenges led to exploring open-source based web-technologies and utilization of cloud computing platforms for developing a cloud-based tool named Flag the Technology Cloud (FTTCloud) that extends the field-based program to a digital environment in a secure and economical manner.

INTRODUCTION

A pilot program called CIFT, Color Indicates Field Technology, was conducted in Clay County, in northeast Arkansas in 2010 to assess the feasibility of promoting a program for preventing misapplication of herbicides through The University of Arkansas System Division of Agriculture's Cooperative Extension Service. The program was repeated for a limited trial run in 2011. After two years of trial runs, the program was launched statewide in 2012 under a new name, Flag the Technology. Under this program, a new innovative and simple method was developed to identify crops based on the herbicide tolerance technology that they possessed. The program was presented before the chairman of the herbicide resistance committee of the Southern Weed Science Society (SWSS) at their annual meeting in 2012 and was accepted as an SWSS officially recognized program for field identification. As a result, this program is now on at least 2 websites of other universities outside of Arkansas. In addition, several companies have come forward to request colors or patterns for their future technologies.

PROCEDURES

FTTCloud has been developed as a cloud-based application that utilizes a centralized location for creating, storing, and analyzing user provided data. A variety of devices (smartphones, tablets, desktops/laptops) can be used to access information from the application. A cloud-based application can be accessed through a web browser that is included by default in every operating system that is installed on these devices. The system architecture of FTTCloud is shown in Fig. 1

The application has been built using web development technologies such as HTML, CSS, PHP, JavaScript, jQuery, and AJAX (asynchronous JavaScript and XML). Server side scripts have been developed using open-source libraries such as Geospatial Data Abstraction Library (GDAL) and GIS related Python modules for incorporating spatial manipulation features. Users interact with the application via an interface built using Google Maps JavaScript API (version 3). The interface allows for adding, editing, and viewing field data. An open-source PHP framework called Yii is used for hosting web technologies and other resources. The entire application is hosted on Amazon Elastic Cloud Computing (EC2) resource that relies on AWS Relational Database Service (RDS) for handling the user provided data.

RESULTS AND DISCUSSION

The goal of Flag the Technology Cloud (FTTCloud) is to develop a digital version of field-based Flag the Technology program using open-source web and cloud computing technologies. Through an interactive interface, producers and consultants can add their fields, color-coded for the herbicide-tolerant technology, to a secure database on the Cloud. By taking the program to the Cloud, users are also assured of quality experience during peak usage time.

The FTTCloud tool is primarily driven by voluntary participation of producers and it regards them as the owner of the data. The main features of FTTCloud are as follows:

- Allows marking of fields using ten different herbicide tolerant technologies (more to come in the future).
- Provides a snapshot of the statewide adoption status of various herbicide-tolerant technologies (for non-registered users).
- Allows establishment of relationship with other users (producers with consultants or commercial applicators or both)

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- Allows import of shapefile boundary data and its overlay on Google Map (producer or consultant with the approval of producer).
- Allows drawing of boundary data and its overlay on Google Map (producer or consultant with the approval of producer).
- Allows visualization of color-coded field data on an interactive map (as per account type settings).
- Allows sharing of field data among the user database (as per producer permission).
- Allows export of digital field data with technology attributes (as per producer permission).
- Allows visualization of field information on multiple devices (e.g., PCs, laptops, tablets, smart phones etc.) and anywhere with an available internet connection. Figures 2-4 shows views of FTTCloud on various devices.

FTTCloud was launched in April, 2014. The program can be accessed from the following address: https://fttcloud.uaex.edu. Only registered users are allowed to upload, edit, query, share, or visualize voluntarily entered field-level information about herbicide-tolerant technologies on a county basis. Data visualization capabilities are controlled by producers as shown in Fig. 5(a, b). The FTTCloud tool has the ability to detect overlapping boundaries (Fig. 6): FTTCloud provides the registered user base with real-time updates about the addition of new fields. This feature could be useful for commercial applicators to adjust their application schedule based on the new field information. A step-by-step user guide is included with each account type. Video tutorials for using various features of FTTCloud are also being developed.

PRACTICAL APPLICATIONS

The FTTCloud tool is a new tool for identifying fields with herbicide-tolerant technologies. It provides a secure and economical approach for field identification. The tool is currently available for agricultural stakeholders in Arkansas for free.

ACKNOWLEDGMENTS

The funding support by the Arkansas Soybean Promotion Board and inputs provided by FTTCloud Advisory Committee is hereby greatly acknowledged. Support was also provided by the University of Arkansas System Division of Agriculture.

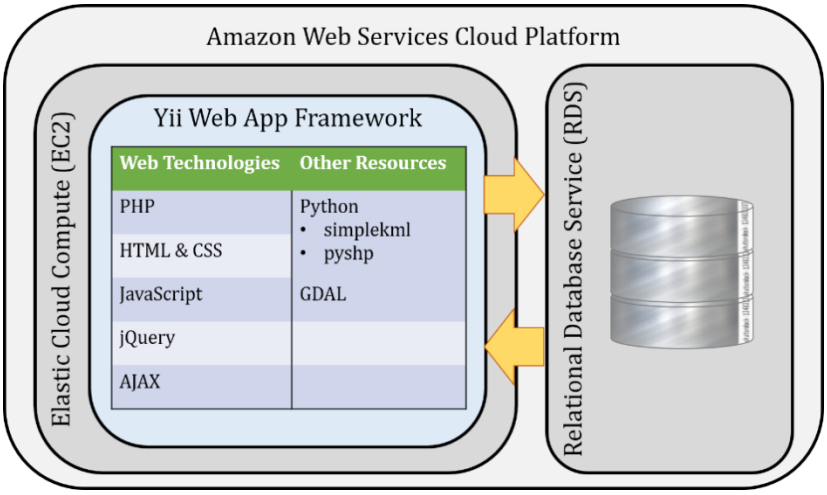

Fig. 1. System architecture of FTTCloud.

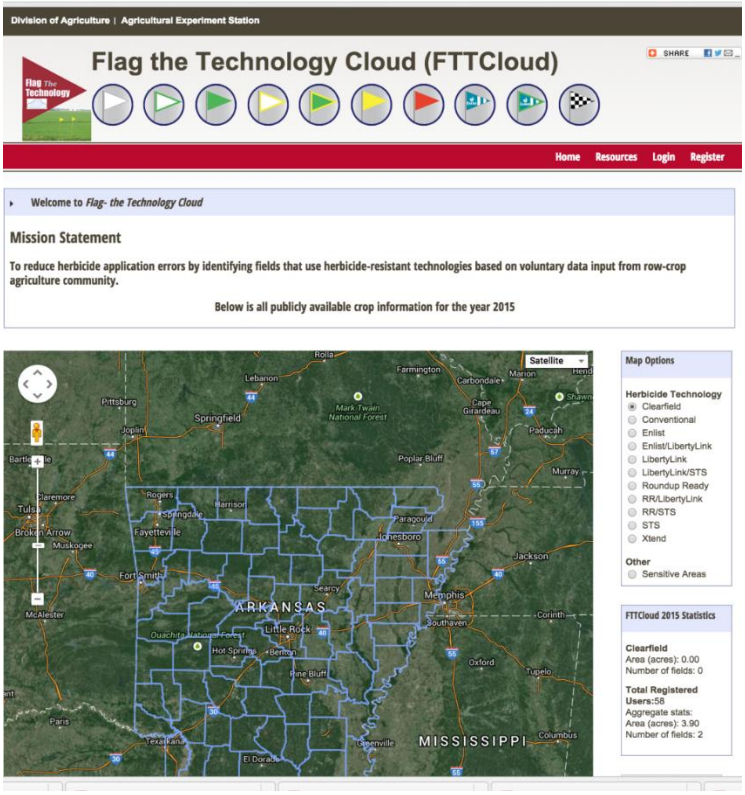

Fig. 2. Desktop/Laptop view.

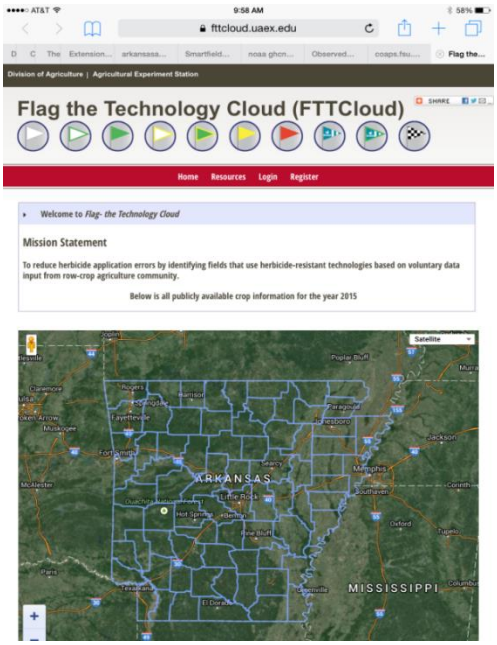

Fig. 3. View on iPad Air. **Fig. 4. View on HTC One.**

(a) (b)

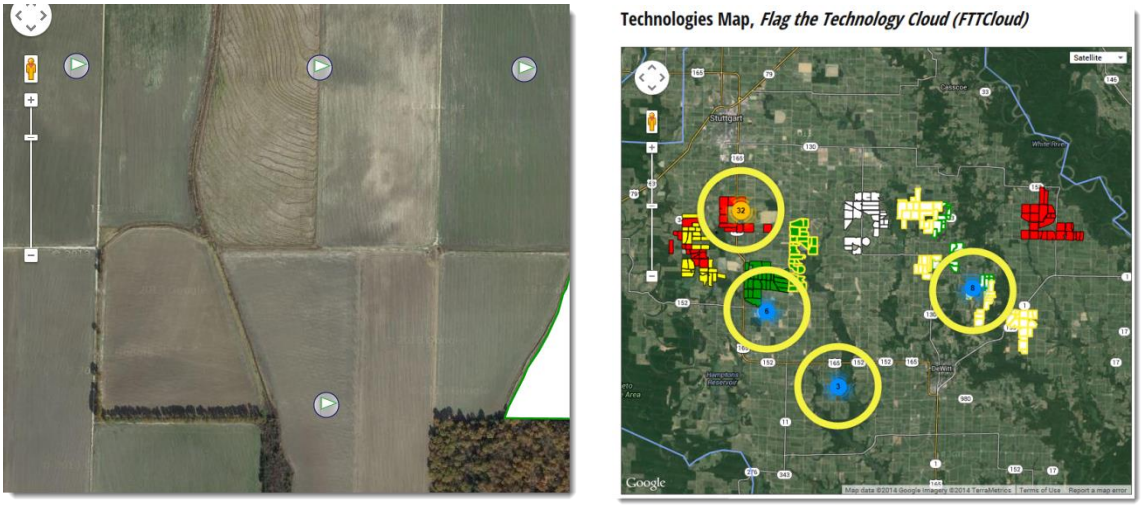

Fig. 5. Field visualization (a) not authorized by producer, (b) authorized by producer.

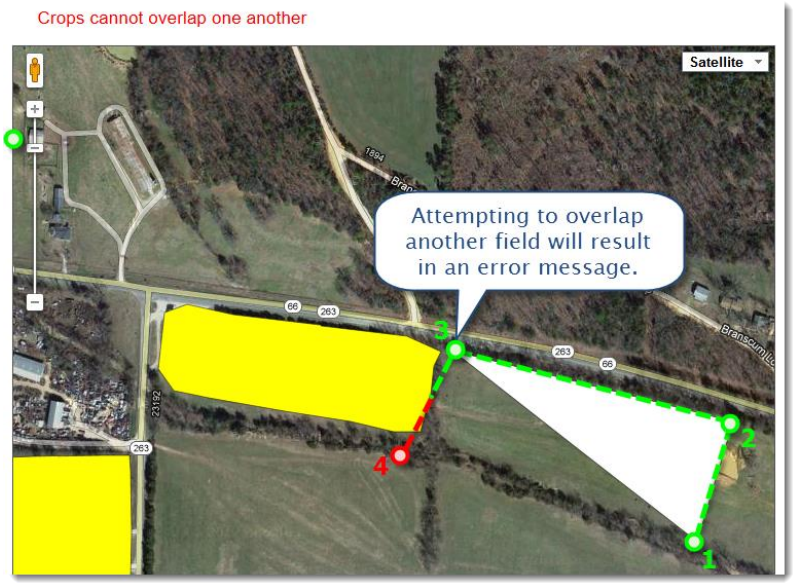

Fig. 6. Overlapping boundary detection.

Harvest Aids in Arkansas Soybeans (*Glycine max*)

L.M. Collie[1], L.T. Barber[1], R.C. Doherty[2], A.W. Ross[1], and W.J. Ross[1]

ABSTRACT

Applying harvest aids to Arkansas soybeans is a common practice in attempt to harvest soybeans earlier in the fall. The timing and the harvest aid selection can be detrimental to success in reaching an earlier harvest date. The objective of this trial was to determine the harvest aid application timing and systems that would provide optimum yields and early harvest to Arkansas farmers. Harvest aids applied at R6.5 will enable producers to harvest beans earlier and more efficiently without affecting yield. Gramoxone® at 1 pt/ac was the most effective harvest aid for soybean desiccation and leaf drop. When harvest aid applications were delayed until 70% defoliation or leaf drop, there were no significant differences in harvest timing between plots sprayed with harvest aids and plots that were not.

INTRODUCTION

Arkansas soybean farmers sometimes need to harvest early due to impending weather outlooks or outside factors. Information about the harvest aids to be used, and the time to apply these aids, is key in providing the quickest and most profitable harvest.

PROCEDURES

These trials were conducted in 2014 at the Lon Mann Cotton Station in Marianna, Ark. Applications were made using a Mudmaster spray tractor equipped with a multiboom sprayer (Bowman Manufacturing, Newport, Ark.). The trials were arranged in a randomized complete block design with four replications. The soybeans were planted on 7.5 in. twin-row spacing on 38-in. beds and each block was 4 rows by 30 ft in length. Treatments were applied at 12 GPA at two different timings of R6.5, or when the beans separate from the pod wall and there was 70% defoliation based on visual observations. Percent leaf drop and brown pods were recorded throughout the trial. Yield was recorded at the end of the season. All treatments throughout the trial were applied with an adjuvant.

RESULTS AND DISCUSSION

All treatments applied at R6.5 showed significantly more leaf drop than the untreated check. When applied at R6.5, Gramoxone® SL at 0.5 lb ai/ac provided the highest leaf drop at 81% and brown pod at 31% (Fig. 1). Sharpen® at 0.0455 lb ai/ac plus 1% MSO/ac provided the lowest rate of leaf drop at 40%, and only 2% brown pods. The R6.5 treatments all showed more than 98% leaf drop and brown pod 21 days after application (DAA) (Fig. 2). Treatments applied at 70% defoliation were not significantly different from the untreated check (Fig. 3). All applications made at 70% defoliation did not show significant differences in leaf drop and brown pod percentages 7 DAA. The untreated check had 98% leaf drop and 98% brown pod 21 DAA. Yield in the untreated check was 50.2 bu/ac. (Fig. 4). The only significant reductions in yield were seen with Sharpen at 0.0455 lb ai/ac at 40.7 bu/ac and Roundup Powermax® at 0.95 lb ai/ac plus Sharpen at 0.0455 lb ai/ac at 41.2 bu/ac. Yield differences could be attributed to slight differences in maturity of plants in the respective plots. In a related study, any harvest aid sprayed just prior to R6.5 caused significant yield reduction (data not included). No significant differences were seen in yield at the 70% defoliation timing. To maintain optimum yield potential, a conservative approach would be to delay harvest aid treatments until R7 or first brown pod.

PRACTICAL APPLICATIONS

Applying harvest aids to soybeans at 70% defoliation or leaf drop will make no significant changes in harvest timing or natural senescence. Delaying harvest aid applications to 70% defoliation is not recommended unless morningglories, or other

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vines are present that will impede the harvest process. However, some harvest aids applied at R6.5 could decrease the amount of time before harvest without affecting the soybean yield. Currently products labeled as soybean harvest aids include Gramoxone,

Sharpen, Aim, Roundup and sodium chlorate. Gramoxone appears to be the most desirable product of choice, however there is a 15 day pre-harvest interval for 1pt/ac of Gramoxone. Based on these data, if Gramoxone is applied at R6.5 or R7, it will take at least 15 days before soybean plants and pods will be ready to harvest. Always read and follow labels and pre-harvest intervals with any harvest aid applications.

ACKNOWLEDGMENTS

Research was funded by a grant from the Soybean Check-off Program administered by the Arkansas Soybean Promotion Board, and the University of Arkansas System Division of Agriculture.

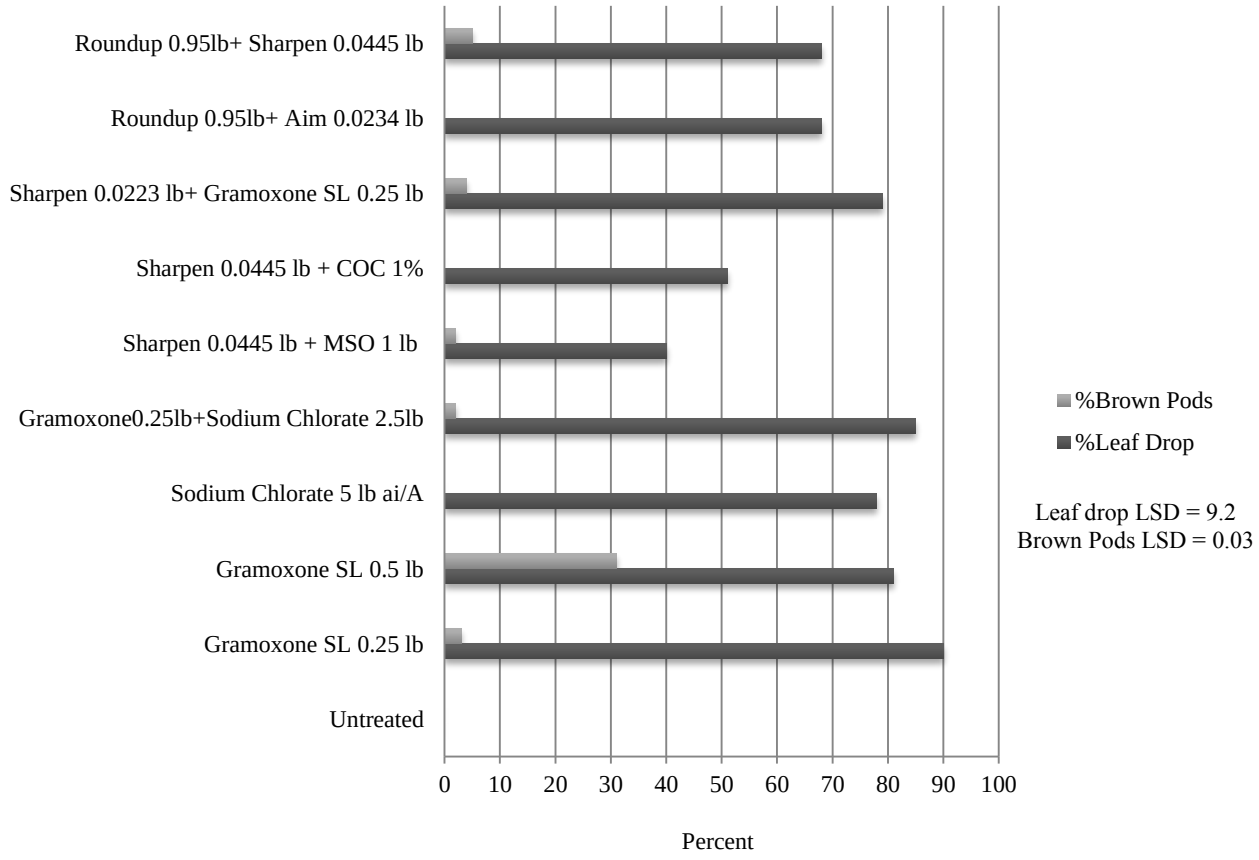

Fig. 1. Harvest aid applications made 7 days after R 6.5 soybean growth stage.

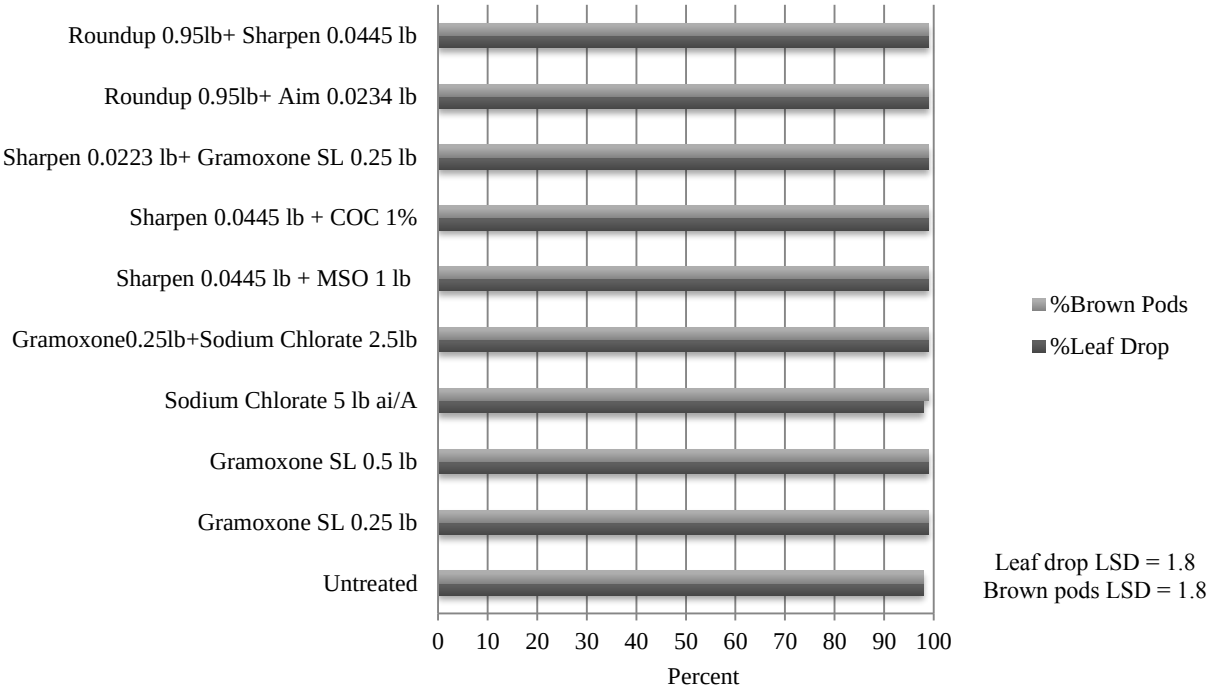

Fig. 2. Harvest aid applications made 21 days after R6.5 soybean growth stage.

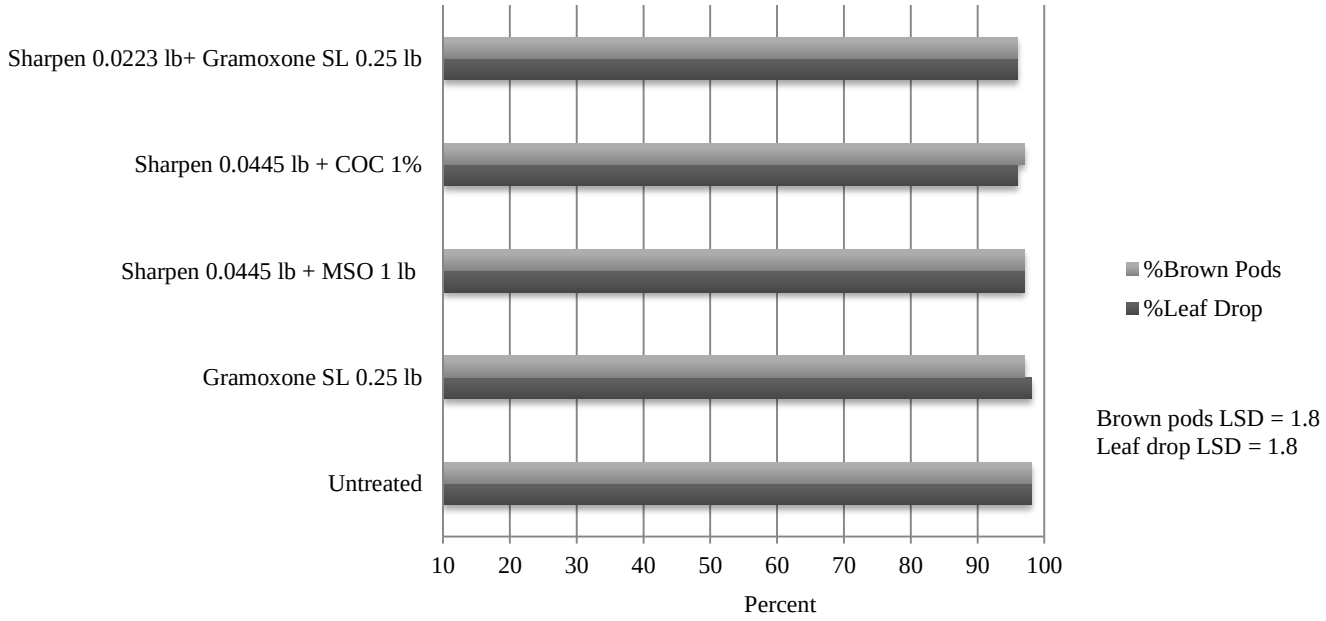

Fig. 3. Harvest aids applied at 70% soybean defoliation.

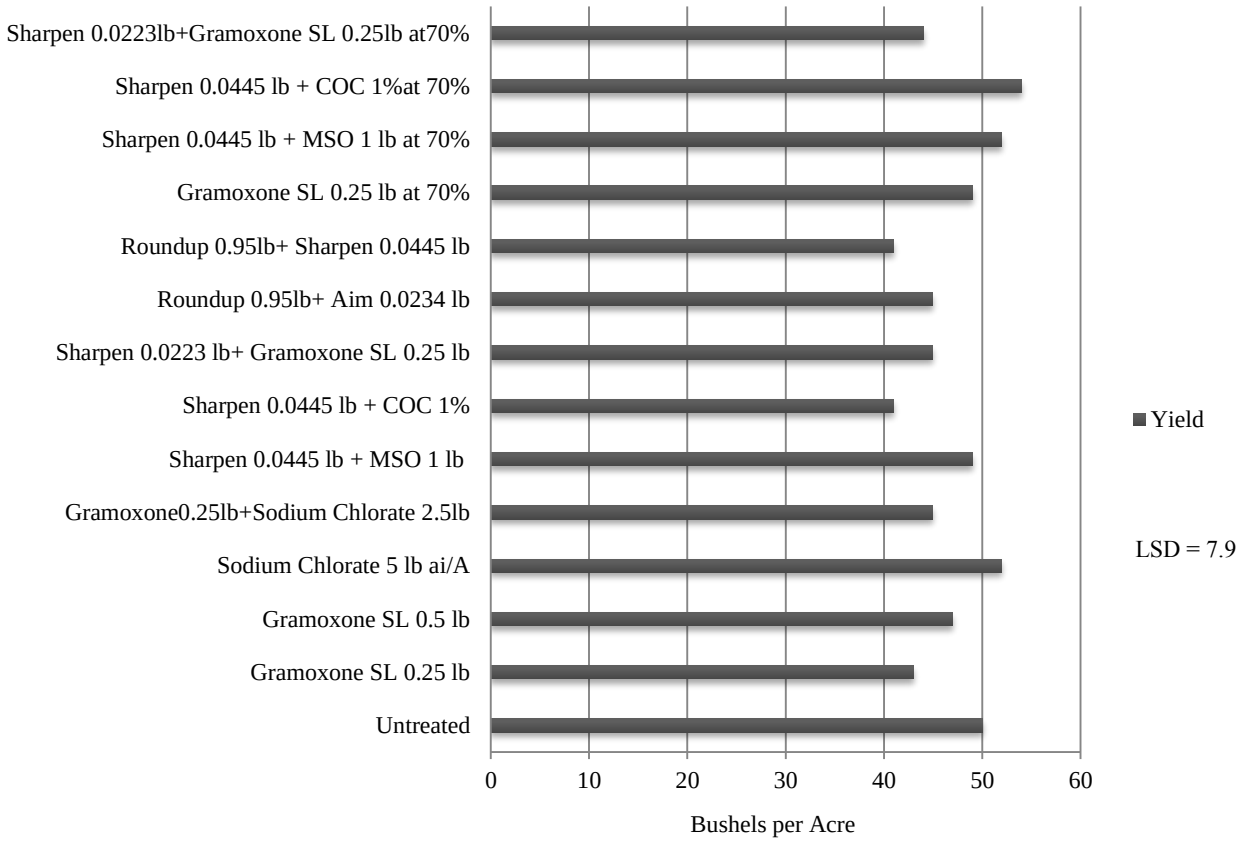

Fig. 4. Soybean yield collected after use of various harvest aids.

Soybean Harvest Aid

A.W. Ross[1], L.T. Barber[1], L.M. Collie[1], R.C. Doherty[2], and W.J. Ross[1]

ABSTRACT

The purpose of this study was to determine application timings for harvest aid in Arkansas soybean using Gramoxone® SL. Gramoxone SL was applied at 1 pt/ac to growth stages R5.5, R6, R6.5, R7, and at 50% total leaf drop. Data observed consisted of visual ratings of leaf drop and yield in bushels per acre. Applications made at R5.5 and R6.0 resulted in premature leaf drop and a significant decrease in bean size. This resulted in significantly lower soybean yield. When applications were made to R6.5 through 50% leaf drop, soybean yield was not significantly decreased from the untreated check.

INTRODUCTION

Applying harvest aids to Arkansas soybean is becoming a common practice in an attempt to harvest earlier in the growing season. There has not been much research conducted on harvest aids for early termination of soybean in recent years. Studies from neighboring states and farmers have sparked an interest for this type of research. The objective of this research was to determine a beneficial timing that would provide earlier harvest and optimum yield in Arkansas soybean. Many times, producers can receive a premium by delivering their soybeans to the elevator in August. With later planting dates due to weather or time consumption, producers have asked questions regarding how early harvest aid applications can be made without sacrificing yield. Being able to harvest earlier could also potentially avoid the risk of fall weather interfering with the harvest process or decreasing soybean quality.

PROCEDURES

This trial was conducted one year (2014) to determine application timings in Marianna, Ark. at the Lon Mann Cotton Research Station. Applications of Gramoxone ® SL (paraquat) at 1pt/ac were sprayed at soybean growth stages R5.5, R6, R6.5, R7, and at 50% of total leaf drop. The trial was arranged in a randomized complete block design with four replications. Leaf drop (desiccation) was recorded on a 0-100 scale with 0 being no desiccation and 100 being complete desiccation. Applications were made using a compressed air broadcast sprayer with Green Leaf Air-Mix nozzles on 19-in. spacing at 12 gallons per acre (GPA). Visual ratings were taken weekly after each application for each growth stage.

RESULTS AND DISCUSSION

Soybean defoliation data are reported as percent defoliated on the rating date of 18 Sept which represent 29 days after R5.5 application (DAA), 22 days after R6 application, 14 days after R6.5 application and 7 days after the R7 application. No significant differences were observed in leaf drop among growth stages R6, R6.5, and R7 on this rating date (Fig. 1). The timing at 50% defoliation had not been sprayed by this date and was not significant from the untreated check. Applications made at R6.5 required >14 days for beans to dry down for harvest (data not shown). Applications at R7 resulted in soybean ready to harvest by 14 DAA and delays until 50% leaf drop resulted in no significant difference in time to harvest from the untreated check. In reference to soybean yield, R7 and 50% desiccation was the highest yielding with no significant difference between the two growth stages (Fig. 2). Also, there were no significant differences between the untreated check and growth stage R6.5 in yield. Spraying Gramoxone at 1 pt/ac significantly reduces yield when applied at growth stage R5.5 and R6. Based on these data, producers can begin to apply harvest aids at R6.5 soybean growth stage; however, if applications are delayed until R7 or first brown pod, no yield will be sacrificed and time until harvest will not be different from the R6.5 timing. Results from this year indicate that harvest can be hastened by 7-10 days by applying harvest aids at R6.5 and R7; however, if timings are delayed until 50% leaf drop, there will be no benefit in applying Gramoxone to hasten harvest.

PRACTICAL APPLICATIONS

Applying Gramoxone SL at 1 pt/ac will significantly reduce yield when applied at growth stages R5.5 and R6. Desiccation at these stages is greater due to the fact that the soybean plant is still trying to produce and therefore, the ability to disrupt cell

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membrane functions is easier. Desiccation a stages R6.5, R7, and at 50% defoliation is less due to the fact the soybean plant is already beginning the natural process of drying down and therefore, is harder for cell membrane disruption to take place. Applications made at the R6.5, R7, and at 50% leaf drop timings do not significantly affect yield. However, desiccation is slower and may take 14 or more DAA for complete desiccation to occur. Recommendations for Arkansas soybean are that harvest aids should not be applied before R7 to obtain maximum yield potential.

ACKNOWLEDGMENTS

Research was funded by a grant from the Soybean Check-off Program administered by the Arkansas Soybean Promotion Board, and the University of Arkansas System Division of Agriculture.

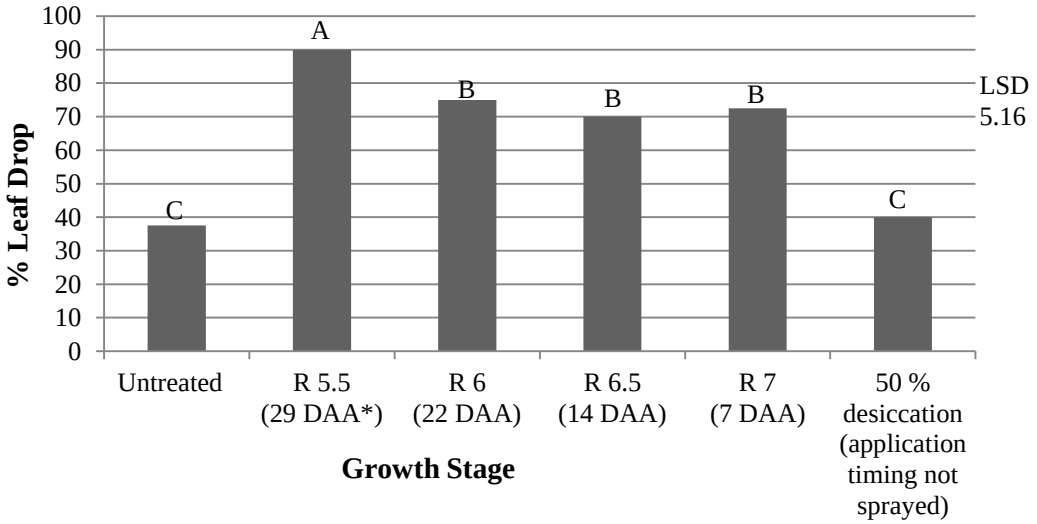

Fig. 1. Percent leaf drop rated on 18 Sept 2014 for each harvest aid timing with Gramoxone at 1pt/A. DAA is days after application. LSD (Least significant difference). Means followed by same letter do not significantly differ *P* = 0.05.

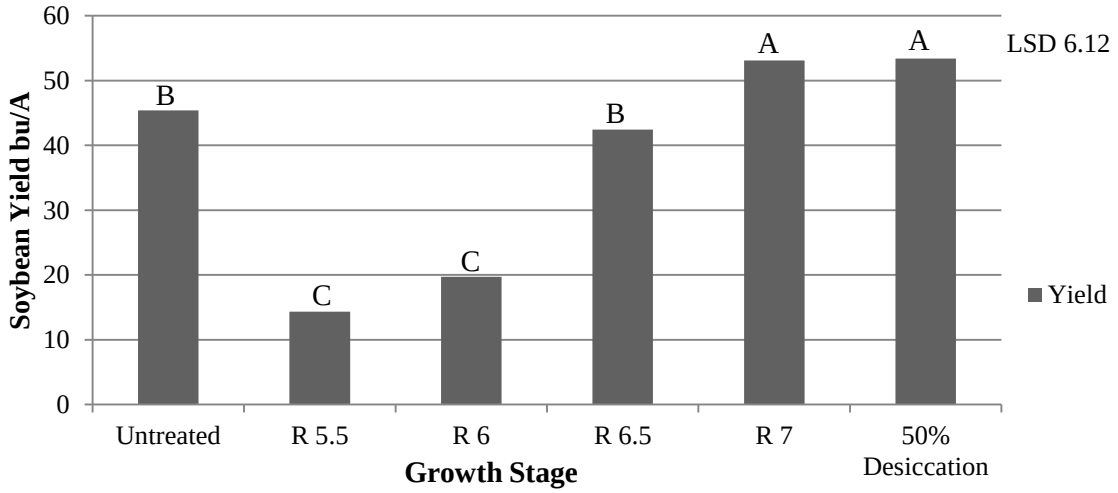

Fig. 2. Soybean yield (bu/A) from each harvest aid application timing 2014. LSD (Least significant difference). Means followed by same letter do not significantly differ *P* = 0.05.

Dicamba Effects on Soybean Plants and Their Progeny

L.T. Barber[1], J.K. Norsworthy[2], and M.S. McCown[2]

ABSTRACT

Dicamba-resistant cotton and soybean have been deregulated and cotton will be planted on limited acreage in 2015. Non-tolerant soybean is extremely sensitive to off-target or tank-contamination rates of dicamba. A study was developed to determine the effects of low rates of dicamba when applied to non-tolerant soybean at various growth stages on soybean yield and progeny. Dicamba was applied at low rates of 3.5 and 0.89 g ae/ac at V3, V6, R1, R2, R3, R4, and R5 growth stages on maturity group IV and V soybean cultivars. Results indicate that a significant yield reduction is most likely to occur when non-tolerant soybean are sprayed at V6 to R2 growth stages. Group V cultivars seem to be more sensitive at each growth stage than group IV. When low rates of dicamba were applied at later growth stages (V4 to V6), significant reductions in seedling vigor of the F1 progeny was observed. These progeny from both maturity group IV and group V cultivars emerged and displayed dicamba symptomology 14 days after emergence.

INTRODUCTION

Dicamba-resistant cotton and soybean developed by Monsanto have recently been deregulated by the USDA and may be available to plant on a small scale in 2015. Dicamba herbicide will offer producers another mode of action to manage broadleaf weeds post-emergence in these crops. Concerns with off-target movement and spray tank contamination of dicamba have resulted in an increase of field research devoted to potential effects on non-resistant soybean and cotton. Soybean is especially sensitive to dicamba and previous research has demonstrated significant yield losses with dicamba at rates as low as 0.23 g ae/ac when applied at sensitive (R1) stages of growth. The purpose of this research was to determine if low-rate applications of dicamba to soybean in reproductive stages will have any effect on progeny produced by affected plants.

MATERIALS AND METHODS

A study was conducted with an indeterminate (maturity group IV) and determinate (maturity group V) soybean cultivar at Marianna, Ark. in 2014. Dicamba was applied at V3, V6, R1, R2, R3, R4, R5, and R6 growth stages at 3.5 (1/64X) and 0.89 (1/256X) g ae/ac at each stage of growth. Additional studies were conducted with multiple soybean varieties at Fayetteville, Ark., Brooksville, Miss., Starkville, Miss., and Stoneville, Miss. with equivalent rates, but only at V3, V6, and either R1 or R2 growth stages. Soybean plants were rated for injury, and plant heights were recorded during the season as well as yield at harvest. During harvest, a 454-g subsample of progeny seed was taken from each plot. Seed from all studies were collected and 15 seed from each representative plot at each location was returned to the principal investigator at each location. Each plot of 15 seed was then planted in the greenhouse to determine if any effects from dicamba applications during the season were apparent in the progeny. Data were subjected to analysis of variance and means were separated by Tukey's protected least significant difference test (P = 0.05).

RESULTS AND DISCUSSION

Yield was decreased in both maturity group IV and V cultivars. The most sensitive timing for yield loss from low rates of dicamba was R1 and R2 for the group IV cultivar at either dicamba rate (Fig. 1). Yield loss appeared to be more severe in the determinate (group V) soybean cultivar, with significant yield loss occurring at each growth stage (Fig. 2). Dicamba applications at R1 provided the greatest yield loss in both soybean cultivars at 20% and 44%, respectively. Progeny produced by injured plants during vegetative growth stages (V3) did not result in significant visual injury or have reduced vigor when planted in the greenhouse (Figs. 3 and 4). However, progeny from plants treated at R1 to R6 growth stages revealed significant injury or dicamba symptomology at 14 days after planting (DAP). Injury to progeny increased significantly when dicamba applications were made at each additional reproductive stage, with R5 and R6 displaying the greatest symptomology. Once again, progeny from the determinate (group 5) cultivar displayed the most injury, up to 50% when dicamba was applied at the R5 and R6 soybean growth stages (data not shown). Seedling vigor was also greatly reduced when dicamba was applied to plants later in reproductive growth stages (Figs. 3 and 4).

These results indicate that yield loss can be significant, depending on growth stage with off-target applications of dicamba to non-tolerant soybean. However, if non-resistant soybean plants are affected with dicamba later in the growing season at the R3

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[2] University of Arkansas System Division of Agriculture, Department of Crop, Soil and Environmental Sciences, Fayetteville, Ark.

to R5 growth stages, yield loss probably will not occur; but seed produced or progeny will be affected and will display symptoms when planted the following season. The end result will be a poor soybean stand that exhibits dicamba-like symptoms and significantly reduced seedling vigor. This research will continue and affected progeny seed will be planted in the spring to determine stand reduction and yield loss under field conditions.

ACKNOWLEDGMENTS

Research was funded by a grant from the Soybean Check-off Program administered by the Arkansas Soybean Promotion Board, and the University of Arkansas System Division of Agriculture.

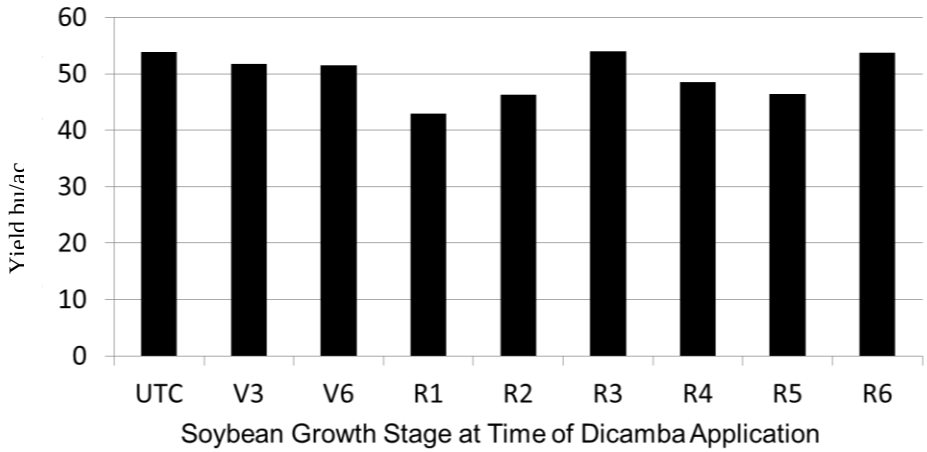

Fig. 1. Group IV soybean yield (bu/ac) averaged over Dicamba contamination rates.

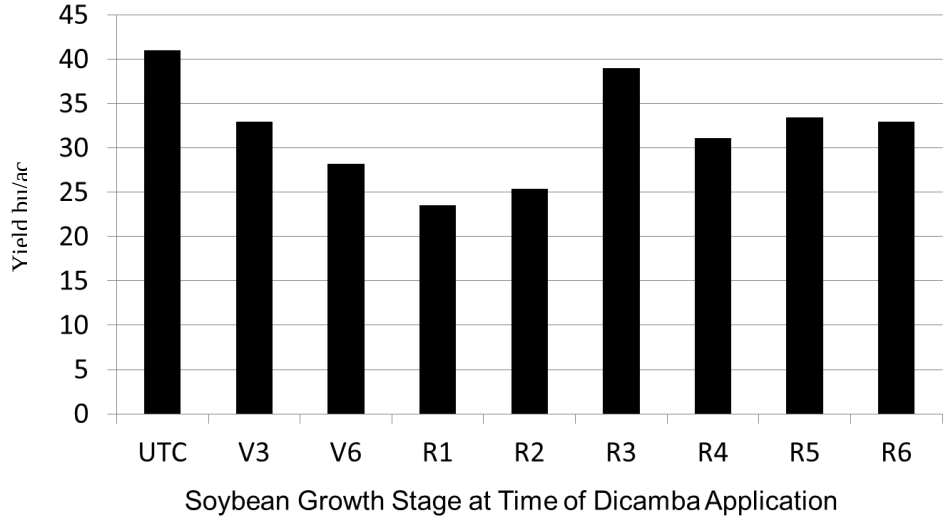

Fig. 2. Group V soybean yield (bu/ac) averaged over dicamba contamination rates.

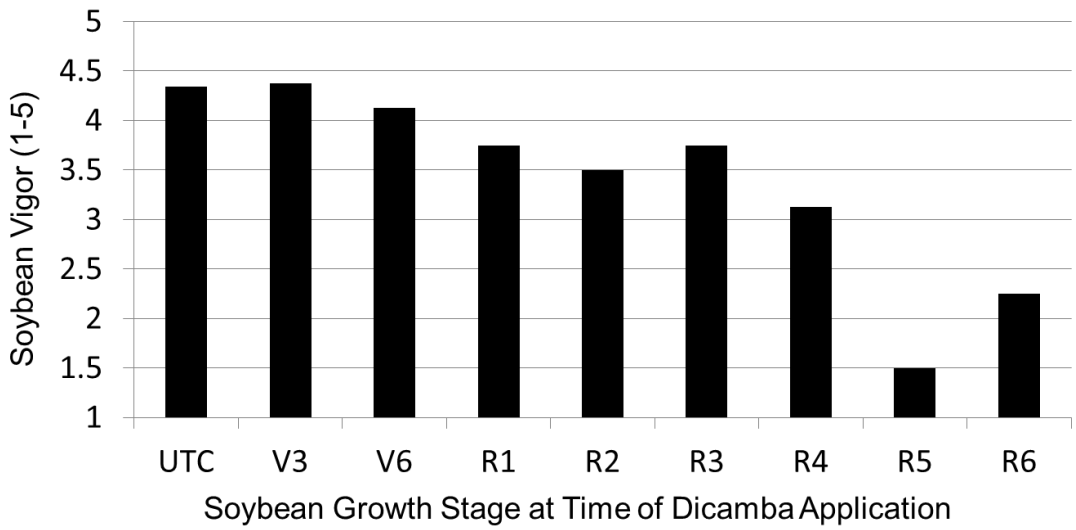

Fig. 3. Group IV soybean vigor (1-5) averaged across dicamba contamination rates.

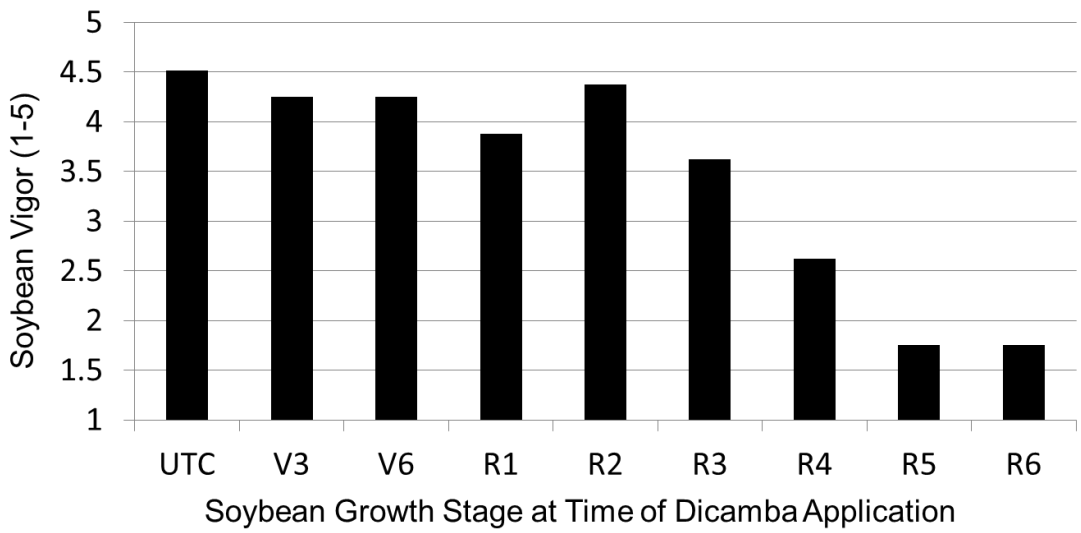

Fig. 4. Group IV soybean vigor (1-5) averaged across dicamba contamination rates.

IRRIGATION

The Effects of Deep Tillage and Gypsum Amendment Across a Range of Irrigation Deficits for Furrow-Irrigated Soybeans in Three Different Arkansas Soil Types

J.P. Gaspar [1], C. Henry [2], P.B. Francis [1], L. Espinoza[3], M. Ismanov [1], S. Hirsh [1], A.P. Horton [1], and H. James [1]

ABSTRACT

Irrigation allows for yield stability by making up the difference between natural rainfall and crop water demand. As production costs escalate, improving profitability can be accomplished through improving irrigation efficiency and timing. The expected decline on current water resources make it more important to develop and improve management practices that improve water-use efficiency. Delays in irrigation initiation, scheduling, and termination can limit yields. Furthermore, these limiting effects can vary among maturity groups, soil types, and growing seasons. Better understandings of the soil-plant-water relationships are imperative to maximize water-use efficiency and for assisting growers in optimizing irrigation management practices in turn, increasing the potential to maximize yield potentials every season. This study is a part of an ongoing effort to improve soybean irrigation practices for three different soils and locations in Arkansas. The goals are: 1) to examine the effects of deep tillage and gypsum applications on soybean yields and water availability to plants across the soil profile (as a measure of soil matric potential), 2) to validate existing target water deficits in irrigation scheduling using atmometers, and 3) to refine, if needed current irrigation scheduling recommendations for furrow-irrigated soybeans. The results indicate that deep soil tillage improved soybean yields in 2 of 3 site-location years. On average, soybean yields were highest using the current recommended target deficits.

INTRODUCTION

Research has shown the positive effects of irrigation on soybean yields. Approximately 80% of the soybean crop is irrigated in Arkansas (USDA-NASS, 2013). Irrigated soybean yields average was 1342 kg ha^{-1} higher than unirrigated average from data obtained in 2011 and 2012 (USDA-NASS, 2013). However, water available for irrigation is declining in the main crop-growing regions. For example, the alluvial aquifer in the east-central region of Arkansas is being depleted at unsustainable rates (ANRC, 2012). At the same time, global populations continue to rise, thus increasing crop production demand. It has been estimated that 1.8 billion people will be living in regions with absolute water shortages and as much as two-thirds the global population may be under water stress conditions by 2025 (FAO, 2013). Soybean production systems must face the dilemma of maintaining or increasing yields with less water available to irrigate. This coupled with high irrigation cost demands that Arkansas growers produce consistent high yields to remain competitive.

Delays in irrigation initiation, scheduling, and termination can limit yields (Heatherly and Spurlock, 1993). Furthermore, these limiting effects show high levels of variability in maturity groups, soil types, and growing seasons (Garcia et al., 2010). A major factor affecting the ability to obtain high yields resides in the soil water storage of a given soil (Boyer et al., 1988). Purcell and Specht (2004) state that water deficit is the most common abiotic stressor reducing soybean yields in Arkansas. Therefore, the optimization of current irrigation practices can ultimately lead to a better understanding of the soil-plant-water relationship, which is imperative for assisting growers in optimizing irrigation management practices and in turn, increasing the potential for high yields as well as establishing yield stability.

Soil compaction is prevalent in soil systems where tillage occurs and can limit yield potential. High soil compaction can result in yield losses up to 45% (Kirnak et al., 2013). Deep tillage breaks the hard pan or compacted zones of the soil intern enhancing water infiltration, drainage, and deep penetration of roots (Singh et al., 2013). For example, in many sugarcane growing regions deep tillage is thought to be vital to obtaining high crop yields (Yang and Quintero, 1986).

Arkansas soils have low organic matter (OM) due to the tillage practices and climate. Typically, during the growing cycle, Arkansas soils experience high OM oxidation rates. The lack of organic matter plus the high proportion of silt in Arkansas's silt loam soils (up to 70% silt) increase the propensity for soil sealing (the formation of soil crust), which can significantly affect seedling emergence, but it also impairs the inherent hydraulic conductivity of silt loams. Surface runoff and erosion are

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responsible for extensive losses of topsoil and agricultural productivity. Surface crusting is one of the most important factors that influence such processes (Flanagan et al., 1997). Gypsum ($CaSO_4$) is a well know anti-crusting agent, with Miller (1987) reporting significant increases in water infiltration and reduction in runoff in typical soils of the southeast U.S. that received gypsum. Significant reductions in surface sealing potential have also been reported by others (Keren et al., 1983). Espinoza et al. (2009) reported significant reductions in aluminum concentrations with sequential applications of FGD gypsum to an Alfisol with a fragipan horizon located 16 inches deep.

The objective of this research was to verify existing irrigation-trigger thresholds while testing less conservative triggers. Less conservative triggers could result in less irrigation water used in Arkansas. Second, the study examined two practices for furrow-irrigated soybean that have the potential to enhance infiltration of water into the soil profile, deep tillage and gypsum amendment. The study should also indicate if different irrigation recommendations are necessary for deep tillage, gypsum amendment, or both.

MATERIALS AND METHODS

Field trials were conducted in 2014 at three different Arkansas locations with varying soil types: Rohwer Research Station, Rohwer, (clay); Lonn Mann Cotton Research Station, Marianna, (silt-loam); and a private farm near Stuttgart, (silt-loam with a pan). The yield effect of deep tillage (ripping) without gypsum and deep tillage (ripping) with gypsum were assessed for four different irrigation treatments. Water use and soil moistures using watermark tensiometer (Irrometer Company, Riverside, Ca.) were monitored, using flowmeters (McCrometer, Inc., Hemet, Calif.) and watermark tensiometer respectively, over the course of the study and reported in order to quantitatively assess the difference in water use and soil moisture among irrigation and soil treatments. Other than specific irrigation and soil management treatments, other cultural practices were in accordance with current University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations.

Plot Design. The field was divided into four blocks and each block received a 1) deep tillage (rip), 2) deep tillage with gypsum application, 3) gypsum application, and 4) no treatment (conventional). These main plots were further divided into 8-row plots with 30-inch row spacing (Stuttgart), 8-row plots with 38-inch row spacing (Marianna), and 8-row plots with 38-inch row spacing (Rohwer), that were watered at four different irrigation deficits (fully irrigated, +1 deficit, +2 deficit, and non-irrigated) each having 3 replicates randomly assigned within each main plot (expect for Marianna only had one replicate for the non-irrigated treatments in each soil treatment). Note fully irrigated was scheduled in accordance with Arkansas irrigation scheduling using atmometer recommendations for each site's soil type (Stuttgart silt-loam with a pan, Marianna silt-loam and Rohwer clay), the +1 deficit is adding one inch to the recommended allowable deficit and the +2 deficit is adding 2 inches. The cultivar for all sites was Pioneer P49T97R. Deep tillage was performed with a John Deere 5 shank, no-till soil management system tillage implement. The implement is a low surface disturbance tillage device, ripping to a 14-18 in. depth comprised of a coulter, straight shank with tips designed to lift and loosen soil at the tillage pan layer, and wheels that keep the soil from upheaving. There are five shanks spaced 30-in. apart, this tool was used at all three sites for this study.

Stuttgart Site Specifics. The blocks with deep tillage were tilled on 23 May 2014 before beds. All plots were planted on 24 May 2014 (this field has been chisel-plowed the previous spring and was limed in 2012 with a target rate of 6.5 ph with a max application of 3500 lbs). Soybean emerged 29 May 2014, and gypsum was applied at one ton per acre using a power take off spreader on 18 June 2014. Quadris was applied at R3, and the following herbicides were applied: 5 oz Verdict 24 May 2014 and 1 lbs /8 oz Flex Star/1 pint Dual on 3 July 2014. The center 6 rows were harvested for each plot on 26 and 27 October 2014.

Rohwer Site Specifics. The blocks with deep tillage were tilled on 29 May 2013 before beds; all plots were planted on 22 May 2014. The gypsum was applied at one ton per acre using a power take off spreader 18 June 2014. Quadris was applied at R3, and the following herbicides were applied: 5 oz verdict 24 May 2014 and 1 lbs /8 oz Flex star/1 pint Dual on 3 July 2014. The middle 2 rows for each plot beginning 50 ft from the polypipe and extending 200 ft were harvested on 26 and 27 October 2014.

Marianna Site Specifics. The blocks with deep tillage were tilled on 20 May 2013 on existing beds. All plots were planted on 22 May 2014. Soybean emerged 29 May 2014, and gypsum was applied at two tons per acre using a power take off spreader on 23 May 2014. The middle 7 rows of each 8 row plot were harvested on 17 October 2014.

Statistical Analysis

In order to compare the yields for the different treatment combinations of treatments, general linear models were used in the form of a 2-way analysis of variance with a response variable of yield (bu/ac) with soil treatment (ripped, ripped with gypsum, gypsum, control) and irrigation treatment (fully irrigated, +1 deficit, +2 deficit, and non-irrigated). Transformations of the responses were conducted order to meet the normality assumptions for the Stuttgart data (a box cox transformation with a lambda of 4 was used) and for Marianna data (a double transformation was performed using a natural log of the log of the responses {Ln[(log(response)]}).

RESULTS AND DISCUSSION

Water Use and Soil Moisture Data. The number of irrigations and amount of water used in irrigation are summarized for each site (Table 1). The yearly average soil moisture across the three depths for each irrigation treatment at each soil treatment is summarized (Table 2).

Stuttgart (Silt-Loam With a Hard Pan). The interaction effect between soil treatment and irrigation treatment was not significant (Table 3). This indicated that trends for soil treatment responses were consistent across all irrigation treatments and vice versa. Main effects of soil treatments and irrigation treatments on yield were significant (Table 3).

No difference in yields were observed between conventional (67 bu/ac), gypsum (68 bu/ac), and ripped with gypsum (68 bu/ac) soil treatments. There was a significant difference in yields between deep tillage (ripped) treatment (72 bu/ac) and all other soil treatments, indicating that the ripped treatment yielded 4 bu/ac, 4 bu/ac, and 5 bu/ac more on average than ripped with gypsum, gypsum, and conventional treatments, respectively (Table 3).

There were no significant differences between +1 deficit (72 bu/ac) and fully irrigated treatments (73 bu/ac). The non-irrigated treatment yielded 12-13 bu/ac less than fully irrigated and +1 deficit, and 8 bu/ac less than +2 deficit. The +2 deficit (68 bu/ac) treatment was also significantly different from the +1 deficit and fully irrigated treatments indicating that plots in +2 deficit treatment yielded 4-5 bu/ac less on average than +1 deficit and fully irrigated treatments (Table 3).

Marianna (Silt-Loam Soil Type). The interaction between soil and irrigation treatment was not significant (Table 4). This indicates that trends for soil treatment responses are consistent across all irrigation treatments and vice versa. Significant effects of soil treatments as well as irrigation treatments on yield were detected.

Fully irrigated yields were different from all of the other treatments. This underscores the importance of irrigation scheduling even in a year like 2014, characterized by very favorable rainfall patterns.

Yields were statistically higher than the control treatment when gypsum was applied by itself or in combination with ripping operations. Similar results were observed at the Rohwer location. However, at this location the combination of gypsum and soil ripping resulted in significantly higher yields than the control treatment. Average yields observed from plots where gypsum was the only treatment were not statistically different from the control treatment.

Rohwer (Clay Soil Type). The interaction effect between soil treatment and irrigation treatment was not significant (Table 5). This indicated that trends for soil treatment and irrigation treatment responses on yields were independent of one another. Significant effects of soil treatments as well as irrigation treatments on yield were detected (Table 5).

Significant differences in yield between ripped with gypsum (57.7 bu/ac) and all other treatments revealed that ripped with gypsum treatment yielded 2 bu/ac, 3.6 bu/ac, and 4 bu/ac more than ripped (55.7 bu/ac), gypsum (54.1 bu/ac), and conventional (53.7 bu/ac) treatments (Table 5). The data also indicate that there was a significant difference between ripped plots and conventional plots implying that ripped plots on average yielded 2 bu/ac more than plots without deep tillage. However, there is some ambiguity in that the ripped treatment had significantly higher yields than the control but the ripped treatment had similar yield to the gypsum treatment and the control yield was similar to yields of the gypsum treatment (Table 5). As a result of the overlap in significant effects of soil treatments, it is difficult to make any clear conclusions about differences between ripped, gypsum, and conventional treatment effects on yields.

There were no significant differences in yields between +1 deficit (57.9 bu/ac) and fully irrigated treatments (58.4 bu/ac) or between non-irrigated (52.3 bu/ac) and +2 deficit (57.9 bu/ac). Fully irrigated and +2 deficit yielded significantly more than +1 deficit and non-irrigated plots indicating that the fully irrigated treatment yielded 5.8 bu/ac more than +1 deficit treatment and 6.1 bu/ac more than non-irrigated treatment. Likewise, +2 deficit treatment yielded 5.3 bu/ac more than +1 deficit treatments and 5.6 bu/ac more than non-irrigated treatments (Table 5).

PRACTICAL APPLICATIONS

The findings indicate that deep tillage has real potential to improve soybean yields and irrigation efficiency in silt loam soils, silt loam soils with a pan, and a cracking clay soil. There has been evidence that gypsum applications can improve soybean yields from one soil type but the research will continue to verify any cumulative effects of this practice on yield response. Current target deficit recommendations appear to be appropriate, but whether increasing the irrigation trigger is appropriate is inconclusive. The study was challenged with frequent rainfall patterns that likely have stifled treatment effects and have made it difficult to truly assess the impact and interaction of irrigation and soil treatments.

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Table 1. Water applied and number of irrigations for 2014 Stuttgart, Marianna, and Rohwer respectively.

Irrigation Trt.	Number of irrigations	Total Water Applied (inches)
Fully irrigated	3	6.53
+1 in. Deficit	2	5.45
+2 in. Deficit	1	2.41
Non-irrigated	0	0
Marianna		
Fully irrigated	3	5.06
+1 in. Deficit	1	3.15
+2 in. Deficit	1	2.50
Non-irrigated	0	0
Rohwer		
Fully irrigated	3	-
+1 in. Deficit	2	-
+2 in. Deficit	0	0
Non-irrigated	0	0

Table 2. Season average soil moistures (cb) for Stuttgart 2014 across three depths (6 in., 18 in., and 30 in.) for each soil treatments at each irrigation level, Marianna 2014 across three depths (6 in., 18 in., and 30 in.) for each soil treatments at each irrigation level, and Rohwer 2014 across a 24-in. profile for each soil treatments at irrigated and non-irrigated irrigation levels, respectively.

	Soil Treatment				
Irrigation Trt.	**Ripped**	**Rip/Gypsum**	**Gypsum**	**No treatment**	**Average**
Fully Irrigated	28.1	20.6	46.7	38.8	33.55
+1 in. Deficit	72.4	28	44.8	48.9	48.525
+2 in. Deficit	64	53.3	59	61.1	59.35
Non-irrigated	77.8	61	86.8	99.5	81.275
Average	60.6	40.7	59.3	62.1	

	Soil Treatment				
Irrigation Trt.	**Ripped**	**Rip/Gypsum**	**Gypsum**	**No treatment**	**Average**
Fully Irrigated	32.35	47.22	36.72	38.77	38.76
+1 in. Deficit	61.4	43.97	76.05	80.85	65.56
+2 in. Deficit	39.78	38.85	45.6	52.85	44.27
Average	44.51	43.35	52.79	57.49	

	Soil Treatment				
Irrigation Trt.	**Ripped**	**Rip/Gypsum**	**Gypsum**	**No treatment**	**Average**
Fully Irrigated	95.1	75.8	71.7	85.6	82.1
Non-irrigated	52.3	59.9	36.1	34.6	45.7
Average	73.7	67.9	53.9	60.1	

Table 3. General linear model output with backtransformed mean (yields in bushels per acre) for Stuttgart 2014.

General Linear Model	
Normality Test (Kolmogorov-Smirnov)	Passed (P = 0.117)
Equal Variance Test	Passed (P = 0.847)

Factor	***P* value**
Soil Treatment	< 0.001
Irrigation Treatment	< 0.001
Soil Treatment × Irrigation Treatment	0.447

Irrigation Treatment	**Mean Yield (bu/ac)**	**Soil Treatment**	**Mean Yield (bu/ac)**
Fully Irrigated	73a†	Ripped	72a
+1 in. Deficit	72a	Ripped with Gypsum	68b
+2 in. Deficit	68b	Gypsum	68b
Non-irrigated	60c	No treatment	67c
Standard error of least squares mean = 30.0		Standard error of LS mean = 30.0	

†Letters indicate Tukey's mean comparison significant groupings.

Table 4. General linear model output with backtransformed mean (yields in bushels per acre) for Marianna 2014.

General Linear Model	
Normality Test (Shapiro-Wilk)	Passed (P = 0.053)
Equal Variance Test	Passed (P = 0.832)

Factor	***P* value**
Soil Treatment	< 0.001
Irrigation Treatment	< 0.001
Soil Treatment × Irrigation Treatment	0.431

Irrigation Treatment	**SEM**	**Mean Yield (bu/ac)**	**Soil Treatment**	**Mean Yield (bu/ac)**
Fully Irrigated	10.2	46a†	Gypsum	54a
+1 in. Deficit	10.2	40b	Ripped with Gypsum	47ab
+2 in. Deficit	10.2	37b	Ripped	33bc
Non-irrigated	10.3	36b	No treatment	31c
			Standard error of LS mean = 10.2	

†Letters indicate Tukey's mean compairison significant groupings.

Table 5. General linear model output with backtransformed mean (yields in bushels per acre) for Rohwer 2014.

Factor	***P* value**
Soil Treatment	0.0002
Irrigation Treatment	0.0001
Soil Treatment × Irrigation Treatment	0.2138

Irrigation Treatment	**Mean Yield (bu/ac)**	**Soil Treatment**	**Mean Yield (bu/ac)**
Fully Irrigated	58.4a†	Ripped with Gypsum	57.7a
+1 in. Deficit	57.9a	Ripped	55.7b
+2 in. Deficit	52.6b	Gypsum	54.1bc
Non-irrigated	52.3b	No treatment	53.7c

†Letters indicate Tukey's mean compairison significant groupings.

A Study of Arkansas Irrigation Pumping Plant Efficiency

C.G. Henry [1], W.M. McDougall [1], and M.L. Reba [2]

Nearly 100 irrigation pumping plants were evaluated over three irrigation seasons using a network of pump monitoring systems. Pump monitors are a form of informatics for irrigation pumps that include sensors to measure flow, pressure, depth, and energy use that acquire, store and transmit data. This data can be used to measure irrigation pump performance and control pumps in real time. Seasonal flow change, cost of water per unit volume pumped, and efficiency as a percentage of the Nebraska Pumping Plant Performance Criteria were evaluated using hourly data. Seasonal averages and trends in pumping plant performance values can be used to develop recommendations to producers for improving pumping plant performance and reduce operating and energy costs.

A synthesis of the collected data is presented in Table 1. Operational times observed using pump monitoring ranged from approximately 300 hours to 1500 hours, with an average annual operational time of 907 hours. The study found that electric deep wells (1510 h/yr, n = 5) showed the highest average annual operational time of all system types, but had a smaller sample size than electric alluvial wells (789 h/yr, n = 38) and electric surface relifts (1211 h/yr, n = 10). No values for annual operational time of diesel systems were reported due to issues with pump monitoring systems, but quality control testing values were collected. The few values that were recorded were relatively close to the average value for electric systems of the corresponding system type. The average pumping flow rate of all systems tested was just over 2100 gpm, with values ranging from around 300 gpm to 9000 gpm. Diesel surface relifts showed the highest average flow rate (4631 gpm, n = 5), while electric deep wells showed the lowest average flow rate (1142 gpm, n = 5). The average electricity consumption rate of electric pumping plants was 47.4 kWh/h. Electric deep wells (101.4 kWh/h, n = 5) consumed electricity at over twice the rate of electric surface relifts (47.5 kWh/h, n = 10) and electric alluvial wells (39.6 kWh/h, n = 38). The average diesel fuel consumption rate of diesel pumping plants was 2.74 gal/h. Diesel surface relifts (3.39 gal/h, n = 5) consumed fuel approximately 40% faster than diesel alluvial wells (2.38 gal/h, n = 9). No data were collected for diesel deep wells. The average total dynamic head (TDH) of all systems tested was 70 ft. The average TDH of the deep wells tested (272 ft, n = 5) far exceeded the average TDH of the alluvial wells (58 ft, n = 47) and surface relifts (37 ft, n = 15) included in the study.

Pump monitoring water flow data consistently showed that pumping flow rate over time of alluvial wells followed a pattern of decline that could be characterized using a power function trend line. This analysis showed that it typically takes approximately 6 hours for a well to reach a linear flow loss pattern. This suggests that any instantaneous irrigation pumping plant performance test performed on an alluvial well immediately or shortly after startup will likely result in performance values that do not accurately reflect actual long-term performance, an important finding for those estimating flow rates from instantaneous testing.

Water pumping flow data over time of deep well and alluvial well pumping plants showed annual flow declines ranging from 9% to 37% of the original flow rate at the start of the irrigation season. The average annual flow loss for well pumping plants was 19.6%. Since flow loss as a percentage of the initial flow value was largely dependent on operational time and pumping flow rate, annual flow loss was also calculated in terms of flow loss per volume pumped (gpm/acre-inch pumped) and flow loss per operational time (gpm/h). The average flow loss per volume pumped was 0.13 gpm per acre-inch pumped. The average flow loss per operational time was 5.1 gpm per operational hour.

Improper sizing of power units is a source of inefficiency in irrigation pumping plants. In this study, electric motor nameplate motor ratings were compared to actual peak and average energy use from the remote monitors. Of the 31 electric motors analyzed using pump monitoring, 19.4% were undersized, 25.8% were oversized, and 54.8% were appropriately sized. Instantaneous testing showed 41.2% of motors undersized, 17.6% oversized, and 41.2% appropriately sized. In total, these measurements suggest that approximately half of the electric motors tested were inappropriately sized, which could be a sign of a more widespread issue.

Cost of water is a metric that can be used to assess an irrigation pumping plant. While cost of water cannot be used to understand efficiency, pumping plants that have a high cost of water relative to other similar pumps are likely candidates to warrant a more in-depth investigation of pumping plant efficiency. Irrigators can use this concept to focus maintenance and upgrade work on pumps in their operations with the highest cost of water. Also cost of water was available for all of the pumps in the study, while overall efficiency data was limited due to lack of pumping water level. Both pump monitoring and instantaneous testing were used to analyze the cost of water ($/acre-inch) of irrigation pumping plants. To account for differences in TDH, these cost values were normalized by TDH by dividing each figure by one-tenth of the actual head at which it was operating, yielding cost of water per 10 feet of TDH. Results, shown in Fig. 1 of this analysis indicated that the cost of water for diesel systems was about 2.7 times more expensive than pumping plants using electricity as a power source.

These results also indicate that irrigation energy costs using well pumping plants is approximately 30% more costly per unit volume pumped than irrigation using surface water relift systems (reservoirs, canals, ditches, etc.).

Limited data due to issues with continuous diesel fuel flow monitoring instrumentation highlighted the need for a better fuel flow measurement alternative than the one used in this study. Major cost savings potential for diesel irrigation pumping

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plants were highlighted where the fuel flow sensors were successful in collecting verified data in the field. The diesel pump monitors were also successfully used to remotely adjust speed and provide on/off safety switches for automatic safety shutdown conditions such as low oil, low fuel, low system pressure, etc.

Another metric of evaluating pump adequacy and performance is to assess the water capacity per acre. This is an important metric for assessing the ability of an irrigation pumping plant to meet crop water demand through the season. To evaluate pumping capacity, the pumping capacity during the season was compared to the Cooperative Extension Service recommendation for rice water needs by crop as published in the most recent version of the Rice Production Handbook. Where acreage and pumping water flow rate were known either via pump monitoring or instantaneous testing, an irrigation capacity value (gpm/acre) was calculated and compared to the published values by soil type. Instantaneous testing showed that about 53% of the systems tested were below adequate at the time of the test. Forty-seven percent showed capacity exceeding the recommended value. Pump monitoring, which provides a continuous test, showed that 46% of the systems tested were always adequate, while 42% were sometimes adequate, and 12% were always below adequate. Pump monitoring data also showed that the average variation of irrigation capacity annually was about 3.6 gpm/acre. These results suggest that an instantaneous test may be misleading in terms of adequacy of irrigation capacity through an entire irrigation season and that many pumps may be inadequate to fully irrigate the intended crop.

For pumps in the southern region, which are generally low-head, high-flow pumps, considerable energy savings appear to exist from the study results. Average operational times and input energy usage rates were used to estimate the average amount of input energy and cost savings that would result from improving irrigation pumping plant performance to the Nebraska Pumping Plant Performance Criteria (100% of NPPPC). This standard is very achievable with proper sizing of motors and pumps to the irrigation water demand. It was found that electric deep wells and diesel surface relifts showed the most potential for savings, with the potential to save at least $4000 dollars per year on average on just energy costs. Diesel systems as a whole ($2816/yr) showed about twice the potential for savings as the electric systems ($1326/yr), which is driven by the higher relative cost of diesel as compared to electricity. On average, all system categories show significant potential for energy and cost savings by improving performance to meet the NPPPC standard (Table 1).

There are approximately 54,223 irrigation pumps in Arkansas according to the 2012 National Agricultural Statistics Service's recent Farm and Ranch Irrigation survey. The average pump efficiencies in our study were found to be about 60-70% of the Nebraska Pumping Plant Performance Criteria. The NPPPC is the level of efficiency that irrigators should expect from their pumping plants. Stated another way, there is potential for a 30-40% savings in annual irrigation costs. From our work we have identified potential savings of more than $112 million annually in energy savings from improving energy efficiency and pumping plant performance. Furthermore additional savings from proper motor sizing and adequate irrigation capacity is likely; while it is difficult to estimate these potential savings, the,y are likely substantial. Additional work is needed to confirm these results and specifically better season-long data on diesel pumps is needed.

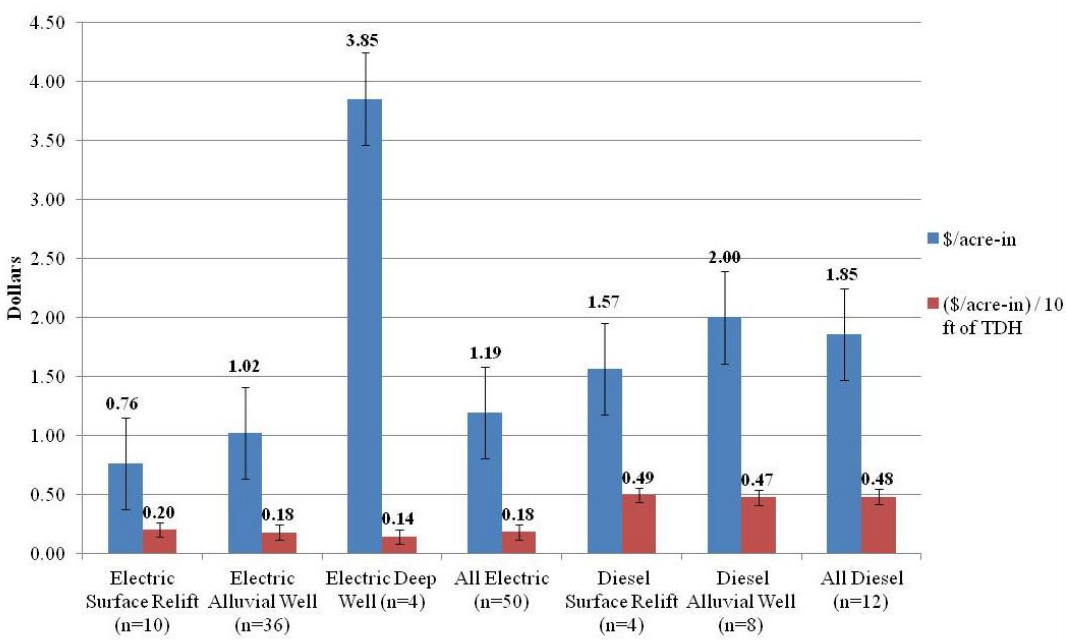

Fig. 1. Cost of water for irrigation pumping plants by energy source.

Table 1. Potential Annual Savings using percent of Nebraska Pumping Plant Performance Criteria (NPPPC) and Annual Operational Time.

System Category	Energy Usage Rate (kWh/hr or gal/h)	Average Operational Time (h)	Average % of NPPPC	Potential Energy Savings (kWh/yr or gal/yr)	Potential Cost Savings ($/yr)
Electric Alluvial Wells	39.6	789	68.2	9,936	$994
Electric Surface Relifts	47.5	1,211	75.1	14,323	$1,432
Electric Deep Wells	101.4	1,510	68.2	48,690	$4,869
Diesel Alluvial Wells	2.38	789	62.9	697	$2,299
Diesel Surface Relifts	3.39	1,211	69.8	1,240	$4,091
All Electric Systems	47.4	908	69.2	13,256	$1,326
All Diesel Systems	2.74	908	65.7	853	$2,816

Regional Irrigation Management for Sustaining Economic Returns and the Aquifer

K. Kovacs

ABSTRACT

Expanding irrigated agriculture and drought in the Lower Mississippi River Basin has led to large-scale withdrawals of groundwater and a consequent decline in the Mississippi River Valley Alluvial Aquifer. Conserving the aquifer, while at the same time providing for economic growth, is a challenge for policy makers. We develop a spatially explicit landscape level model for analyzing the aquifer and economic consequences of alternative crop mix patterns.

INTRODUCTION

The Mississippi River Valley Alluvial Aquifer (MRVA) is the third most used aquifer in the United States, and its sustainability is vital to maintaining long-term agricultural profitability in Arkansas, one of the most productive agricultural regions in the country. The number of irrigated acres continues to increase in the Arkansas in order to maintain and increase yields, avoid risk, and as a result of recurring drought conditions. Moreover, most irrigated acres have resulted from producers privately funding the installation of irrigation wells, with groundwater from the MRVA as the primary source of water for irrigation. As a result, a number of counties in east Arkansas have been designated as critical groundwater areas due to the continued decline in groundwater levels (ANRC, 2012).

We combine aquifer and economic models to search for efficient crop and water conservation practice patterns. An efficient pattern is one that generates the maximum economic returns for a given volume of the aquifer sustained. By maximizing the economic returns over the entire range of possible aquifer volumes we can trace out an efficiency frontier for the landscape. The efficiency frontier illustrates what can be achieved in terms of aquifer and economic objective by carefully arranging the spatial allocation of crops and water conservation practices across the landscape. The efficiency frontier also demonstrates the degree of inefficiency of other crop and irrigation practices not on the frontier.

PROCEDURES

Greater detail on the methods and data can be found in Kovacs et al. (2014). The study area has three, eight-digit hyrdologic unit code (HUC) watersheds that represent the region of the Arkansas Delta where unsustainable groundwater use is occuring. The watersheds overlap eleven Arkansas counties: Arkansas, Craighead, Cross, Desha, Lee, Monroe, Phillips, Poinsett, Prairie, St. Francis, and Woodruff. The study area was divided into 2973 sites to evaluate how farmers make decisions about crop allocation and water use in a spatially differentiated landscape (Fig. 1).

The goal of the analysis was to find crop and irrigation technology patterns that maximize an economic objective for a given level of the aquifer, and vice versa. By finding the maximum economic returns for a fixed volume of the aquifer, and then varying the volume of the aquifer over its entire potential range, we trace out the efficiency frontier. The efficiency frontier illustrates what is feasible to attain from the landscape in terms of the economic and aquifer objectives, and the necessary tradeoffs between the aquifer and economic objectives on the landscape. The efficiency frontier also illustrates the degree of inefficiency of other land and water use patterns not on the frontier, which shows how much the economic returns and/or the aquifer could be increased.

RESULTS AND DISCUSSION

We find efficiency frontiers for aquifer conservation and economic returns in the Arkansas Delta (shown in Fig. 2) where only conventional irrigation is possible (i.e., furrow for crops other than rice and flood for rice), shown by points A through E, and where all irrigation technologies are available (i.e. on-farm reservoirs, center pivot, computerized poly pipe-hole selection, surge, land leveling, alternate wet-dry, multiple-inlet), shown by points F to J. Starting from point A in Fig. 2 and moving around the efficiency frontier, we find crop changes initially increase economic returns markedly while having minimal impact on the aquifer. Moving from point A to point C increases the economic returns from $1146 to $2996 million, which is 70% of the total possible increase in economic returns, while reducing the aquifer by less than 15% (see Table 1 for aquifer volumes and economic returns for selected points on the efficiency frontier).

Among the first crop changes made are to produce irrigated corn, primarily in Arkansas and Monroe counties in the south of the study area (see Table 2 and Fig. 3). The expansion of profitable and low irrigation corn comes out of low margin non-irrigated crops. Moving further around the efficiency frontier from point C to point E requires shifting nearly all non-irrigated

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crops into irrigated production. The main crop change from C to D involves placing a large block of non-irrigated crop in the southeastern part of the study area (mostly Phillips county) into irrigated soybeans. Next the north and west components of the study area shift out of non-irrigated crops into irrigated soybean and corn moving from point D to E (see Fig. 3).

The crop pattern labeled by point F in Fig. 2 achieves the same maximum aquifer as point A and permits higher economic returns, principally because reservoirs provide cheap irrigation water that sustains profitable crops without any loss to the aquifer. The use of reservoirs means minimal crop changes along the efficiency frontier (Fig. 3), and there is a lower opportunity cost of aquifer for higher economic returns. By moving from point F to point H, economic returns increase from $6285 to $6535 million, which is 75% of the total possible increase in economic returns, while reducing the aquifer by only 10%. To increase the economic returns from point F to point H, fewer reservoirs are built and more irrigated soybeans produced in the southeast where groundwater is comparatively plentiful (see Table 2).

Continued use of the 2013 crop pattern, shown as point K, results in overdraft of the aquifer and large groundwater pumping costs that cause economic returns to be negative. In contrast, the crop pattern for point C generates an aquifer volume that is 86% of the highest aquifer found for the landscape, and generates $2996 million in economic returns, 79% of the maximum economic returns. These results show that for the Arkansas Delta it is possible to maintain a high aquifer volume and generate large economic returns by paying careful attention to spatial crop management and the adoption of irrigation technologies.

PRACTICAL APPLICATIONS

The largely positive findings for the Arkansas Delta, where certain crop patterns can jointly generate high aquifer volume and economic returns, occur because some crops grown in the Delta require less irrigated water than rice while still delivering high economic returns. The fact that the highest value crop for the Delta recently is corn, which requires les irrigation water than rice, is also important in limiting the degree of conflict between aquifer and economic objectives. If the price for rice increases, there will be a more apparent tradeoff between aquifer and economic objectives.

ACKNOWLEDGMENTS

Support for this research was provided by the Arkansas Soybean Promotion Board and by the University of Arkansas System Division of Agriculture.

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Table 1. Groundwater and economic return values for selected points along the efficiency frontiers and for the 2013 landscape.

Land use pattern	Present value of economic returns ($ M)	Percentage of maximum economic return	Volume of the aquifer (thousand acre-feet)	Percentage of maximum volume of aquifer
	Efficiency frontier			
	Without new irrigation technologies			
A	1146	30	91,710	100
B	2312	61	85,200	93
C	2996	79	78,700	86
D	3481	91	72,200	79
E	3806	100	61,350	71
	With new irrigation technologies			
F	6285	95	91,710	100
G	6435	97	86,975	95
H	6535	98	82,240	90
I	6598	99	77,505	85
J	6619	100	72,770	79
	2013 land use pattern			
K	-890	-23	54,250	59

Note: The values of economic returns are reported in millions of 2013 constant dollars and the volume of the aquifer in 2043 is reported in thousands of acre-feet.

Table 2. Land-use in 2043 for selected points along the efficiency frontier and the 2013 landscape.

Land use	2013 landscape K	Efficiency frontier points					
		Without new irrigation technologies 2043			With new irrigation technologies 2043		
		A	C	E	F	H	J
			Rice				
Conventional	221	0	0	0	0	0	0
Alternate wet/dry	--	--	--	--	0	0	0
Multiple inlet	--	--	--	--	0	0	0
Land leveling	--	--	--	--	205	205	206
			Full season irrigated soybeans				
Conventional	448	0	32	736	0	0	0
Center pivot	--	--	--	--	0	0	0
Pipe hole selection	--	--	--	--	0	0	0
Surge	--	--	--	--	428	443	460
Land leveling	--	--	--	--	0	0	0
			Irrigated corn				
Conventional	142	0	103	248	0	0	0
Center pivot	--	--	--	--	1	1	1
Pipe hole selection	--	--	--	--	129	130	136
Surge	--	--	--	--	279	279	280
Land leveling	--	--	--	--	25	25	28
Irrigated cotton	26	0	0	0	0	0	0
Wheat	129		0	4	0	0	0
Non-irrigated sorghum	20	783	358	72	0	0	0
Non-irrigated soybeans	155	358	648	81	0	0	0
Reservoirs	--	--	--	--	74	59	30

Note: All values are reported in thousands of acres.

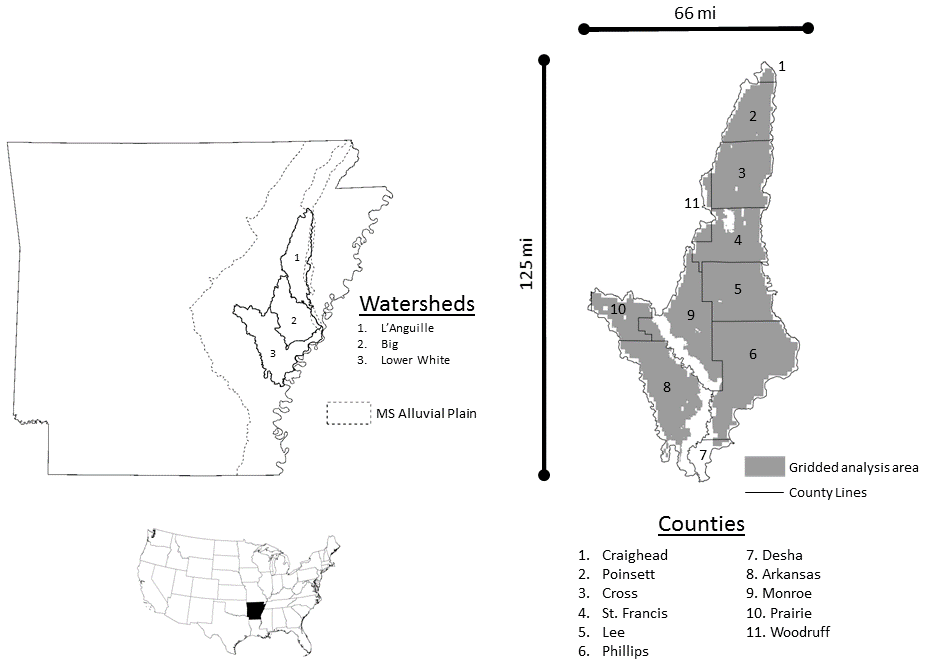

Fig. 1. Three eight-digit hydrologic unit code (HUC) watersheds in the Mississippi Delta region of eastern Arkansas define the outer boundary of the study area. An eight-digit HUC defines the drainage area of the sub-basin of a river. County lines overlay the study area. Public land and urban areas are excluded. The location of the study area within the State of Arkansas is shown.

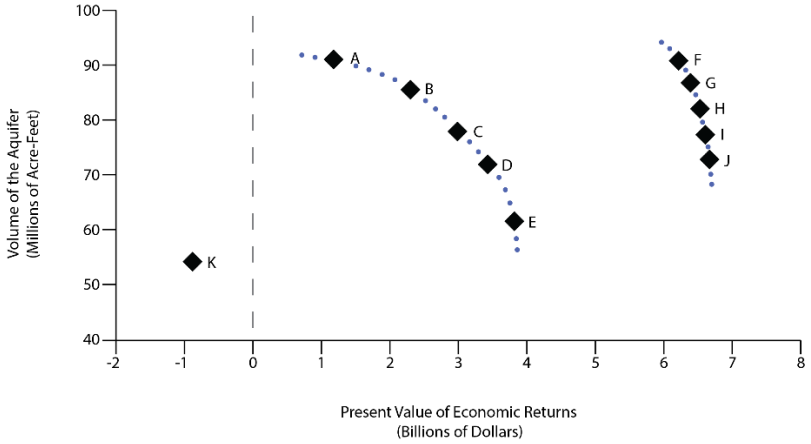

Fig. 2. Efficiency frontiers. The present value of economic activity generated by a crop mix pattern is shown on the horizontal axis. The volume of the aquifer sustained by a crop mix pattern is shown on the vertical axis. The efficiency frontiers are outlined by circles. The lettered diamonds represent specific crop mix patterns along the frontier. Point A represents the highest volume of the aquifer found when there is no groundwater pumping. Only non-irrigated crops are grown because no reservoirs or new irrigation technologies are available. Point E represents the maximum economic returns possible without new irrigation technologies available. Point F represents the highest volume of the aquifer when there is no groundwater pumping, but reservoirs are available to provide surface water and new irrigation technologies make irrigation water use more efficient. Point J represents the maximum economic returns possible with new irrigation technologies available. Point K represents the volume of aquifer and economic returns when the crop mix pattern is constrained to be the 2013 crop mix pattern for the entire study period.

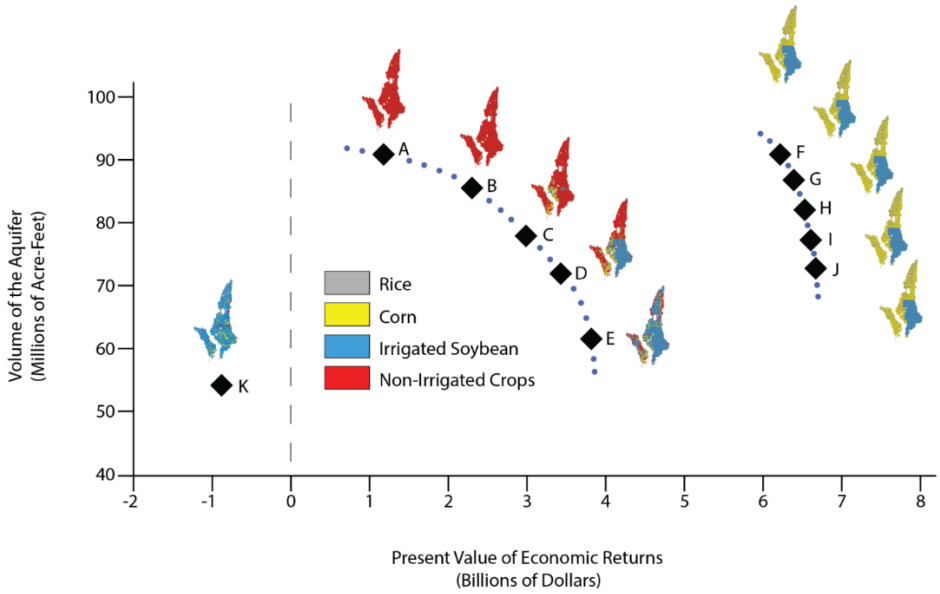

Fig. 3. Crop mix patterns associated with specific points along the efficiency frontiers and the current landscape. Each crop mix pattern shown outside of the efficiency frontiers corresponds to a lettered point on the frontiers. The current crop mix pattern is also shown. Compared to the current landscape, points on the efficiency frontier without new irrigation technologies available have less soybeans and more non-irrigated crops, and points on the efficiency frontier with new irrigation technologies available have less soybeans and more corn and rice. When no new irrigation technologies are available, there is a shift from predominantly irrigated crops toward non-irrigated crops as the aquifer objective is emphasized more relative to the economic objective. With the new irrigation technologies available, irrigated crop mix pattern is largely unchanged along the efficiency frontier.

Plant, Soil and Weather Based Cues for Irrigation Timing in Soybean Production

J.L. Chlapecka [1], N.R. Benson [1], A.M. Mann[2], D.K. Morris[1], M.L. Reba[3], and T.G. Teague[1]

ABSTRACT

Expanded use of irrigation management tools are needed to improve irrigation and water use efficiency in eastern Arkansas soybean production. In 2014 we initiated an Arkansas Soybean Promotion Board supported project to examine irrigation initiation timing on a sandy loam soil in a furrow-irrigated commercial field in Mississippi County. A major research objective was to develop, validate and expand use of irrigation timing cues, incorporating information from local weather stations, atmometers, and soil moisture measurements. For this study, cues for irrigation initiation timing were based on plant maturity measures and evapotranspiration (ET). Four irrigation initiation timing treatments were evaluated: irrigation initiation occurred when deficits reached 1.2 in. (early start), 2 in. (standard), and 3 in. (late start), and rainfed. Plots consisted of 32 rows running the full length of the field (approx. 1250 ft); each plot strip was separated by 16 rows. Although the predominate soil type was a sandy loam, the field was variable with multiple areas of coarse sand (sand blows) present at random locations throughout the field. The experimental design was a randomized complete block with 4 replications and comprised approximately 40 acres. Meteorological data were obtained from an on-farm weather station. We also monitored crop and pest response to irrigation timing. In the high rainfall 2014 season, results from the study showed little variation of soybean yield among irrigation timing treatments. Analysis of yield monitor data indicated yield penalties for irrigation treatments only within rainfed strips in areas of the field with soils characterized as sand blows.

INTRODUCTION

Effective and profitable irrigation management in soybean requires appropriate timing and application. Previous research with furrow irrigation in Arkansas has shown that poor timing was a major cause for reduced yield response (Tacker et al., 1994). Irrigation initiation prior to the R1 stage has been reported to provide little yield benefit in some soils (Reicosky and Heatherly, 1990); however, there are indications that in soils that have low water-holding capacity (e.g. sands) or with plants with limited rooting depth, an earlier start to irrigation may be beneficial in dry years (Heatherly, 1998). Irrigation timing decisions on initiation in different soil textures may be improved by using technology available to characterize soil moisture, plant requirements for water and evapotranspiration (ET). Current recommendations on initiation timing based on ET have not been validated on sandy soils in northeast Arkansas. We evaluated initiation timing in three irrigation cues based on information from a local weather station, atmometers, and soil moisture measurements.

PROCEDURES

The research site was a commercial farm located in Mississippi County, Ark., in a field with sandy loam soil (Routon-Dundee-Crevasse Complex) that ranged from sand to sandy loam to silt loam soils. There were four irrigation treatments 1) Early Start (ET = 1 in.) 2) Standard UA Recommendation (Based on ET Chart, ET = 2.5 in.), 3) Late Start (ET Deficit = 3 in.), and 4) Rainfed. The experiment was arranged in a randomized complete block with 4 replications. Asgrow 4633, a cultivar of Group IV soybean, was planted in 7.5 in. twin rows on raised beds spaced at 38 in. (1 m). The cooperating producer performed all standard field operations. Irrigations were applied using 18 in. × 10 mm poly irrigation tubing using a PHAUCET plan to maximize the effectiveness of the irrigations. A surge valve was used to control irrigation application. Irrigation start time was cued using estimates with ET from an ET gauge (Atmometer; Loveland, Colo.), and a weather station (Table 1). Soil moisture was monitored using Watermark sensors (Irrometer; Riverside, Calif.). Six sensors per treatment in replication I were installed at different depths, with three sensors on the top of the bed (6 in., 12 in., and 24 in.), two on the shoulder of the bed (6 in., 12 in.), and one in the furrow beside the bed (12 in.).

Evapotranspiration was estimated using both the modified Penman equation (Batchelor, 1984) and an atmometer. Decision guides developed by the University of Arkansas System Division of Agriculture's Cooperative Extension Service recommend irrigation timing using a suggested ET deficit based on predominant soil type as well as plant growth stage (Fig. 1). Data collected at the on-farm weather station (Campbell Scientific, Inc.; Logan, Utah) located approximately 1 km from the field was used to calculate the modified Penman equation. Meteorological data from the weather station included solar radiation, wind speed, air temperature, dew point temperature, relative humidity, precipitation, and barometric pressure. The ET was estimated and recorded from 14 June, where the profile was at field capacity after a week of rain, until the final irrigation on 20 August. The ET was adjusted using crop coefficients derived from weekly evaluations of growth stage (e.g., Fig. 1).

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Yields were determined by catch weights using the cooperating producer's grain cart with load cells which was loaded, weighed, and then dumped after each plot. Also, yield monitor data from the cooperating growers' combine was accessed to examine site-specific difference among treatments and across the diverse soil textural areas of the field. All plant and insect monitoring and yield data were analyzed using PROC GLM and analysis of variance statistics with mean separation using protected least significant difference test (SAS Institute; Cary, N.C.). Spatial analysis was completed using the ArcGIS©10.1 (ESRI; Redlands, Calif.).

RESULTS AND DISCUSSION

Weather. Precipitation during the 2014 season is summarized in Table 2. Rainfall was almost 50% above average for the April through August growing season. Evapotranspiration rates exceeded recommended levels in mid to late June and again in early August in the rainfed treatment, while only in mid to late June in the delayed initiation and not at all in the early and normal initiation treatments.

Crop Monitoring. The crop was monitored throughout the season for differences which could be attributed to irrigation timing differences and, in turn, moisture availability. Plant height was taken weekly and was directly correlated to the irrigation initiation throughout the growing season. By harvest, average height of the early and normal initiation was 84 cm: heights for the late initiation and rainfed treatments were approximately 72 cm. Insect response was also measured across the treatments, but insect pressure in 2014 was very low, and no differences in insect abundance or plant injury were found.

Yield. Fig. 2 shows yields as measured by catch weight for the length of field plots in a center harvest swath of each treatment strip. Highest mean yields were observed in the late start irrigation treatment, where irrigation initiation was delayed until an ET deficit of 3.0 in. Mean yields were similar in the early start treatment, initiation at 1.0 in. deficit. Lowest yields were observed in the rainfed treatment.

Soil variability across the field appeared to contribute to lack of consistent trends among irrigation timing treatments. Spatial variation in soil textures across the field likely contributed to these results. When yield monitor data were evaluated, coarse sand compared to sandy loam became apparent. Figure 3 provides results from analysis of yield monitor data showing that irrigation had no effect on yield of sandy loam areas, yet the differences appear in the sandier areas of the field. Yields were significantly lower in the sand blow areas of the field that received no supplemental irrigation. Expanded evaluations are planned in 2015 with development of soil EC maps for the study field and expanded soil moisture monitoring among soil textural zones in order to increase understanding of how in-field variability may impact irrigation efficiency.

PRACTICAL APPLICATIONS

Irrigation scheduling in furrow irrigation systems in northeast Arkansas is commonly done on a weekly schedule as opposed to timing based on actual crop demand. Irrigation scheduling based on a combination of monitoring ET and soil moisture are two practical tools for improving water use efficiency in soybean production. Evapotranspiration is a relatively easy measurement to keep track of daily, whether it is given from a weather station or manually read from an ET gauge.

Using proper irrigation scheduling techniques can improve water use efficiency, which will have a positive effect on water savings and, therefore, farm efficiency from a standpoint of sustainability as well as reduction in production costs.

ACKNOWLEDGMENTS

Support for this research was generously provided by the Arkansas Soybean Promotion Board. We extend special thanks to David, Justin, and Tab Wildy and Paul Harris at Wildy Family Farms for their continuing and exceptional cooperation and support for on-farm research in Arkansas. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Timing details for soybean irrigation initiation study at Wildy Family Farms in Manila, Ark., 2014.

	Irrigation Start[a]			
Treatment Description	**ET Cue (in.)**	**Growth stage**	**Date**	**Days after planting**
Early start	1.2	R2.5	18-Jun	57
Standard (CES recommendation)	2.5	R3	24-Jun	63
Late start	3.0	R3.5	6-Jul	75
Rainfed				

[a] All irrigated treatment plots received irrigation on 6, 10, 28 July and 4, 25 August.
ET = evapotranspiration.

Scheduling Irrigation using an Atmometer (ET Gauge) for Arkansas Soybeans

Table 1. Allowable Deficits-Soybeans

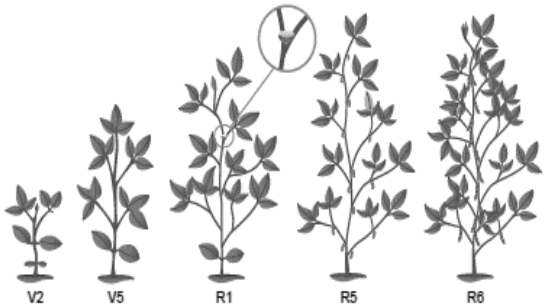
Predominant Soil	Flood, Furrow, Border (inches)	Sprinkler/ Center Pivot (inches)
Clay	2	1.5
Silt loam w/pan	1.75	1.25
Silt loam wo/pan	2.5	2
Sandy loam	2.25	1.75
Sandy	2	1.5

Use alfalfa ET reference #54 canvas for this chart.

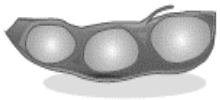
Table 2. Atmometer Setting — Set Atmometer to this value based on soil type

Move to this value if canopy closes before growth stage is reached

Stage of Growth	1.25	1.5	1.75	2	2.25	2.5
V1 1st Node	5.4	6.5	7.6	8.7	9.8	10.9
V2 2nd Node	3.1	3.8	4.4	5.0	5.6	6.3
V3 3rd Node	2.1	2.5	2.9	3.3	3.8	4.2
V4	1.9	2.3	2.7	3.1	3.5	3.8
V5	1.7	2.0	2.3	2.7	3.0	3.3
V6	1.6	1.9	2.2	2.5	2.8	3.1
R1 Begin Bloom	1.5	1.8	2.1	2.4	2.6	2.9
R2 Full Bloom	1.4	1.7	1.9	2.2	2.5	2.8
FULL CANOPY	**1.3**	**1.6**	**1.8**	**2.1**	**2.4**	**2.6**
R3 Begin Pod	1.3	1.6	1.8	2.1	2.4	2.6
R4 Full Pod	1.3	1.6	1.8	2.1	2.4	2.6
R5 Begin Seed	1.3	1.6	1.8	2.1	2.4	2.6
R6 Full Seed	*1.3*	*1.6*	*1.8*	*2.1*	*2.4*	*2.6*



Description of Vegetative Stages



Terminate irrigation at R6.5 if the profile is full.

Step 1. Select Allowable Deficits based on soil type and irrigation system (Table 1).

Step 2. Select deficit based on growth stage of crop (Table 2). Set upper orange ring on gauge sight tube to water level just after last irrigation or when the profile is full (such as a rain that fills the soil profile and brings deficit to zero). For example for furrow irrigated clay soil at the V4 stage, the deficit is 3.1 inches. As growth stage changes, adjust deficit accordingly on the atmometer.

Fig. 1. Current University of Arkansas Cooperative Extension Service recommendations for irrigation scheduling in soybean using an Atmometer (Henry et al., 2014); recommended irrigation timing for the 2014 Mississippi County study sandy loam site is highlighted.

Table 2. Monthly precipitation at Wildy Family Farms compared to long-term (40 yr) average from Manila, Ark.

Month	Average Precipitation	2014 Precipitation	Variation from Average
	---------- in. ----------		
April	4.75	6.04	1.29
May	5.37	4.51	(0.86)
June	3.99	6.37	2.38
July	4.04	4.69	0.65
August	2.36	8.19	5.83
Total Season	20.51	29.80	9.29

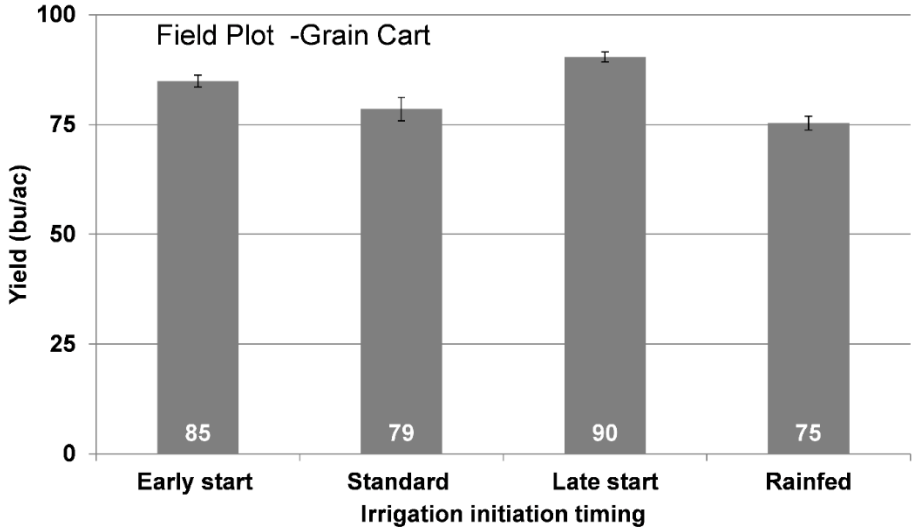


Fig. 2. Yield (±SEM) determined by from field length measurements taken at harvest using our cooperating producer's grain cart with load cells – Manila, Ark., 2014.

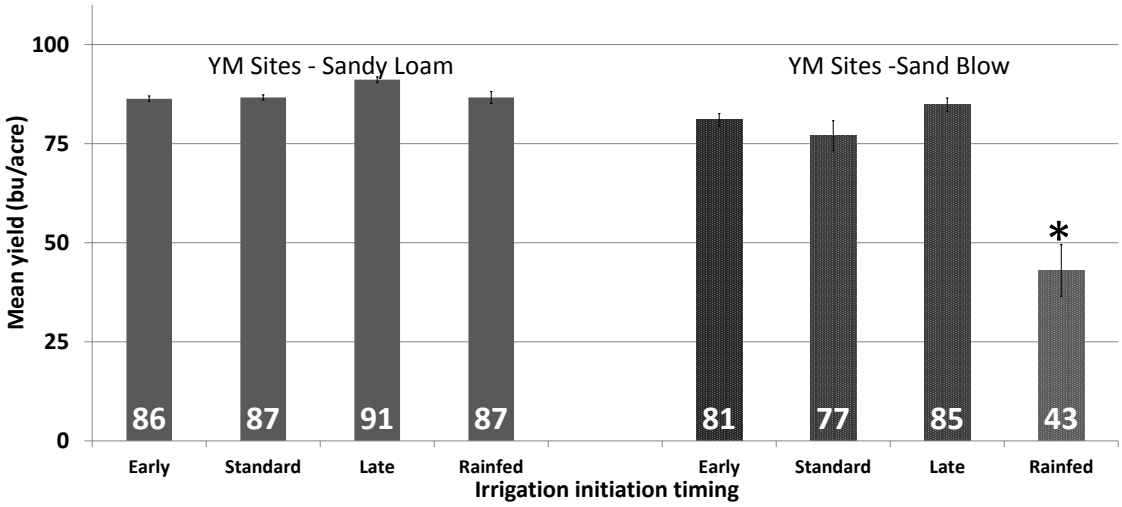


Fig. 3. Mean yields (±SEM) from georeferenced yield monitor (YM) sample points selected in sandy loam and sand blow soils to evaluate impact of within field variability on soybean yield in 2014 soybean irrigation initiation study – Manila, Ark., 2014. * = significant difference using a protected least significant difference test.

Soybean Response to Delays in Irrigation Initiation

P.B. Francis[1], P. Tacker[2], L. Earnest[3], and S. Hayes[3]

ABSTRACT

Research to determine the response of furrow-irrigated soybean to delays in the first irrigation application were conducted at the University of Arkansas System Division of Agriculture's Rohwer Research Station, Rohwer, Ark., in 2009 and 2010. The Arkansas Irrigation Scheduler program was used for scheduling delays of 0 to 15 days for maturity groups (MG) 3, 4, and 5 on a McGehee silt loam, and a MG 5 on a Sharkey silty clay soil. A 15-day delay reduced yields for MG 3 and 4 cultivars in the McGehee soil in 2009, and a 5-day delay lowered yields for the MG 3 in 2010. Delays of up to 15 days did not significantly reduce yields for the MG 5 in either year on the McGehee site. However, a 10-day delay in 2009 and a 15-day delay in 2010 in irrigation initiation reduced yields for the MG 5 in the Sharkey. Reductions in plant height and canopy coverage were observed when the first irrigation event was delayed, which may have influenced yields due to limits in crop photosynthesis capacity during critical growth stages. By reproductive growth, soil moisture did not appear to be affected by irrigation delays. Overall, our results indicate that delaying the first irrigation from 5-15 days can potentially reduce yield for indeterminate cultivars on loamy soils and determinate cultivars on more clayey soils.

INTRODUCTION

Proper irrigation can increase yield, yield stability, seed quality, and net returns for soybean (Heatherly and Spurlock, 1993; Frederick et. al., 2001; and Sweeny et al., 2003). Consistently high soybean yields are essential for sustaining profitable soybean production systems in the mid-South, and moisture stress at all growth stages can reduce yields (Stegman et al., 1990; and Amin et al., 2009). Drought stress during seed fill can lower yields more than earlier growth stages (Stegman et al., 1990; Foroud et al., 1993; and Heatherly and Spurlock, 1993) and response to irrigation can be related to maturity groups (Garcia and Garcia, 2010). Furrow irrigation is a common method of irrigation in eastern Arkansas. Often, farmers are busy with planting operations of many crops and delays in the first irrigation event of the season may occur. There is limited research concerning the magnitude of early season irrigation management on yield for modern cultivars in the mid-South. Therefore, studies to determine the effects of delayed irrigation initiation on the growth and yield of determinate and indeterminate soybean cultivars under furrow irrigation in the mid-South were initiated.

PROCEDURES

Studies were conducted at the University of Arkansas System Division of Agriculture's Rohwer Research Station, Rohwer, Ark., in 2009 and 2010 to determine the effects of delayed irrigation initiation on soybean growth and yield. Cultivars representing maturity groups (MG) 3, 4, and 5 were established in a McGehee silt loam (Aeric Ochraqualfs) to determine the effects of delaying the first irrigation by 0, 5, 10, and 15 days. Scheduling was determined using the Arkansas Irrigation Scheduler (AIS) program (Cahoon et. al., 1990) using a target deficit of 2.5 in. Delays were the number of days past the first scheduled event, adjusted for rainfall. Cultivars were 'Armor 39K4' (MG 3), 'HBK 4727' (MG 4), and 'HBK 5525' (MG 5) in 2009; and 'PION 93Y92' (MG 3), 'HBK 4727' (MG 4), and 'HBK 5525' (MG 5) in 2010. The experimental design was a randomized complete block with a split-plot treatment arrangement and three replications. Main plot treatments were MG and the subplot treatment was irrigation initiation delay. Subplots were five, 19-in. wide row strips approximately 400 ft long. An 8-ft alley between strips with a small dike was constructed to contain the furrow irrigation treatments.

A similar study was established on a Sharkey silty clay (Vertic Haplaquepts), approximately 0.6 mile from the McGehee site, but only the MG 5 cultivar was planted due to spatial constraints. The target deficit was 2 in. and the experimental design was a randomized complete block of irrigation delay treatments with four replications. Alley construction was similar to the McGehee site, but the subplot width was extended to 10 rows to reduce the influence of lateral water flow in the clayey soil. At both locations, WaterMark® soil-water tensiometers were positioned at 9 and 18 inches in the middle row drill, 200 ft from the irrigation pipe. Irrigation applications were terminated at R 6.5 growth (Fehr et. al., 1971). Plant heights were measured from three representative plants near the tensiometers and visual percent canopy closure (in increments of five percent) at reproductive growth stages (R1-R7). At both sites, yield was measured by harvesting the interior three rows of each treatment strip in a 200 ft long length, beginning 49 ft from the polypipe pad.

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Data were analyzed each year using the MIXED Procedure of SAS (SAS v. 9.2, SAS Institute, Cary, N.C.) using models suggested by Littell et. al., 2006. Maturity group and irrigation treatment were considered fixed factors and block as a random factor on the McGehee site and irrigation treatment as a fixed factor and block as a random factor on the Sharkey site. Mean comparisons were made for significant ($P < 0.05$) effects using the least squares means statement of PROC MIXED with the PDIFF option.

RESULTS AND DISCUSSION

A 15-day delay reduced yields by 17.1 bu/acre for the MG 3 cultivar and 25.3 bu/acre for the MG 4 cultivar on the McGehee soil in 2009 (Table 1). In 2010, a 5-day delay reduced yield of the MG 3 by about 10 bu/acre, and a 15-day delay by 13 bu/acre. Yield for the MG 4 cultivar was not affected by irrigation delays in 2010, and the MG 5 cultivar yield was not significantly lowered by any delays in the first irrigation in 2009 or 2010 on the silt loam soil. The treatment differences could be due to growth habit (indeterminate versus determinate), the crop phenology, or a combination. The MG 3 cultivar reached R7 (physiological maturity) approximately 17 days before the MG 5 cultivar, and the MG 4 cultivar reached R7 approximately 10 days before the MG 5 cultivar in both seasons.

On the clay soil in 2009, yield for the MG 5 cultivar was almost 13 bu/acre lower with a 10-day delay, and a 15-day delay reduced yields 14 bu/acre (Table 2). In 2010, lower yields were not observed until a 15-day delay in the first irrigation. It is interesting to note the contrasts in response to delays in the first irrigation between the silt loam soil and the silty clay soil. The Sharkey soil is a ‘cracking’ clay soil having large, dense, wedge-shaped structure in the subsoil that exhibit shear planes known as ‘slickensides’. Soybean root masses are often observed growing around these dense wedges suggesting a limited soil root distribution. Additionally, the available plant water holding capacity for clay soils is less than for silt loam soils (Brady and Weil, 2010). A limited root distribution and lower plant available water holding capacity of the Sharkey silty clay soil relative to the silt loam soil may explain the observed differences in yields.

Plant height and canopy cover decreased with delays in irrigation initiation (Tables 3-6). The only exception was for the MG 5 cultivar on the Sharkey soil in 2010 (Table 6). By reproductive growth, there were no observable effects of irrigation delays on soil moisture in 2009 or 2010 as inferred by the soil-water tension at 9- and 18-in. depths (Tables 7 and 8), indicating that any detrimental effects of delayed irrigation on the crop occurred early during vegetative growth by influencing plant internode extension and leaf growth.

PRACTICAL APPLICATIONS

When planting indeterminate soybean cultivars of maturity groups 3 and 4 in Arkansas, it is vital to establish the irrigation delivery system as soon as possible and begin irrigation immediately when scheduling indicates the need. This principle is also important when planting determinate maturity group 5 cultivars on clay soils. We documented that delays in the first irrigation under these circumstances can reduce plant heights, canopy coverage, and yield.

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Table 1. Influence of irrigation initiation delays on seed yield of three soybean maturity groups on a McGehee silt loam soil in 2009 and 2010, Rohwer, Ark.

Irrigation Delay (days)	Soybean Maturity Group 3	4	5
	---------- (bu/acre) ----------		
		2009	
0	61.5a†	81.7a	63.5a
5	61.5a	77.8ab	64.8a
10	57.5a	69.7b	66.0a
15	44.4b	56.4c	60.9a
		2010	
0	64.5a	56.3a	42.4a
5	53.6b	52.1a	39.0a
10	58.4ab	52.6a	38.4a
15	51.3b	50.1a	37.8a

†Means followed by the same letter are not significantly different, $P < 0.05$.

Table 2. Influence of irrigation initiation delays on seed yield for a MG 5 soybean cultivar on a Sharkey silty clay soil in 2009 and 2010, Rohwer, Ark.

Irrigation Delay (days)	Year 2009	2010
	---------- (bu/acre) ----------	
0	54.5a†	55.7ab
5	50.4ab	54.5ab
10	41.8bc	57.6a
15	40.8c	52.4b

†Means followed by the same letter are not significantly different, $P < 0.05$.

Table 3. Effect of delayed irrigation on canopy characteristics for maturity group (MG) 3, 4, and 5 soybeans on a McGehee silt loam, 28 July 2009.

Delay (d)	MG 3, R3 growth		MG 4, R2 growth		MG 5, V12 growth	
	ht (in.)	%canopy	ht (in.)	%canopy	ht (in.)	%canopy
0	28.4a†	100a	25.9a	97a	29.8a	100a
5	25.2b	100a	24.1a	95a	24.9b	97ab
10	22.9b	95ab	19.9b	88b	23.2bc	92b
15	23.8b	92b	20.6b	88b	22.4c	92b

†Column means followed by the same letter are not significantly different, $P < 0.05$.

Table 4. Effect of delayed irrigation on canopy characteristics for a maturity group (MG) 5 soybean at R2 growth on a Sharkey silty clay, 10 Aug. 2009.

Days delay	canopy height	% canopy
	----- in. ------	
0	25.4a†	95.0a
5	22.8b	77.5c
10	24.2ab	82.5bc
15	24.6ab	88.8ab

†Column means followed by the same letter are not significantly different, $P < 0.05$.

Table 5. Effect of delayed irrigation on canopy characteristics for maturity group (MG) 3, 4, and 5 soybeans on a McGehee silt loam, 29 July 2010.

Delay (d)	MG 3, R5 growth		MG 4, R4 growth		MG 5, R3 growth	
	ht (in.)	%canopy	ht (in.)	%canopy	ht (in.)	%canopy
0	46.3a†	100a	44.2a	100a	35.0a	100a
5	37.3b	96.7b	37.0b	95b	31.1ab	98.3ab
10	38.5b	95.0b	37.9b	96.7ab	31.1ab	96.7ab
15	37.0b	95.0b	36.5b	96.7ab	27.0b	95b

†Column means followed by the same letter are not significantly different, $P < 0.05$.

Table 6. Effect of delayed irrigation on canopy characteristics for a maturity group (MG) 5 soybean at R3 growth on a Sharkey silty clay, 10 Aug. 2010.

Days delay	canopy height	% canopy
	----- in. ------	
0	29.6a†	100a
5	30.4a	100a
10	29.9a	100a
15	29.8a	100a

†Column means followed by the same letter are not significantly different, $P < 0.05$.

Table 7. Influence of irrigation initiation delay on soil-water tension for three maturity group (MG) soybeans on a McGehee silt loam, 10 Aug. 2009.

	MG3, R5 growth		MG4, R4 growth		MG5, R2 growth	
	---------- depth (in.) ----------					
Delay (d)	9	18	9	18	9	18
	---------- -kPa ----------					
0	40a†	47a	36a	28ab	74a	35a
5	42a	17b	45a	13a	54a	37a
15	42a	48a	36a	35b	31a	59a

†Column means followed by the same letter are not significantly different, $P < 0.05$.

Table 8. Influence of irrigation initiation delay on soil-water tension for three maturity group (MG) soybeans on a McGehee silt loam, 21 July 2010.

	MG3, R4 growth		MG4, R3 growth		MG5, R2 growth	
	---------- depth (in.) ----------					
Delay (d)	9	18	9	18	9	18
	---------- -kPa ----------					
0	100a†	60a	64a	59a	108a	60a
5	51a	48a	79a	58a	65a	77a
15	131a	78a	84a	126b	105a	52a

†Column means followed by the same letter are not significantly different, $P < 0.05$.

Arkansas Discovery Farms: Improving Irrigation Efficiency in Soybean with Pipe Planner Design and a Surge Valve

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ABSTRACT

The State of Arkansas has declared parts of 13 counties in Eastern Arkansas "Critical Ground Water Decline Areas" due to large cones of depression in the underlying Mississippi alluvial aquifer. Furrow irrigation of soybean with poly tubing as a delivery header is practiced on thousands of acres in Arkansas. Pipe Planner and PHAUCET are computer-assisted hole sizing programs that can improve furrow irrigation efficiency on average by 25%. It is thought that by integrating a surge valve into the design that irrigation efficiency can be further increased. A field trial was conducted by dividing a 100-acre soybean field in half to compare the use of a surge valve against a control. Tail water losses totaled 3.94 inches and 7.45 inches for the treatment (Surge Valve) and control, respectively. Irrigation efficiency was calculated for each irrigation event as (Irrigation Total – Tail Water Loss) / Irrigation Total. The mean efficiency was 0.78 and 0.57 for surge valve treatment and control, respectively. This indicates that the surge valve was 21% more efficient in reducing tail water losses. Nitrate-N losses were 0.25 and 0.46 lbs/ac from the treatment and the control respectively while soluble P losses were 0.028 and 0.078 lbs/ac, respectively. Soybean yield was 51 bu/ac for both the treatment and the control. Results from this field trial indicated that the surge valve can increase irrigation efficiency by 20% while minimizing soluble nutrient losses in runoff.

INTRODUCTION

The State of Arkansas has declared parts of 13 counties in Eastern Arkansas "Critical Ground Water Decline Areas" (ANRC, 2015) due to large cones of depression in the underlying Mississippi alluvial aquifer. Secondary concerns arise from nutrient loss concerns in tail water losses. Furrow irrigation of soybean with poly tubing as a delivery system is practiced on thousands of acres in Arkansas. One challenge to using polytube as a distribution system is obtaining uniform flow of water for each furrow as water pressure and furrow length can vary along the length of the distribution header causing uneven water and greater tail water losses. Pipe Planner and PHAUCET are computer-assisted hole sizing programs that can improve furrow irrigation efficiency on average by 25% (Delta Plastics of the South, 2015). These programs account for pressure and furrow length changes along the distribution header so that hole-sizes can be differentially punched and distributed along the polytube resulting in uniform application of water to each furrow and decreased tail water loss. Integrating a surge valve into the computer design delivery system is thought to further increase efficiency. A surge valve can be programmed to automatically switch irrigation water from one set to another, thereby allowing more flow on one set while the other rests and lets irrigation water more time to soak into the soil profile (Younts and Eisenhauer, 2008). The purpose of the field trial was to determine if the use of a surge valve can further increase irrigation efficiency when integrated into a Pipe Planner design for furrow-irrigated soybeans using poly tubing.

PROCEDURES

In 2011, the University of Arkansas System Division of Agriculture along with its partners established Discovery Farms for row crop operations in Cross County. In 2014, a 100-acre soybean field was divided approximately in half to compare the use of a surge valve integrated into Pipe Planner design against a control of no surge valve with Pipe planner design (Fig. 1). Delta Plastics provided the Pipe Planner design for this study. The half of the field with the surge valve was further divided in half to create two sets that were irrigated alternately. Irrigation water use was monitored separately using two separate turbine-type in-line irrigation flow meters (Fig. 2a) equipped with data loggers. The surge valve (Fig. 2b) was placed near the well and two different poly tubing laterals went to the treatment side of the field. At the lower end of each half of the field, automated, runoff water quality monitoring stations (Fig. 2c) were established to: 1) measure runoff flow volume, 2) to collect water quality

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samples of runoff for water quality analysis and 3) measure precipitation. The ISCO 6712 automated portable water sampler was utilized to interface and integrate all the components of the flow station. Runoff flow volume was collected with open-channel pipes. Runoff discharge curves integrated over time (hydrographs) were used to calculate total discharge for a single runoff event. Discharge data were utilized to trigger flow-paced, automated collection of up to 100, 100-ml subsamples which were composited into a single 10-liter sample. A subsample of the 10-liter sample was collected, processed in the field for preservation and shipped in insulated shipping vessels to keep samples chilled to meet EPA guidelines for prepping and handling samples. Samples were shipped to the University of Arkansas' Water Resources Lab (certified by the Arkansas Department of Environmental Quality) to determine concentration of soluble phosphorus, nitrate-Nitrogen, total nitrogen (N), total phosphorus (P) and total solids according to handling, prepping and analytical methods outlined by EPA.

RESULTS AND DISCUSSION

Irrigation was applied at similar times in each half of the field, however the control received one less irrigation (5) than the surge valve treatment (6) and thus used 17.21 inches of irrigation for the season as compared to 18.02 inches for the surge-valve treatment side (Tables 1 and 2). Irrigation timing and duration was strictly at the discretion of the producer. Tail water losses totaled 3.94 inches and 7.45 inches for the treatment and control, respectively. The mean irrigation amount applied was 3.00 and 3.44 inches for surge valve treatment and control, respectively. The mean tail water loss per irrigation event was 0.66 and 0.83 inches for surge valve treatment and control, respectively.

Irrigation efficiency was calculated for each irrigation event as (Irrigation Total – Tail Water Loss) / Irrigation Total. The mean efficiency was 0.78 and 0.57 for surge valve treatment and control, respectively. This indicates that the surge valve was 21% more efficient in reducing tail water losses.

Nitrogen and phosphorus loss in tail water were low in both fields (Tables 3 and 4), but numerically losses were slightly larger in the control as compared to the surge valve treatment. Nitrate-N losses were 0.25 and 0.46 lbs/acre from the treatment and the control respectively while soluble P losses were 0.028 and 0.078 lbs/acre, respectively. Soybean yield was 51 bu/ac in both the treatment and control.

PRACTICAL APPLICATIONS

These data indicate that surge valves integrated into Pipe Planner of PHAUCET designs can increase irrigation efficiency ((Irrigation Total – Tail Water Loss) / Irrigation Total) by 21%. This coupled with the efficiency provided by computerized design of furrow irrigation with poly tubing indicates that irrigation efficiency can be increased by reducing tail water losses. In communicating with the producer, he felt that the computerized hole-selection design reduced his watering time from 60 hours to 30 hours, which translated in both water and energy savings. Data indicated that soluble nutrient losses were very low on a per acre basis. While this field trial represents one field in one season, it does create confidence that we can increase irrigation efficiency using computerized hole-design integrated with surge valves while minimizing nutrient losses in tail water.

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Table 1. Tail water loss from individual irrigation events for soybean from furrow irrigation designed with Pipe Planner with surge valve.

Date	Irrigation	Tail water Loss (TWL)	Irrigation - TWL/Irrigation	Effective Irrigation
	---inches---			
8/11/2014	3.11	0.10	0.97	3.01
8/21/2014	3.60	1.03	0.71	2.57
8/30/2014	1.53	0.52	0.66	1.02
9/10/2014	3.21	0.51	0.84	2.69
9/26/2014	4.06	1.21	0.70	2.85
10/1/2014	2.51	0.57	0.77	1.94
Totals	18.02	3.94	0.78	14.08

Table 2. Tail water loss from individual irrigation events for soybean from furrow irrigation designed with Pipe Planner without a surge valve.

Date	Irrigation	Tail Water Loss (TWL)	TWL/Irrigation	Effective Irrigation
	---inches---			
7/29/2014	3.65	1.67	0.54	1.98
8/25/2014	4.18	1.81	0.57	2.37
9/9/2014	2.27	1.44	0.37	0.83
9/24/2014	4.23	1.38	0.67	2.85
9/30/2014	2.88	1.16	0.60	1.72
Totals	17.21	7.45	0.57	9.76

Table 3. Nutrient loss in runoff from furrow irrigation of soybean designed with Pipe Planner and with a surge valve.

Date	Nitrate-N	Total N	Soluble-P	Total P	Total Solids
	---lbs---				
8/11/2014	11.33	16.90	0.709	1.679	403
8/21/2014	2.15	8.98	0.277	0.619	176
8/30/2014	0.39	9.90	0.187	0.437	237
9/10/2014	0.26	7.75	0.179	0.295	125
9/25/2014	0.20	1.10	0.052	0.279	539
9/26/2014	0.47	9.69	0.218	0.772	807
10/1/2014	0.07	8.65	0.020	0.871	291
Mean	2.12	9.00	0.235	0.707	368
Loss / Acre	lbs/A	lbs/A	lbs/A	lbs/A	lbs/A
	0.25	1.07	0.028	0.084	44

Table 4. Nutrient loss in runoff from furrow irrigation of soybean designed with Pipe Planner and without a surge valve.

Date	Nitrate	Total N	Soluble -P	Total P	Total Solids
	---lbs---				
7/29/2014	8.39	20.37	1.090	3.239	942
8/25/2014	2.12	12.74	0.541	1.680	1317
9/9/2014	3.41	15.54	0.818	1.368	86
9/24/2014	4.41	12.38	0.598	2.305	2042
9/30/2014	0.41	35.96	0.163	2.484	545
Mean	3.75	19.40	0.642	2.215	986
Loss/acre	lbs/acre	lbs/acre	lbs/acre	lbs/acre	lbs/acre
	0.46	2.37	0.078	0.270	120

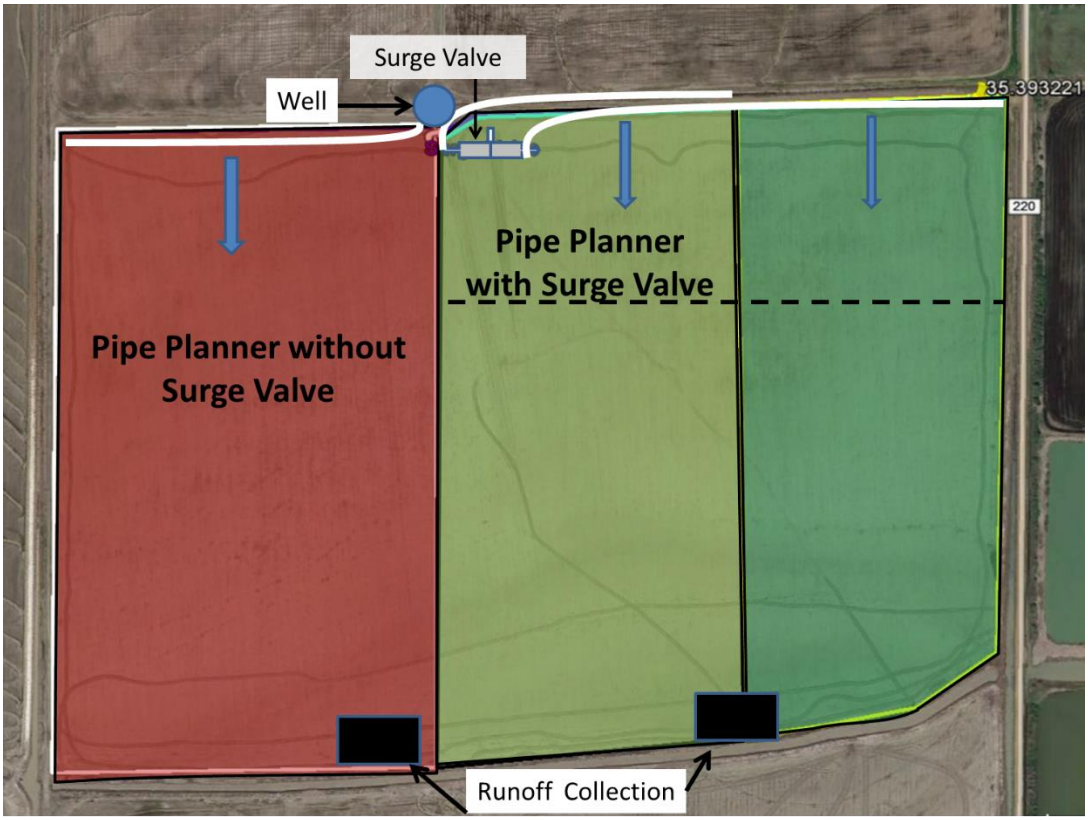

Fig. 1. Overview of field set up to compare the performance of a surge valve integrated into Pipe Planner design for furrow irrigation of soybeans (Two sections at right of well) against the control of Pipe Planner design without a surge valve (Left).

Fig. 2. Irrigation flow meters (a), surge (b) and automated runoff monitoring station utilized to measure irrigation flow, automatic distribution of flow and tail water loss from irrigation.

Suitability of Energy Beets for Double-Cropping with Soybeans in the Arkansas Delta

S. Green[1] and T. Meadors[1]

ABSTRACT

Double crop soybeans in Arkansas have generally been limited to winter wheat (*Triticum aestivum*). Our objective in this study was to determine the suitability of energy beets (*Beta vulgaris*) as an alternative double crop with soybean. Our treatments consisted of various beet harvest dates with corresponding soybean planting as well as full-season and double crop with winter wheat soybean. Due to harsh winter conditions in 2014, all winter energy beets were winter killed, while winter wheat survived the harsh conditions. Our study shows that early-planted soybean results in greater yield, but we cannot discuss the effect of the winter beet crop due to winter kill. Winter beets may be appropriate in some years, but in an abnormally cold and icy winter, they do poorly. Winter wheat is a less risky double crop companion for soybean.

INTRODUCTION

Soybean's capacity to produce similar yields in a variety of environments paired with the longer growing seasons experienced in the mid-South allow producers the option of implementing the double-crop production system (DCPS). Wesley (1999) listed the potential advantages of the DCPS as (1) increased cash flow that results from better utilization of climate, land and other resources; (2) reduced soil and water losses by having the soil covered with a plant canopy most of the year; and (3) more intensive land use and utilization of machinery, labor, and capital investments.

An alternative winter crop with a flexible harvest time could lessen the risk traditionally associated with DCPS, but still provide profits and improve farm efficiency through yearlong land and equipment use. Energy beets (*Beta vulgaris*) are one potential crop that satisfies the aforementioned parameters. Energy beets are not harvested for seed, but for root yield; therefore, there is no defined maturity. This allows for a flexible harvest date.

The objective of this study was to compare a traditional DCPS of the mid-South with winter wheat (*Triticum aestivum*), a full-season production system (FSPS) of soybeans, and the energy beet/soybean DCPS to evaluate the suitability of such alternative double-cropping systems to the Arkansas Delta region.

PROCEDURES

The experimental design was a randomized complete block with five treatments and four replications. The treatments were winter wheat followed by soybeans (WWS), winter fallow/ full-season soybean production (WFFS), and energy beet with three harvest dates followed by soybeans, where each energy beet harvest date was a treatment (EB1S, EB2S, and EB3S). Plot size was 82.0 × 10.2 ft for all plots.

Field preparations were made in the late-summer where the ground was tilled twice, and seedbeds were prepared using a hipper/roller. Winter fallow full season and all energy beet/soybean treatments had seedbed widths of 30-in., while WWS seedbeds were 60 in. in width. All plots received a broadcast fertilizer application of N (90 lb N/acre), P (40 lb P_2O_5/acre) and K (404 lb K_2O/acre). All plots of energy beets were planted on 27 September 2013 with 30-in. row spacing using Betaseed 305 ENR at a target rate of 69,668 seed/acre. All plots of wheat (Dixie, vr. McAlister) were planted on 25 October 2013 using a grain drill with 6-in. row spacing at a rate of 100 lb/acre. Plant population data was collected prior to winter for each plot of energy beets at three randomly generated locations of one of two center rows, and again following winter at the same locations to determine winter mortality rate. An application of N was made to wheat at a rate of 60 lb N/acre as urea in the spring. Winter wheat was harvested on 18 June 2014 using a small plot combine. Harvest samples were 49 ft × 5 ft and representative of the entire plot; winter wheat sample weights were corrected to 13% moisture content.

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Winter energy beets were winter killed by unusually severe winter weather for the region. Therefore, all soybeans planted following energy beet treatments were planted within the guidelines for Early Soybean Production System (ESPS), FSPS, and DCPS into a stale seedbed as originally planned. Table 1 provides the variety, seeding rate, and planting date of each soybean treatment. Soybeans were planted on 30-in. row spacing. The soybeans following energy beet treatments and WFFS treatment were planted into stale seedbeds. The WWS treatment was planted into standing wheat stubble following winter wheat harvest. Pesticide applications were made as needed following University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations. Plots were furrow irrigated as needed. Prior to harvest, plant maturity data was taken for all treatments; this included assigning a lodging score and plant height (Table 2). Soybeans were harvested using a small plot combine on a 49 ft representative sample harvest from the center two rows and yields were adjusted to 13% moisture content. Data were analyzed using the analysis of variance (ANOVA) procedure in SAS V. 9.2 (SAS Institute Inc., Cary, N.C.). Mean separations were evaluated using Fishers' least significant difference test when ANOVA indicated significant differences at $P < 0.05$.

RESULTS AND DISCUSSION

For the 2013/2014 double-cropping trial, the winter energy beets were all winter killed due to unusually cold temperatures and numerous ice storms, and provided no testable data. However, the winter wheat did survive the season and provided a harvestable yield. When evaluated for grain yield, the 2014 soybean crop had a significant difference among treatments (Table 2). The EB1S and EB3S treatments were not significantly different from one another, but the EB1S and all other treatments, excluding the EB3S, were significantly different. This data conflicts with the findings of Kyei-Boahen and Zhang (2006), Pfeiffer (2000), and Egli and Cornelius (2009). However, there may have been confounding factors associated with the soybean trials of 2014 due to an inadvertent drift application of two growth regulators, potentially negatively impacting soybean yield; but the impact of this application is unquantifiable. The EB2S and WFFS were the treatments most visually impacted and could partly explain the relatively low yields of the two treatments compared to the later-planted treatments.

PRACTICAL APPLICATIONS

The earliest and latest planting dates provided the greatest soybean yield. Double-cropped wheat soybean along with mid- and late-planted soybean and full-season soybean following fallow all had similar yields. Although energy beets have been grown during the winter in northeast Arkansas, there is greater risk of winter kill of energy beets than winter wheat during harsh winters.

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Table 1. Soybean variety and planting dates.

Treatment	Variety	Planting Date	Seeding Rate (seed/acre)
EB1S†	Dynagro 33LL49	4/24/2014	109955
WFFS	Progeny 5220LLS	5/27/2014	129947
EB2S	Progeny 5220LLS	5/27/2014	129947
EB3S	Progeny 5220LLS	6/19/2014	139943
WWS	Progeny 5220LLS	6/20/2014	139943

† EB1S, winter energy beet followed by early soybean planting; EB2S, winter energy beet followed by mid-season soybean planting; EB3S, winter energy beet followed by late soybean planting; WFFS, winter fallow followed by full-season soybean; WWS, winter wheat followed by double-crop soybean.

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Table 2. Soybean yield and crop characteristics.

	Treatment				
Crop Characteristic	**EB1S**	**EB2S**	**EB3S**	**WWS**	**WFFS**
Grain Yield (bu/ac)	48.4a †	35.8b	39.6ab	34.2b	34.3b
Lodging	0.875b	3.125a	1.375b	1.000b	2.125ab
Plant Height (ft)	3.80c	5.35a	4.76b	4.40b	5.41a
Emergence (%)	66a	58ab	59ab	48b	60ab
Plant Population (plants/ ac)	29086a	30690a	33612a	27266a	31614a

† Numbers followed by the same letter within a row are not significantly different at the $P < 0.05$ probability level according to Fisher's least significant difference test.

EB1S, winter energy beet followed by early soybean planting; EB2S, winter energy beet followed by mid-season soybean planting; EB3S, winter energy beet followed by late soybean planting; WFFS, winter fallow followed by full-season soybean; WWS, winter wheat followed by double-crop soybean.

Developing Profitable Irrigated Rotational Cropping Systems

J. Kelley[1]

ABSTRACT

A field trial evaluating yield and resulting economic outcomes of eight rotational cropping sequences that Arkansas producers may use was initiated at the Lon Mann Cotton Branch Research Station in April of 2013. Wheat yields from wheat harvested in June 2014 did not differ whether planted following corn, grain sorghum, or early-season soybean the previous year and averaged 72 bu/acre. Corn yield was not impacted by previous crop and yielded 250 bu/acre when following soybean and 245 bu/acre when following corn. Significant yield differences were seen for early-season soybean with plots planted following soybean yielding 43 bu/acre and 64 bu/acre when following corn or grain sorghum. Double-crop soybean yields in 2014 were also impacted by crop rotation. Double-crop soybean yields following soybean in 2013 only made 30 bu/acre but double-crop soybean that followed corn or grain sorghum in 2013 produced 39 and 40 bu/acre. Differences in soybean yields were likely in part caused by high soybean cyst nematode levels. Economic analysis of profitability of cropping systems evaluated is ongoing.

INTRODUCTION

In Arkansas and the mid-South region, most of the crop rotation studies in past years have focused on cotton and have shown greater yields when crop rotation is used. Reasons for increased cotton yields generally involved reduction in reniform nematodes, less disease pressure and/or increased soil fertility, or from unknown reasons. As crop makeup shifts based on economic decisions, more information is needed for producers on which crop rotation produces the greatest yields and profitability under mid-South irrigated conditions. There is a lack of long-term crop rotation research that documents how corn, soybean, wheat, and grain sorghum rotations perform in the mid-south. A comprehensive evaluation of crop rotation systems in the mid-South is needed to provide non-biased and economic information for Arkansas producers.

PROCEDURES

A field trial evaluating yield and resulting economic outcomes of eight rotational cropping systems that Arkansas producers may use was initiated at the Lon Mann Cotton Branch Research Station near Marianna, Arkansas in April of 2013.

The eight rotational cropping systems evaluated include;

1. **Corn–Soybean–Corn–Soybean.** Corn planted in March/April, then early-season group IV soybean the following year.
2. **Corn–Wheat–Double-Crop Soybean–Corn**. Corn planted in March/April, wheat planted following corn harvest, double-crop soybean planted after wheat harvest, and corn planted the following year.
3. **Soybean–Wheat–Double-Crop Soybean–Wheat.** Early-season group IV soybean, wheat planted after soybean harvest, double-crop soybean after wheat harvest.
4. **Grain Sorghum–Wheat–Double-Crop Soybean–Grain Sorghum.** April planted grain sorghum, wheat planted following grain sorghum harvest, double-crop soybean planted after wheat harvest and full-season grain sorghum planted the following year.
5. **Continuous Corn.** Corn planted in March/April every year.
6. **Continuous Soybean.** Early-planted group IV soybean planted in April every year.
7. **Grain Sorghum–Soybean–Grain Sorghum–Soybean.** Full-season grain sorghum, followed by early-planted group IV soybean planted the following year.
8. **Soybean–Wheat–Double-Crop Grain Sorghum–Soybean.** April-planted group IV soybean, wheat planted following soybean harvest, double-crop grain sorghum planted after wheat harvest followed by early-planted group IV soybean the following year.

Soil on this site is a Memphis silt loam which is typical for the area. The field had previously been cropped to soybean in 2012. Crop rotation treatments were replicated four times within a randomized complete block design and all treatments were conducted each year and plots size is 25 ft wide (8 rows wide) by 200 ft long. All plots were conventionally tilled and summer crops were planted on raised beds on 38-inch row spacing. Wheat plots planted each fall were also planted on 38-inch wide raised beds and planted with a grain drill with 6-inch row spacing. All summer crops were irrigated via furrow irrigation according to the University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) irrigation scheduler program. Normal production practices such as planting dates, seeding rates, weed control, insect control, and fertilizer for each crop followed current CES recommendations. Harvest yield data was collected from the center two rows of each plot and remaining standing crops were harvested with a commercial combine. Soil nematode samples were taken at trial initiation from all plots and analysis showed high levels of soybean cyst nematode in most plots that were above economic threshold.

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RESULTS AND DISCUSSION

The results discussed below are from 2014 and represent the first full year of data (Table 1) from this project. Wheat yields harvested in June 2014 ranged from 69-75 bu/acre and did not vary whether wheat was planted following early-season soybean, corn, or grain sorghum. Wheat harvest was delayed by the lateness of the crop and rainfall at harvest. Following wheat harvest, double-crop soybean and double-crop grain sorghum were planted 7 July. Yields from double-crop soybean were reduced due to late planting; however significant differences in yield were seen based on previous crop. Double-crop soybean averaged 39 or 40 bu/acre when following corn or grain sorghum and only 30 bu/acre when following early-season soybean the previous year. Due to the late planting date and severe infestations of sugarcane aphid (even with insecticide spraying), yields from double-crop grain sorghum were not obtained in 2014.

Yields from early-season soybean varied greatly depending on which crop had been planted the previous year. When early-season soybean followed corn or grain sorghum, yields were 64 bu/ac compared to only 43 bu/acre for when following early-season soybean. Yields of early-season soybean and double-crop soybean were likely negatively impacted by high numbers of soybean cyst nematodes; however, at this time, data from soil nematode samples taken in the fall of 2014 are not available.

Yields of corn did not vary greatly based on previous crop, with yields of 250 bu/ac following early-season soybean or 245 bu/acre when following corn the previous year. Grain sorghum is grown in rotation and each year will always be following a soybean crop.

This is the first year of yield results and corresponding economic analysis is ongoing.

PRACTICAL APPLICATIONS

As producers search for the most profitable production system, data from this project will provide local yield and corresponding economic data to help guide decisions on ways to improve profitability of irrigated cropping systems.

ACKNOWLEDGMENTS

Funding for this project was provided by the Arkansas Soybean, Corn/Sorghum, and Wheat Research Promotion Boards and is greatly appreciated. Support was also provided by the University of Arkansas System Division of Agriculture.

Table 1. Wheat, corn, grain sorghum, early-season soybean, and double-crop soybean yields from 2014 based on previous crops grown in 2013.

Previous Crop in 2013	Wheat	Corn	Grain Sorghum	Early-Season Soybean	Double Crop Soybean
		----------Bu/ac----------			
Early-Season Soybean	75	250	143	43	30
Corn	72	245	---	64	39
Grain Sorghum	69	---	---	64	40
LSD (0.05)	NSD	NSD	---	13	4

LSD = Least significant difference test. NSD = No significant difference.

Effect of Planting Date and Inoculation on Soybean Yield

T. L. Roberts[1], W.J. Ross[2], N. Slaton[1], J. Shafer[1], C. Greub[1], S. Williamson[1] and C. Scott[1]

ABSTRACT

Seed inoculation of [*Glycine max* (L.) Merr.] soybean was a common practice, but in recent times has not garnered the attention of producers that it once did. Identification and development of new inoculant strains and cocktails have led to the need for more research on the potential benefit of these products for soybean production in Arkansas. The objective of this research was to determine the influence of new inoculation products and planting date on soybean yield under a variety of Arkansas production systems. Planting dates were selected in mid-May, June and July to encompass the primary planting dates that are used in Arkansas production systems. A total of five treatments were used including an untreated check, an industry accepted peat-based inoculant and three liquid products that are currently being sold in Arkansas. There was a significant planting date by product interaction indicating that for earlier planting dates there was no benefit to inoculation with any of the products. Conversely at the two later planting dates, June and July, there was a significant yield increase when any inoculant product was used compared to the untreated control. The data obtained from this trial indicates the potential for yield increases from seed inoculation for planting dates near 15 June or later.

INTRODUCTION

Soybean [*Glycine max* (L.) Merr.] is a legume which can form a symbiotic relationship with *rhizobia* bacteria to access and assimilate nitrogen (N) from the atmosphere. Of all the row-crops produced in Arkansas, soybean has the highest N requirement on a per acre basis. The ability of this crop to perform N fixation prevents the need for producers to apply N to this important crop when that symbiotic relationship is active and effective. Previous research focused on N fixation in soybean has indicated that the persistence of rhizobia in the soil can be effected by environmental conditions including prolonged soil saturation or water ponding (Pederson, 2004), which is common in Arkansas soils. Additional research has shown that some species of rhizobium are more efficient at fixing N under anaerobic or flooded soil conditions (Roughley et al., 1995). All these environmental factors combined with lower soybean yields for planting dates later than 1 June, lead us to investigate this interaction of planting date and inoculant product.

PROCEDURES

Trials were established at the Pine Tree Research Station (PTRS), Vegetable Research Station (VRS) and Rohwer Research Station (RRS) during 2014. Management with respect to seeding rate, irrigation, and pest control closely followed recommendations from the University of Arkansas System Division of Agriculture's Cooperative Extension Service. In each trial, soybean was irrigated as needed using furrow irrigation at RRS, flood irrigation at PTRS and sprinkler irrigation at VRS.

A single cultivar (Pioneer 49T80) was chosen for this study to represent a high-yielding late maturity group (MG) IV soybean cultivar that is well adapted to Arkansas growing conditions. Soybean seed were treated with Cruiser Maxx® seed treatment prior to the application of any inoculant products. The inoculant products used in this trial included Rhizostick®, Optimize® 400, Dynastart Max® and Primo® CL and were applied to the seed based on manufacturer recommendations.

Soybean plots were established as near to the 15 May, 15 June and 15 July as possible with the exact planting dates listed in Table 1. For the VRS location, the earliest planting date that was achieved was 3 June 2014. At the RRS and VRS locations, plots consisted of 4 rows spaced 38 inches and 36 inches, respectively. At PTRS the plots were drilled in 9 rows spaced 7 inches apart. All plots were 20 feet in length.

Each experiment was a randomized complete block design with four blocks. The analysis of variance (ANOVA) model was a simple one-way comparison of inoculant products within a planting date. The ANOVA was performed by site using JMP Pro 11.0 (SAS Institute, Inc., Cary, N.C.). When appropriate, mean separations were performed using Fisher's protected least significant difference method with $P = 0.05$.

RESULTS AND DISCUSSION

Soybean yield varied across locations and plantings dates aside from the inoculant treatments, which is what lead the statistical analysis to be conducted by site within planting dates. There were some trends that were seen across locations including a decrease in yield with later planting dates (Tables 2-4). Overall yields were highest at the RRS location reaching >90

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bushels/ac in the May planting date. Yields at the PTRS and VRS locations were lower, but still respectable considering the influence of some late planting dates. For the purpose of this trial, we will be discussing differences in inoculant treatment within a planting date for each location. Unfortunately, in this trial there were only mid-May plantings established at PTRS and VRS. The May planting date tended to have the highest yields for each location. For these two locations, there were no statistical differences in any of the inoculant treatments.

The June planting date resulted in similar yields to the May planting date for all locations. At the VRS location during the early June planting date, there was a significant difference in soybean yield influenced by inoculant treatment, with all treatments receiving an inoculant product yielding significantly higher than the untreated control. Inoculant treatment had a significant influence on soybean yield at the RRS with no differences seen at the PTRS or VRS locations for mid-June planting dates. Soybean response to inoculation at RRS was similar to what was seen for the early June planting date at VRS, all treatments receiving an inoculant yielded significantly higher than the untreated control. The yield increase from using an inoculant for the June planting date at RRS ranged from 8-10 bushels/acre (Table 3).

Yield was significantly influenced by inoculant treatment at all locations for the July planting date. Similar to the results for RRS in June and VRS in early-June, the primary difference was between treatments that received an inoculant versus the untreated control. For the PTRS location, the yield increase from treatments that were inoculated ranged from 10-13 bushels/acre. For the RRS location, yield increases from inoculation ranged from 7-13 bushels/ac; and similarly at the VRS location, yields were increased by 8-13 bushels/acre.

The July planting date resulted in a significant increase in soybean yield for all products and all locations when compared to the untreated control. The most consistent yield increases were seen in the latest planting date, but both the May VRS and June RRS planting date × location combinations exhibited yield responses to inoculation. Although there were some slight numerical differences between inoculant products, they were typically less than 5 bushels/acre indicating that there was no benefit from new liquid inoculant formulations over the standard peat-based inoculant.

PRACTICAL APPLICATIONS

The data presented in this paper suggests that inoculating soybeans, even where soybeans have been grown in the past, can be economically beneficial. Although the data showed mixed results for the May and June planting dates across locations, there were some benefits. However, the use of an inoculant, regardless of the product, always resulted in significant yield increase at all locations for the July planting date. The breakeven yield gain to pay for most of these inoculant products is <1 bushel/acre (considering $8.00/bushel), but where statistically significant yields were increased anywhere from 7-13 bushels/acre. Results of this research indicate that inoculation of soybean seed prior to planting can lead to significant yield increases especially for later planting dates. The cost of inoculation is relatively cheap compared to the potential yield gains from its use making inoculation a relatively cheap insurance policy.

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Table 1. Selected soil and agronomic management information for soybean inoculation trials conducted in 2014 in Arkansas.

Information or Event	Pine Tree Research Station	Rohwer Research Station	Vegetable Research Station
Soil series	Calloway silt loam	Hebert silt loam	Roxanna silt loam
Previous crop	Rice	Rice	Soybean
Row width (inches)	7	38	36
Seed rate (seed number/acre)	155,000	155,000	155,000
May Seeding Date	May 22	May 21	June 3
June Seeding Date	June 16	June 17	June 16
July Seeding Date	July 14	July 16	July 14

Table 2. Soybean yield across planting dates at the Pinetree Research Station (PTRS) in 2014.

	May	June	July
Treatment		----------Yield (bu/ac)----------	
Untreated Control	57	60	39
Rhizostick	60	60	52
Optimize 400	58	59	49
Dynastart Max	55	63	52
Primo CL	55	58	49
LSD 0.05	NS	NS	5.7

Table 3. Soybean yield across planting dates at the Rohwer Research Station (RRS) in 2014.

	May	June	July
Treatment		----------Yield (bu/ac)----------	
Untreated Control	94	69	56
Rhizostick	95	79	69
Optimize 400	93	77	64
Dynastart Max	96	78	63
Primo CL	93	78	66
LSD 0.05	NS	3.9	4.6

Table 4. Soybean yield across planting dates at the Vegetable Research Station (VRS) in 2014.

	Early June	Mid-June	July
Treatment		----------Yield (bu/ac)----------	
Untreated Control	40	62	43
Rhizostick	49	62	56
Optimize 400	52	60	53
Dynastart Max	50	63	52
Primo CL	50	62	51
LSD 0.05	7.9	NS	6.4

Improving Germination Rate of Soybean Seed Dried Using Recently Introduced In-Bin Drying Systems

G.G. Atungulu[1], Z.R. Young[1], S. Thote[1], H-M. Zhong[1], and S. Sadaka[1]

ABSTRACT

Recently introduced technology comprised of cables used to monitor grain moisture content (MC) and temperature throughout the entire grain bin mass during drying offers a means to utilize low-temperature natural air drying for soybean seed. From an electronic monitor and fan control standpoint, the new technology appears very promising for managing soybean seed. However, the ultimate success hinges on (1) accurate equilibrium moisture content (EMC) data to determine fan run time; (2) knowledge of germination rate reduction for soybean placed in these new systems, particularly those in the upper layers where the soybeans remain at high MC for prolonged periods of time; and (3) understanding the extent to which seed germination rate could be impacted by the inadvertent fluctuation of MC and drying and rewetting of grain during the drying process. This research addresses the problem of establishing an accurate EMC database, across temperature and relative humidity ranges that are typically encountered during natural air, low-temperature drying of soybean seed.

INTRODUCTION

Typically, soybean seed companies prefer to use natural air, without any heat added, for seed drying to maintain desirable seed germination rates. The practice in Arkansas is to allow soybeans to dry in the field to a moisture content (MC) of around 13% before they are harvested. Since soybeans give up and take on moisture easily, rehydration and dehydration brought upon by variable temperature and relative humidity (RH) conditions in the field, and during on-farm in-bin drying can greatly reduce seed integrity. Past literature (Khan et al., 2011) suggested that the stress the seed endures during periods of dehydration and rehydration greatly reduce the rate of successful germination as well as negatively impact overall plant vigor.

Recently introduced technology for use in on-farm drying systems offers a means to utilize the advantages of low-temperature, in-bin drying systems for soybean seed. The new technology controls drying fan operation by the principle of equilibrium moisture content (EMC), which is the MC that a specific grain will attain if exposed to air with a given RH and temperature for a long enough duration. Thus, drying fans are operated only under set conditions to avoid over-drying of seeds. The new in-bin technology comprises sensors to measure ambient air conditions, as well as cables to monitor grain MC and temperature throughout the grain bin mass, and the data can also be accessed anytime via the internet, which has revolutionized monitoring capabilities. From an electronic monitor and fan control standpoint, this new technology appears very promising for managing soybean seed. However, the ultimate success hinges on determination of accurate EMC data to establish fan run time; understanding the extent of germination rate reduction for soybean placed in these new systems, particularly those in the upper layers where the soybeans stay at high MC for prolonged periods of time; and how seed germination rate could be impacted by the inadvertent fluctuation of MC and drying and rewetting of grain during the drying process. This research focuses on addressing the problem of establishing accurate EMC data of recently grown soybean seeds. This information is critical for accurate control of the new in-bin systems. In practice, the EMC profile of soybean in-bin drying systems is calculated using measured soybean temperature and RH of air in contact with the grain and grain-specific constants as input parameters (Ondier et al., 2011).

The study hypothesized that for true EMC prediction, constants in the EMC models may need to be adjusted to account for soybean cultivar and growing location. The specific study objectives were to determine (1) accurate EMCs of currently produced soybeans; (2) impact of soybean cultivar; and (3) impact of soybean growing location on EMC profiles at different air temperature and relative humidity conditions.

PROCEDURES

Three soybean cultivars harvested in 2013 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS), Colt, and Northeast Research and Extension Center (NEREC), Keiser, were selected for the first round of study. For each cultivar (Terral REV 51R53, UA 5213C and UA5612), three seed lots from random plots were harvested and transported to the Arkansas Variety Testing Lab, Fayetteville, Arkansas. The seeds were allowed to dry naturally under room conditions to 8-10% MC before use. The EMC of the soybean seed at 15, 25, and 35 °C and equilibrium relative humidity (ERH) at 10% to 90% were determined using a Vapor Sorption Analyzer (VSA). The absorption and desorption constants were calculated separately for four standard equations—the modified Halsey, modified Henderson, modified Chung-Pfost, and Modified Oswin (Table 1). Model fitting used a procedure invoking non-linear regression analyses in a MATLAB program.

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RESULTS AND DISCUSSION

Sorption isotherms of soybean cultivars (Terral REV 51R53, UA 5213C and UA5612) which were grown at NEREC and PTRS are shown in Fig. 1(a-b). Temperature has the greatest effect on EMC, though growing location and cultivar do have some affect as well. Hysteresis effect tended to be higher at low temperature of 15 °C compared to 35 °C. Constants of empirical equations (Table 1) for prediction soybean EMC are shown in Table 2 (a-c) and Table 3 (a-b). The constants established for the used prediction models gave better results for the higher temperature conditions of 35 °C; therefore, they are not recommended for EMC at 15 °C and 25 °C. Further data fitting will be necessary to establish constants at lower temperatures.

PRACTICAL APPLICATIONS

Building an accurate database of the soybean EMCs for ranges of temperature and RH encountered during natural air, low temperature drying of currently grown soybean cultivars is an important step for successful implementation of the new in-bin drying and storage technology to improve seed germination rate and vigor.

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Table 1. Four commonly used sorption isotherm models. †

Name of model	Equilibrium moisture content model	Water activity / ERH model
Modified Henderson	$MC \approx \left[\frac{-\ln(1-a_w)}{A(T+B)}\right]^{1/C}$	$a_w \approx 1-\exp[-A(T+B)M^C]$
Modified Chung-Pfost	$MC \approx \frac{-1}{C} ln\left[-\frac{(T+B)}{A} ln(a_w)\right]$	$a_w \approx exp\left[\frac{-A}{(T+B)} exp(-CM)\right]$
Modified Halsey	$MC \approx \left[\frac{-\ln(a_w)}{\exp(A+BT)}\right]^{-1/C}$	$a_w \approx exp[-exp(A+BT)M^{-C}]$
Modified Oswin	$MC \approx (A+BT)\left[\frac{a_w}{1-a_w}\right]^{1/C}$	$a_w \approx \frac{1}{\left[\frac{(A+BT)}{M}\right]^C+1}$

†M, moisture content, % (d.b.); aw, water activity (decimal); ERH, Equilibrium relative humidity (decimal); T, absolute temperature, K; A, B and C, constants specific to individual equations (Aviara et al., 2004).

Table 2. Constants for models (modified Chung Pfost, Modified Halsey, Modified Henderson, and Modified Oswin) used to predict sorption isotherms of different soybean cultivars grown at the Northeast Research and Extension Center, Keiser, Arkansas. Better prediction at 35 °C.

	Emperical Constants (Location: Keiser; Cultivar: UA 5213C)								
Model Type	**A**			**B**			**C**		
	Constant Value	**SE**	***P*-Value**	**Constant Value**	**SE**	***P*-Value**	**Constant Value**	**SE**	***P*-Value**
Modified Chung Pfost									
Absorption	-28.096	6.84E-07	< 0.05	-311.43	1.305	< 0.05	-0.014	0.001	< 0.05
Desorption	-27.626	6.67E-07	< 0.05	-311.44	1.297	< 0.05	-0.014	0.001	< 0.05
Modified Halsey									
Absorption	19.765	2.932	< 0.05	-0.062	0.009	< 0.05	0.948	0.090	< 0.05
Desorption	24.998	2.827	< 0.05	-0.076	0.009	< 0.05	1.172	0.084	< 0.05
Modified Henderson									
Absorption	0.010	0.002	< 0.05	-265.33	5.500	< 0.05	0.516	0.068	< 0.05
Desorption	0.006	0.002	< 0.05	-273.15	3.350	< 0.05	0.706	0.076	< 0.05
Modified Oswin									
Absorption	108.11	80.435	> 0.05	-0.342	0.257	> 0.05	0.998	0.153	< 0.05
Desorption	396.11	314.49	> 0.05	-1.263	1.010	> 0.05	1.277	0.173	< 0.05

(a) Location: Pine Tree; Cultivar: UA 5612

	Emperical Constants (Location: Keiser; Cultivar: UA 5213C)								
Model Type	**A**			**B**			**C**		
	Constant Value	**SE**	***P*-Value**	**Constant Value**	**SE**	***P*-Value**	**Constant Value**	**SE**	***P*-Value**
Modified Chung Pfost									
Absorption	-28.585	6.51E-07	< 0.05	-311.79	1.392	1.05E-24	-0.014	0.001	< 0.05
Desorption	-28.042	6.51E-07	< 0.05	-311.82	1.432	1.53E-24	-0.014	0.001	< 0.05
Modified Halsey									
Absorption	18.447	2.993	< 0.05	-0.057	0.009	5.79E-05	0.978	0.095	< 0.05
Desorption	24.701	2.736	< 0.05	-0.074	0.009	1.85E-06	1.246	0.083	< 0.05
Modified Henderson									
Absorption	0.009	0.002	< 0.05	-263.33	6.656	4.39E-14	0.528	0.074	< 0.05
Desorption	0.005	0.001	< 0.05	-273.44	3.295	6.26E-18	0.762	0.078	< 0.05
Modified Oswin									
Absorption	112.7	83.788	> 0.05	-0.355	0.267	> 0.05	1.030	0.151	< 0.05
Desorption	534.82	418.44	> 0.05	-1.703	1.343	> 0.05	1.361	0.171	< 0.05

(b) Location: Keiser; Cultivar: UA 5213C

	Emperical Constants (Location: Keiser; Cultivar: Terral REV 51R53)								
Model Type	**A**			**B**			**C**		
	Constant Value	**SE**	***P*-Value**	**Constant Value**	**SE**	***P*-Value**	**Constant Value**	**SE**	***P*-Value**
Modified Chung Pfost									
Absorption	-36.804	9.36E-07	< 0.05	-319.78	5.243	< 0.05	-0.018	0.002	< 0.05
Desorption	-36.222	1.1E-06	< 0.05	-319.44	6.049	< 0.05	-0.018	0.002	< 0.05
Modified Halsey									
Absorption	10.204	2.187	< 0.05	-0.026	0.007	< 0.05	1.273	0.102	< 0.05
Desorption	12.754	2.160	< 0.05	-0.032	0.007	< 0.05	1.460	0.099	< 0.05
Modified Henderson									
Absorption	0.0021	0.001	< 0.05	-231.1	25.951	< 0.05	0.766	0.101	< 0.05
Desorption	0.0015	0.001	< 0.05	-248.39	15.349	< 0.05	0.942	0.110	< 0.05
Modified Oswin									
Absorption	246.22	166.52	> 0.05	-0.737	0.516	> 0.05	1.479	0.149	< 0.05
Desorption	758.29	493.85	> 0.05	-2.318	1.544	> 0.05	1.729	0.152	< 0.05

(c) Location: Keiser; Cultivar: Terral REV 51R53

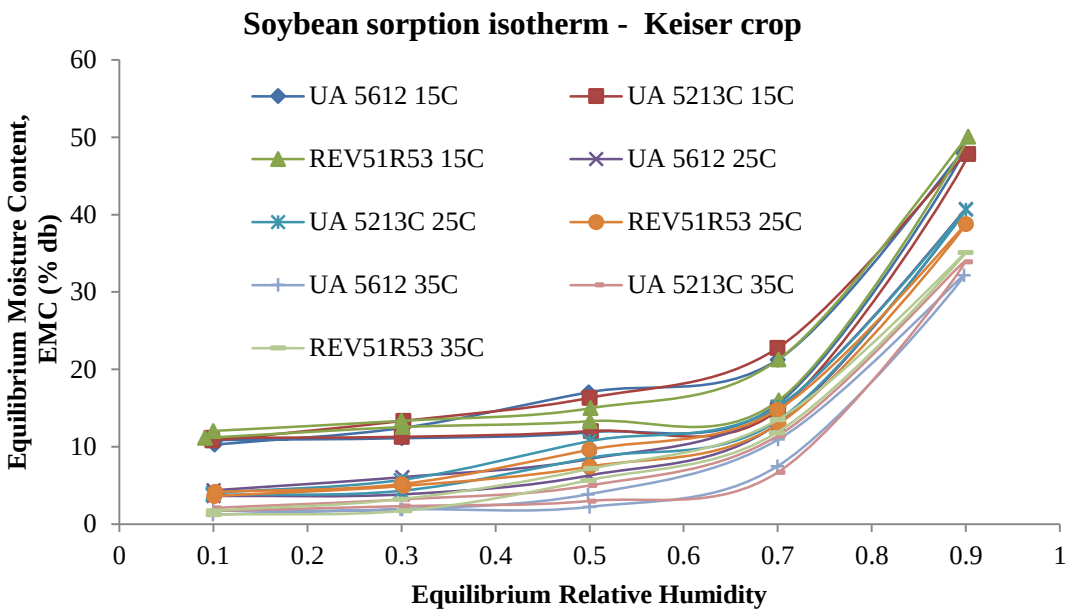
Table 3. Constants for models (modified Chung Pfost, Modified Halsey, Modified Henderson, and Modified Oswin) used to predict sorption isotherms of different soybean cultivars grown at Pine Tree Research Station, Colt, Arkansas. Better prediction at 35 °C.

	Emperical Constants (Location: Pine Tree; Cultivar: UA 5612)								
Model Type	**A**			**B**			**C**		
	Constant Value	**SE**	***P*-Value**	**Constant Value**	**SE**	***P*-Value**	**Constant Value**	**SE**	***P*-Value**
Modified Chung Pfost									
Absorption	-28.437	7E-07	< 0.05	-311.27	1.318	< 0.05	-0.014	0.001	< 0.05
Desorption	-27.995	7E-07	< 0.05	-311.25	1.316	< 0.05	-0.014	0.001	< 0.05
Modified Halsey									
Absorption	22.148	3.515	< 0.05	-0.069	0.011	< 0.05	0.998	0.102	< 0.05
Desorption	27.854	3.418	< 0.05	-0.086	0.011	< 0.05	1.209	0.094	< 0.05
Modified Henderson									
Absorption	0.010	0.002	< 0.05	-268.28	5.365	< 0.05	0.537	0.078	< 0.05
Desorption	0.007	0.002	< 0.05	-275.37	3.128	< 0.05	0.724	0.084	< 0.05
Modified Oswin									
Absorption	115.08	95.307	> 0.05	-0.365	0.306	> 0.05	1.012	0.171	< 0.05
Desorption	378.52	332.37	> 0.05	-1.209	1.069	> 0.05	1.266	0.192	< 0.05

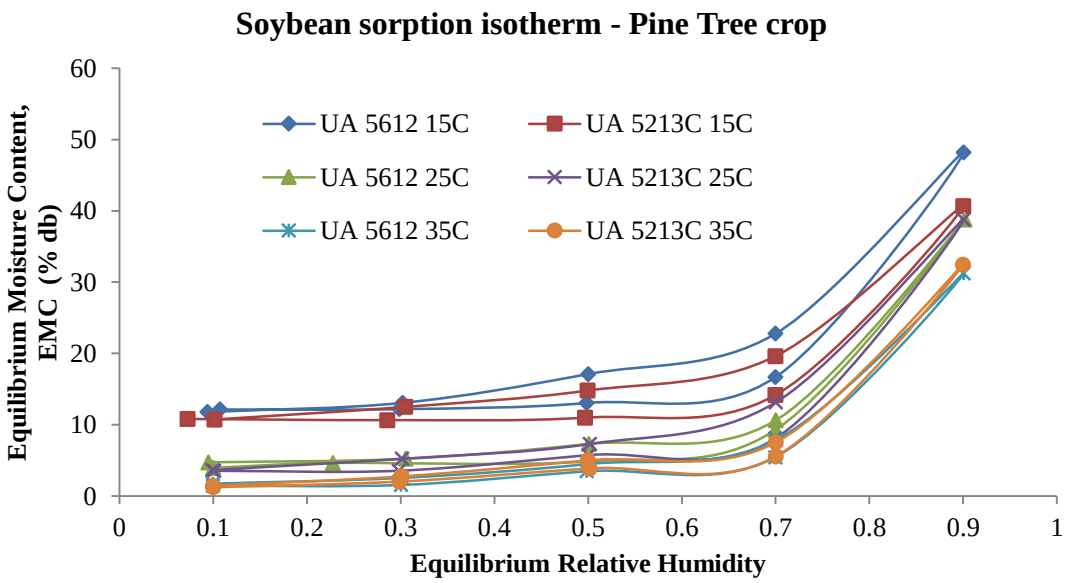
(a) Location: Pine Tree; Cultivar: UA 5612

	Emperical Constants (Location: Pine Tree; Cultivar: UA 5213C)								
Model Type	**A**			**B**			**C**		
	Constant Value	**SE**	***P*-Value**	**Constant Value**	**SE**	***P*-Value**	**Constant Value**	**SE**	***P*-Value**
Modified Chung Pfost									
Absorption	-39.514	1E-06	< 0.05	-321.1	6.661	< 0.05	-0.020	0.002	< 0.05
Desorption	-38.376	1E-06	< 0.05	-320.01	6.784	< 0.05	-0.019	0.002	< 0.05
Modified Halsey									
Absorption	7.309	2.584	< 0.05	-0.018	0.008	< 0.05	1.131	0.128	< 0.05
Desorption	11.146	2.833	< 0.05	-0.028	0.009	< 0.05	1.417	0.134	< 0.05
Modified Henderson									
Absorption	0.002	0.001	0.148	-190.03	67.531	< 0.05	0.625	0.106	< 0.05
Desorption	0.002	0.001	0.086	-238.26	26.353	< 0.05	0.902	0.131	< 0.05
Modified Oswin									
Absorption	78.913	65.155	> 0.05	-0.227	0.199	> 0.05	1.282	0.173	< 0.05
Desorption	508.12	399.82	> 0.05	-1.545	1.247	> 0.05	1.686	0.187	< 0.05

(b) Location: Pine Tree; Cultivar: UA 5213C



(a)



(b)

Fig. 1. The sorption isotherm for soybean seeds (*cv.* Terral REV 51R53, UA 5213C and UA 5612) at 15, 25, and 35 ºC. The seeds were grown at (a) Northeast Research and Extension Center, Keiser, and (b) Pine Tree Research Station, Colt, Ark.

Effect of Row-Spacing, Seeding Rate, and Plant Architecture on Grain Yield of Soybean with Glyphosate-Resistant *Palmer amaranth* Interference

W.J. Ross[1], M. Fuhrman[1], N. Pearrow[1], and R.C. Scott[1]

ABSTRACT

Arkansas soybean producers use a wide range in row widths and seeding rates for soybean production. Field studies examining MG IV and MG V soybean varieties were conducted in 2014 at the Newport Extension Center to determine the effect of soybean row spacing, seeding population, and plant architecture on weed density and soybean grain yield. In both trials, soybean grain yields were significantly greater in the 15-inch row spacing treatments when compared to the two wider row configurations. Little yield difference was seen between the two plant architectures at the three different row spacings for the two trials. When seeding rates were examined, no statistical difference in soybean grain yields was observed within each row width. However, across the three seeding rates, the 15-in. row spacing had greater soybean grain yield than the wider row spacings. The data obtained from these trials indicates the potential for soybean yield increases from narrow row spacings, but no yield increases with higher seeding rates.

INTRODUCTION

Arkansas soybean [*Glycine max* (L.) Merr.] producers use a wide range of row spacings and seeding rates for soybean production. Average row spacing for soybean production in Arkansas is 20 inches with the majority of acres planted using row spacings of ≤ 7.5- (31%), 15- (24%), 30- (13%), and >30-in. (32%) row spacings (NASS, 2014). The introduction of glyphosate-resistant soybean cultivars in 1996 gave soybean producers the flexibility to control a broad spectrum of weeds that was not seen prior to this introduction. However, with the discovery of glyphosate-resistant weeds in the last 10 years, soybean producers have had to rely more on conventional herbicides and change up agronomic practices to control weeds in soybean fields. Previous research has focused on the interaction of seeding rates and row spacings of soybean with the competitiveness of other weed species (Rich and Renner, 2007), but little work has been done in Arkansas with these agronomic practices and how they influence Palmer amaranth [*Amaranthus palmeri* (L.) S. Wats] competitiveness. Therefore, the objective of this study was to compare different combinations of agronomic practices and their effectiveness of suppressing Palmer amaranth growth.

PROCEDURES

Trials were established at the Newport Extension Center during 2014. Management with respect to irrigation, fertility, and late-season pest control closely followed recommendations from the University of Arkansas System Division of Agriculture's Cooperative Extension Service. In each trial, soybean was irrigated as needed using over-head irrigation.

Two cultivars were chosen for each trial based on relative maturity group and plant architecture. Pioneer 47T36 (upright structure) and HBK LL4950 (bushy structure) were planted in the Maturity Group (MG) IV trial, and Pioneer 54T94 (upright structure) and HBK RY5221 (bushy structure) were planted in the MG V trial. Soybean seed were treated with Cruiser Maxx seed treatment prior to planting.

Soybean plots were established on 20 June 2014. Seeding rate treatments consisted of 100,000, 150,000, and 190,000 seeds/ac. Plots consisted of 4 rows spaced 15, 30, and 36 in. All plots were 35 ft in length. Immediately after planting, 1.67 pt/ac of Dual was applied to both trials. Weeds were controlled in the weed-free plots with 0.33 oz/ac of Firstrate and 16 oz/ac Select applied 10 days after planting, 1.5 pt/ac Flexstar applied 35 days after planting, and hand-weeding during the season.

The experimental design was a split-split-split plot with four replications. The main plot was row width, the subplot was soybean population, and the sub-subplot was plant architecture, and the sub-sub-subplot was weed management. Data were subjected to analysis of variance (ANOVA), using ARM 9 (Gylling Data Management, Inc., Brookings, S.D.). When appropriate, mean separations were performed using Fisher's protected least significant difference method with $P = 0.05$.

RESULTS AND DISCUSSION

Little yield differences were seen between the weedy and weed-free treatments for both the MG IV and MG V test due to poor Palmer amaranth populations. This could be due to the late planting date, reduction of Palmer amaranth population due to tillage, good control from the initial pre-emergence herbicide application, and dry soil conditions after planting. Yields were significantly greater in the weed-free treatments compared to the weedy treatments in 2013 (data not shown).

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When the different plant architectures were examined, the upright MG IV soybean variety show significantly higher soybean yields when compared to the bushy MG IV variety for the three row spacings (Table 1). However, for the MG V varieties, the bushy soybean variety had higher soybean yields than the upright MG V variety at all row spacings (Table 3). Both these results could be explained due to varietal differences.

For each variety, in both the MG IV and MG V studies, soybean grain yields were significantly greater in the 15-in. row spacing treatments than for the other two wider row spacings. The 15-in. row spacing increased soybean grain yield in the MG IV study by 29% and 23%, and in the MG V study by 25% and 14% for the 30-in. and 36-in. row spacings, respectively (Tables 2 and 4). These findings are similar to other research findings that show narrow row spacings increase soybean grain yield compared to wider rows.

Soybean grain yield was not influenced by seeding rate for individual row spacing in the MG IV trial. However, the 15-in. row spacing significantly had greater grain yields at all three seeding rates when compared to the 30- or 36-in. row spacings (Table 2). The yield increase across the three seeding rates for the 15-in. row spacing ranged from 4.5 – 16.0 bushel/acre when compared to the wider row widths. A similar pattern was seen in the MG V study, with the 15-in. row spacing having higher grain yields than the wider spacings (Table 4). However, the 100,000 seed/acre treatments in the 30- and 36-in. row spacings had significantly lower grain yields than the higher seeding rates. This could indicate that greater than 100,000 seed/ac is required for a MG IV soybean variety to maximize yield at these wider row widths.

PRACTICAL APPLICATIONS

The data presented in this paper suggest that reducing row widths can be economically beneficial. With approximately 45% of the Arkansas soybean crop being planted on 30-in. spacings or greater, these producers could potential increase soybean yields by 14-29% by using row spacings less than 30 inches. As for seeding rates, the findings from these trials are similar to recent finds that seeding rates could be reduced without significantly reducing soybean grain yields, with an additional benefit of reduced seed cost. Results of this research indicate that narrow row spacings and reduced seeding rates can lead to significant yield increases, and have an additional economic benefit by reducing seed cost.

ACKNOWLEDGMENTS

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Table 1. Soybean yield across row widths and plant architecture for two MG IV soybean varieties with and without weed pressure at the Newport Extension Center in 2014.

	Row Width		
	15 in.	**30 in.**	**36 in.**
Variety	**Grain Yield (bu/ac)**		
Bushy (Weedy)	42.9 bc†	29.9 g	33.0 efg
Upright (Weedy)	49.7 a	34.6 def	37.3 de
Bushy (Weed Free)	43.9 b	31.8 fg	33.0 efg
Upright (Weed Free)	47.4 ab	34.5 def	38.2 cd

† Means followed by the same letter do not significantly differ (P = 0.05).

Table 2. Average soybean yield across seeding rates and row width for two MG IV soybean varieties at the Newport Extension Center in 2014.

	Seeding Rate (seed/ac)		
	100,000	**150,000**	**190,000**
Row Spacing (in.)	**Grain Yield (bu/ac)**		
15	48.7 a†	42.8 bc	46.5 ab
30	32.7 e	33.3 de	32.0 e
36	36.1 de	38.3 cd	31.8 e

† Means followed by the same letter do not significantly differ (*P* = 0.05).

Table 3. Soybean yield across row widths and plant architecture for two MG V soybean varieties with and without weed pressure at the Newport Extension Center in 2014.

	Row Width		
	15 inch	**30 inch**	**36 inch**
Variety	**Grain Yield (bu/ac)**		
Bushy (Weedy)	39.7 a†	27.4 ef	34.5 bc
Upright (Weedy)	32.0 cd	23.9 f	24.1 f
Bushy (Weed Free)	37.0 ab	29.3 de	35.3 bc
Upright (Weed Free)	32.2 cd	25.0 f	27.4 ef

† Means followed by the same letter do not significantly differ (*P* = 0.05).

Table 4. Average soybean yield across seeding rates and row width for two MG V soybean varieties at the Newport Extension Center in 2014.

	Seeding Rate (seed/ac)		
	100,000	**150,000**	**190,000**
Row Spacing (in.)	**Grain Yield (bu/ac)**		
15	35.1 a†	35.0 a	35.6 a
30	21.9 d	28.3 bc	28.9 bc
36	24.7 cd	32.0 ab	34.3 a

† Means followed by the same letter do not significantly differ (*P* = 0.05).

Preliminary Evaluation of Soil Property Differences Between High- and Average-Yielding Soybean Fields Throughout Arkansas

T.C. Adams[1], K.R. Brye[1], L.C. Purcell[1], and W.J. Ross[2]

ABSTRACT

"Grow for the Green" is a yearly soybean [*Glycine max* (L.) Merr] yield contest in Arkansas, sponsored by the Arkansas Soybean Promotion Board in collaboration with the Arkansas Soybean Association, which began in 1999. In 2013, the state was divided into seven geographic divisions for contest purposes. The objective of this study is to evaluate the effects of region and soil depth on soil physical, chemical, and biological property differences between high- and average-yielding areas. In summer 2014, two locations in each of the seven geographical divisions within Arkansas with a high-yield contest area in close proximity to an average-yield area were soil sampled. Samples were collected from 0- to 10- and 10- to 20-cm depth increments in each high- and average-yield area and bulk density, soil pH, electrical conductivity (EC), and soil organic matter (SOM) were measured. Bulk density was greater in the high- (1.31 g cm^{-3}) than in the average-yield area (1.28 g cm^{-3}), and as expected, bulk density was greater in the 10- to 20-cm depth (1.37 g cm^{-3}) than in the top 10 cm (1.23 g cm^{-3}). Soil pH was greater in Region 7 (7.39) than in all other regions. In addition, soil pH was greater in the 10- to 20-cm depth (6.79) than in the top 10 cm (6.66). Region 2 had a greater EC (0.141 dS m^{-1}) than any other region and EC was greater in the top 10 cm (0.114 dS m^{-1}) than in the 10- to 20-cm depth (0.101 dS m^{-1}). Soil OM was greater in Region 7 (2.6%) than in all other regions, and as expected, SOM was greater in the top 10 cm (1.9%) than in the 10- to 20-cm depth (1.4%). Furthermore, SOM was greater in the average-yield areas (1.8%) than in the high-yield areas (1.6%). Results from this study have the potential to help growers better understand soil properties in their own fields that contribute to or hinder high soybean yields.

INTRODUCTION

In 1999, a yearly soybean [*Glycine max* (L.) Merr] yield contest, "Grow for the Green", was initiated by the Arkansas Soybean Promotion Board (ASPB) together with the Arkansas Soybean Association (ASA). In 2011, the ASPB and ASA divided the contest entries into early-season, full-season, and double-crop production systems. Another change occurred in 2013, when the state was split into seven geographic regions (Fig. 1), and an eighth, statewide, non-genetically-modified-organism category.

A substantial difference throughout the state between irrigated (2217 to 2902 kg ha^{-1}) and non-irrigated (1250 to 1693 kg ha^{-1}) soybean yields exists (Egli, 2008), and currently there is a lack of information examining a multitude of soil characteristics that contribute to high-yielding soybean growth and productivity. Characterization of soil properties in high-yielding areas within fields compared with properties of average-yielding areas in the same or adjacent fields could allow the identification of key differences that may explain the differences in yield potential and offer opportunities for site-specific management. Therefore, the objective of this study was to evaluate the effects of region and soil depth on soil physical, chemical, and biological property differences between high- and average-yielding areas.

PROCEDURES

In late summer to early fall 2014, two cooperating producers in each of the seven regions were identified who had a field area entered into the 2014 yield contest as well as an average-yielding area within the same field or in an adjacent field (Table 1). The two areas (i.e., the high- and average-yielding areas) per producer within a region were used for subsequent soil sampling purposes.

In each high- and average-yielding area, five sample points were established in a diamond formation, with three points in the same row approximately 62 m apart, and two points perpendicular to the middle row approximately 38 m in the opposite direction from the middle point of the middle row. At each point immediately before or just after soybean had been harvested, soil samples were collected from the 0- to 10- and 10- to 20-cm depth intervals using a 4.7-cm diameter, stainless-steel soil core chamber that was beveled to the outside to reduce compaction while sampling. Samples were oven-dried at 70 °C for 48 h and weighed for bulk density determinations. Samples were then ground until they could pass through a 2-mm mesh sieve. Soil pH

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and electrical conductivity (EC) were determined potentiometrically using a 1:2 soil mass:water volume mixture. Soil organic matter (SOM) concentration was determined by weight-loss-on-ignition at 360 °C for 2 h. All soil samples are in the process of being analyzed for extractable soil nutrients and particle-size distribution.

A three-factor analysis of variance (ANOVA), assuming a completely random design, was conducted using SAS V. 9.3 (SAS Institute, Inc., Cary, N.C.) to evaluate the effects of region, yield area (i.e., high- and average-yielding areas), soil depth, and their interactions on near-surface soil properties (i.e., bulk density, pH, EC, and SOM). Significance was judged and, when appropriate, means were separated by least significant difference $P = 0.05$.

RESULTS AND DISCUSSION

Soil bulk density measured in fall 2014 ranged from a high of 1.61 g cm^{-3} in the 10- to 20-cm soil depth of a high-yield area in Region 3 to a low of 0.82 g cm^{-3} in the 0- to 10-cm soil depth of an average-yield area in Region 4. Bulk density was affected ($P < 0.05$) by all treatment main effects, and was not influenced by their interactions (Table 2). Averaged across yield area and soil depth, bulk density in the top 20 cm was greater in Region 3 (1.39 g cm^{-3}) than in all other regions (<1.33 g cm^{-3}). Both locations sampled in Region 3 had mapped soil surface textures that were fine sandy loam; whereas for nearly all other locations within regions, the mapped soil surface texture was silt loam or finer (Table 1). Averaged across region and soil depth, bulk density was greater in the high- (1.31 g cm^{-3}) than in the average-yield area (1.28 g cm^{-3}). Averaged across region and yield area, as expected, bulk density was greater in the 10- to 20-cm depth (1.37 g cm^{-3}) than in the top 10 cm (1.23 g cm^{-3}).

Soil pH ranged from a high of 8.31 in the 0- to 10-cm soil depth of a high-yield area in Region 7 to a low of 5.22 in the 0- to 10-cm soil depth of an average-yield area in Region 6. Similar to that for bulk density, soil pH was affected by region and soil depth (Table 2). Averaged across yield area and soil depth, soil pH was greater in Region 7 (7.39) than in all other regions. Region 3 had the lowest soil pH (6.38). As a result of the fine sandy loam soil surface texture in areas of fields in Region 3 (Table 1), it is likely these soils have a low buffering capacity and greater rates of infiltration and percolation, and thus are subject to greater rates of acidification than in the other regions. Averaged across region and yield area, soil pH was greater in the 10- to 20-cm depth (6.79) than in the top 10 cm (6.66) (Table 2). Soil pH was unaffected by yield area (Table 2).

Electrical conductivity ranged from a high of 0.302 dS m^{-1} in the 10- to 20-cm soil depth of an average-yield area in Region 2 to a low of 0.032 dS m^{-1} in the 10- to 20-cm soil depth of an average-yield area in Region 6. Similar to pH, soil EC was affected by region and soil depth, as well as the interaction of region and yield area (Table 2). Averaged across yield area and soil depth, Region 2 had a greater EC (0.141 dS m^{-1}) than any other region. Regions 1, 4, 6 and 7, which did not differ, had a greater EC (0.114 dS m^{-1}) than Regions 3 and 5 (0.077 dS m^{-1}), which did not differ. A reason for this disparity in EC might involve the source of irrigation water; when irrigation water is too saline, soluble salts can accumulate in the upper profile of the soil stratum. Averaged across region and yield area, soil EC was greater in the top 10 cm (0.114 dS m^{-1}) than in the 10- to 20-cm depth (0.101 dS m^{-1}). Electrical conductivity was unaffected by yield area (Table 2). Electrical conductivity was greater in the average-yield areas of Region 2 (0.158 dS m^{-1}; Table 3) than in all other region-yield area combinations. In addition, all other region-yield area combinations had greater EC than that of the high- and average-yield areas in Regions 3 and 5 (Table 3), which did not differ.

Soil organic matter ranged from a high of 3.9% in the 0- to 10-cm depth in a high-yield area in Region 2 to a low of 0.5% in the 10- to 20-cm depth in a high-yield area in Region 5. Soil OM was affected by all treatment factors evaluated, and by the interaction of region with yield area (Table 2). Averaged across yield area and soil depth, SOM was greater in Region 7 (2.6%) than in all other regions (Table 3). It is possible Region 7 has greater amounts of clay than other regions and thus the soils are wetter longer, which promotes OM accumulation (USDA-NRCS, 2015). Averaged across region and yield area, as expected, SOM was greater in the top 10 cm (1.9%) than in the 10- to 20-cm depth (1.4%). Averaged across region and soil depth, SOM was also greater (1.8%) in the average- than in the high-yield areas (1.6%). Unexpectedly, soil OM concentration was greater in the average-yield areas of Region 7 (3.0%; Table 3), which was greater than all other yield area-region combinations, than in the high-yield areas of Region 7 (2.1%). Soil OM was lowest in the high-yield areas of Region 6 (1.2%), which did not differ from the high-yield areas of Regions 1, 3, and 5 (Table 3), and was lower than average-yield areas in Region 6 (1.6%), which did not differ from high- and average-yield areas in Regions 1, 3, and 4.

PRACTICAL APPLICATIONS

The "Grow for the Green" yield contest has been a highly visible and successful program that has demonstrated the untapped yield potential in the Arkansas soybean crop. We believe that there is a tremendous amount of information that can be gleaned from studying soil property differences among high- and average-yield areas that will allow producers to better understand the limitations and potential of their own fields. With careful characterization of soil properties in contest fields compared with typical fields, we may be able to identify key differences that allow for an extra yield bump in lower-yielding fields. Through an enhanced understanding of soil properties in their own fields, producers may be able to determine those fields with the potential for increased productivity given appropriate management and resources. This information also may be valuable in helping producers understand which fields are unlikely to respond to increased management and resources.

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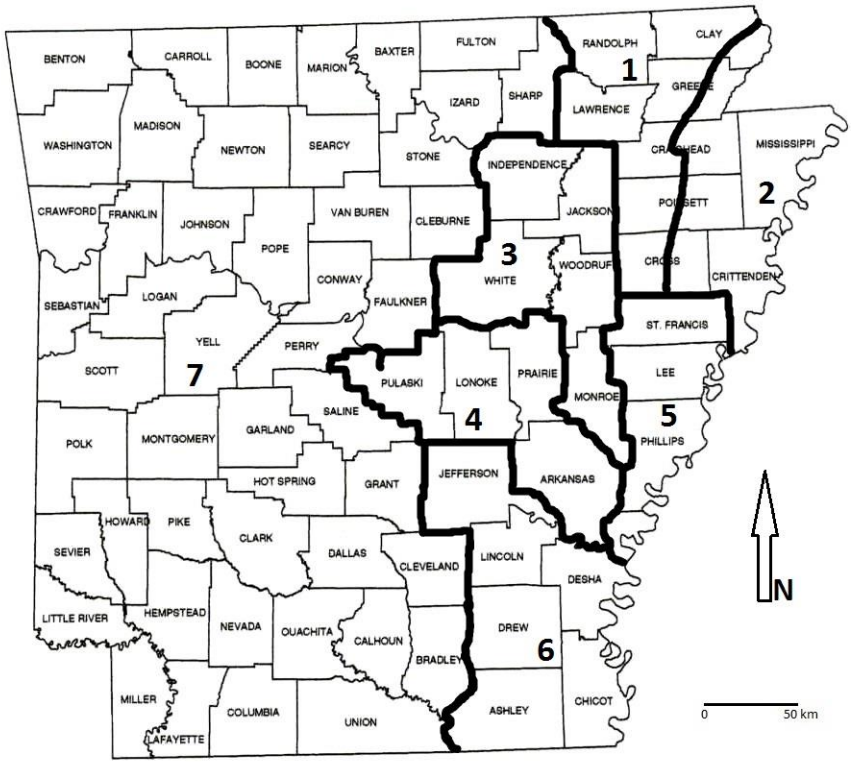

Fig. 1. Seven regions for the "Grow for the Green" contest sponsored by the Arkansas Soybean Promotion Board together with the Arkansas Soybean Association. Division 1: Northeast Delta; Division 2: Northeast; Division 3: White River Basin; Division 4: Central and Grand Prairie; Division 5: East Central Delta; Division 6: Southeast Delta; Division 7: Western.

Table 1. Summary of growers participating in the 2014 "Grow for the Green" soybean yield contest sponsored by the Arkansas Soybean Promotion Board whose fields were soil sampled in fall 2014.

Region	County	Site	Contest participant before 2014?	2013 Contest-reported Yield Bu/ac (kg ha^{-1})	Dominant Soil Series (Taxonomic Description) in High-yielding Area †	Soil Surface Texture
1 - Northeast Delta	Craighead	1	Yes	86 (5772)	Dundee (Typic Endoaqualfs)	Fine sandy loam
	Poinsett	2	Yes	79 (5324)	Dundee (Typic Endoaqualfs)	Silt loam
2 - Northeast	Cross	1	Yes	84 (5664)	Arkabutla (Fluventic Endoaquepts)	Silt loam
	Cross	2	No	-	Crowley (Typic Albaqualfs)	Silt loam
3 - White River Basin	Jackson	1	Yes	86 (5773)	Bosket (Mollic Hapludalfs)	Fine sandy loam
	Woodruff	2	Yes	90 (6022)	Wiville (Ultic Hapludalfs)	Fine sandy loam
4 - Central & Grand Prairie	Lonoke	1	No	-	Hebert (Aeric Epiaqualfs)	Silt loam
	Lonoke	2	Yes	94 (6339)	Rilla (Typic Hapludalfs)	Silt loam
5 - East Central Delta	Phillips	1	Yes	89 (6011)	Commerce (Fluvaquentic Endoaquepts)	Silt loam
	Monroe	2	Yes	91 (6152)	Dubbs (Typic Hapludalfs)	Silt loam
6 - Southeast Delta	Drew	1	Yes	101 (6771)	Rilla (Typic Hapludalfs)	Silt loam
	Desha	2	Yes	108 (7232)	Hebert (Aeric Epiaqualfs)	Silt loam
7 - Western	Conway	1	No	-	Gallion (Typic Hapludalfs)	Silt loam
	Miller	2	No	-	Bossier (Aeric Epiaquerts)	Clay

† Data obtained from USDA-NRCS (2014a, b).

Table 2. Analysis of variance summary for the effects of region, yield area (i.e., high-yielding or average-yielding), and soil depth (i.e., 0- to 10-cm or 10- to 20-cm) on bulk density (BD), pH, electrical conductivity (EC), and soil organic matter (SOM) from soil samples collected in fall 2014 throughout Arkansas.

Source of Variation	BD	pH	EC	SOM
	P			
Region	< 0.01†	< 0.01	< 0.01	< 0.01
Yield Area	0.02	0.09	0.85	< 0.01
Soil Depth	< 0.01	0.05	0.02	< 0.01
Region x Yield Area	0.18	0.14	0.01	< 0.01
Region x Soil Depth	0.73	0.13	0.59	0.86
Yield Area x Soil Depth	0.19	0.94	0.67	0.80
Region x Yield Area x Soil Depth	0.93	0.83	0.84	0.50

†$P \leq 0.05$ are indicated in bold.

Table 3. Summary of the effects of yield area [i.e. high- (HY) or average-yielding (AY)] and region on electrical conductivity (EC, dS m^{-1}) and soil organic matter (SOM, %) concentration from soil samples collected in fall 2014 throughout Arkansas.

Soil Property	Yield Area	Region 1	2	3	4	5	6	7
EC	HY	0.106 b†	0.125 b	0.082 c	0.126 b	0.076 c	0.109 b	0.127 b
	AY	0.120 b	0.158 a	0.077 c	0.115 b	0.074 c	0.106 b	0.107 b
SOM	HY	1.4 fgh	1.9 cd	1.4 fgh	1.7 de	1.3 gh	1.2 h	2.1 b
	AY	1.7 cde	1.8 cd	1.3 fgh	1.5 efg	1.9 c	1.6 ef	3.0 a

†Means with the same letter within a soil property are not significantly different at the 0.05 level.

Alternative Residue Management Practice Effects over Time on Near-Surface Soil Properties in a Wheat-Soybean, Double-Crop System in Eastern Arkansas

C.R. Norman[1] and K.R. Brye[1]

ABSTRACT

Adoption of management practices that maintain or increase soil organic matter (SOM), which contains 58% carbon (C) on average may help to mitigate climate change by sequestering atmospheric C. Management of crop residue can strongly affect the fate of SOM in agricultural soils, especially in double-crop systems. Therefore, the main objective of this study was to examine long-term trends in SOM and soil C in the top 10 cm as affected by residue burning (burning and non-burning), tillage (conventional and no-tillage), irrigation (irrigated and non-irrigated), and N-fertilization/residue level (high and low) in a wheat (*Triticum aestivum* L.)-soybean [*Glycine max* (L.) Merr.] double-crop system in eastern Arkansas. The site has been consistently managed for 13 years at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (N 34°, 44', 2.26"; W 90°, 45' 51.56") in Marianna, Arkansas on a Calloway silt-loam (fine silty, mixed, active, thermic Glossaquic Fraglossudalf). All four field treatment factors significantly affected the trend in SOM content (kg m^{-2}) over time. However, the largest and most obvious differences occurred between irrigated and non-irrigated treatments. Averaged across all other factors, SOM did not differ over time when irrigated, while SOM content increased over time until around year 10 when SOM decreased thereafter under dryland production. As with SOM content, the largest and most obvious differences in soil C over time occurred between irrigated and non-irrigated treatments. Tillage, residue level, and irrigation significantly affected the trend in soil C content (kg m^{-2}) over time. Averaged across all other factors, soil C content decreased over time until around year 9 when soil C content increased thereafter under irrigated production, and soil C content increased over time until around year 10 when soil C content decreased thereafter under dryland production. The results of this study indicate that irrigation management caused greater differences in SOM and C trends over time than any other treatment factor.

INTRODUCTION

Soil OM strongly affects many soil properties that are relevant to crop production, such as soil fertility and water content, and is a determining factor in soil C sequestration (Follet et al., 2001). Considering SOM is typically composed of organic residues of plants, animals, microbes, and stabilized organic compounds, the long-term balance of SOM is determined by how much plant biomass is added to the system and the timeline of decomposition. Management factors such as tillage, burning, fertilization, and irrigation may influence the rate at which microbes decompose SOM by altering the physical and chemical soil environment.

An understanding of how different agricultural management practices impact SOM and soil organic C (SOC) is essential for determining sustainable practices of food production. The Intergovernmental Panel on Climate Change concluded that agriculture generates 10% to 12% of total global anthropogenic emissions of greenhouse gases, including 60% of the nitrous oxide (N_2O) and 50% of the methane (CH_4) emissions (IPCC, 2013) through the burning of fossil fuels and the oxidation of SOM. Certain practices, such as no-tillage (NT), may increase accumulation of C in the soil, while simultaneously decreasing C emissions from cultural operations. Therefore, the main objective of this study is to determine the long-term trends of near-surface SOM and soil C as affected by residue burning (burning and non-burning), tillage (conventional (CT) and no-tillage), irrigation (irrigated and dryland), and N-fertilization/wheat-residue level (high and low).

PROCEDURES

An on-going field study was initiated in Fall 2001 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (N 34°, 44', 2.26"; W 90°, 45' 51.56", Cordell et al., 2006) in Marianna, Arkansas on a Calloway silt-loam (fine silty, mixed, active, thermic Glossaquic Fraglossudalf). Four factors were evaluated: 1) residue level (high residue, achieved with a split application of N fertilizer, or low residue, achieved with minimal to no N additions); 2) burning of residue (burning or non-burning); 3) tillage (CT or NT); and 4) irrigation (irrigated or non-irrigated). The experimental area consisted of 48, 3 × 6-m plots with three replications for every tillage-irrigation-burning-residue level combination (Amuri et al., 2008).

In approximately mid-June each year, a glyphosate-resistant soybean cultivar, maturity group 5.3 or 5.4, was drill-seeded with 19-cm row spacing at a rate of approximately 47 kg seed ha^{-1}. Potassium (K) fertilizer was applied according to recommended rates (UACES, 2000) when the previous year's soil test indicated K was needed. Soybean residue was left in place, into which the subsequent wheat crop was sown to begin the next cropping cycle. Wheat was drill-seeded with a 19-cm row spacing each autumn. In late October to early November, soybeans were harvested with a plot combine.

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Soil Sample Collection and Processing. Soil samples collected from the top 10 cm prior to soybean planting in 2007 through 2014 were oven-dried for 48 h at 70 ˚C and ground until they could pass through a 2-mm mesh screen for soil chemical analyses (Brye et al., 2006). Soil OM was determined by weight-loss-on-ignition after 2 h at 360 ˚C. Soil C was determined by high-temperature combustion with a LECO CN-2000 analyzer (LECO Corp., St. Joseph, Mich.) or an Elementar VarioMAX Total C and N Analyzer (Elementar Americas Inc., Mt. Laurel, N.J.). All soil C was assumed to be organic C because soil of the upper solum does not effervesce upon treatment with dilute hydrochloric acid (Brye et al., 2006). Measured SOM and C concentrations (mg kg^{-1}) were converted to contents (kg ha^{-1}) using the measured bulk density and 10-cm sample depth interval.

Data Analyses. Analysis of covariance (ANCOVA) was conducted using SAS V. 9.3 (SAS Institute, Inc., Cary, N.C.) to determine the effects of residue level, tillage, and burning/irrigation on the trend in SOM and soil C over time (i.e., 2007 through 2014). When appropriate, regression coefficients (i.e., linear and quadratic coefficients) were separated by least significant difference at the 0.05 level.

RESULTS

Over the course of eight complete wheat-soybean cropping cycles, in treatment combinations managed consistently for 13 years, SOM content (kg m^{-2}) in the top 10 cm was affected ($P < 0.05$) by all treatment factors evaluated. The largest and most obvious differences occurred between irrigated and non-irrigated treatments. Averaged across tillage, burning, and residue level, SOM content increased over time under dryland production and began to decrease around year 10 ($P < 0.001$; Fig. 1). There was no change in SOM content over time under irrigation. SOM content also decreased over time under burn treatment ($P < 0.05$) and increased over time under no-burn treatment ($P < 0.05$). Carbon content (kg m^{-2}) similarly increased over time under dryland production and began to decrease around year 10 ($P < 0.05$). In contrast, C content decreased over time under irrigation and began to increase around year 9 ($P < 0.05$; Fig. 2).

PRACTICAL APPLICATIONS

Irrigation strongly affects the activity of plants and soil microorganisms, leading to changes in SOM formation and decomposition. While increased soil moisture can increase SOM and soil C by promoting development of plant and microbial biomass, increased soil moisture also promotes microbial decomposition of SOM and respiration of soil C (Churchman and Tate, 1986). The results of this study suggest that microbial decomposition of SOM under dryland production was inhibited by the lack of irrigation, and that irrigation management, more than any other treatment factor, caused the greatest differences in SOM and C trends over time.

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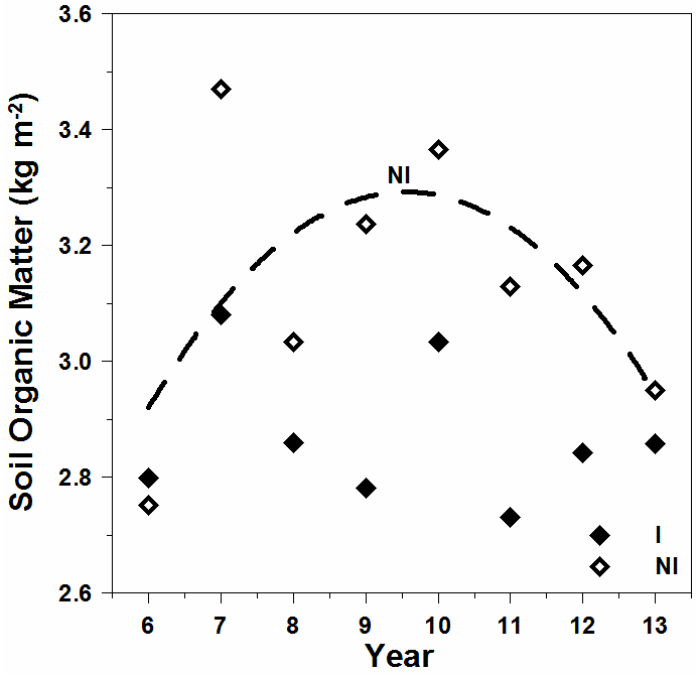

Fig. 1. Soil organic matter content trends over time from year 6 to year 13 averaged across tillage, burning, and residue level to show trends in irrigated (I) and non-irrigated (NI) treatments.

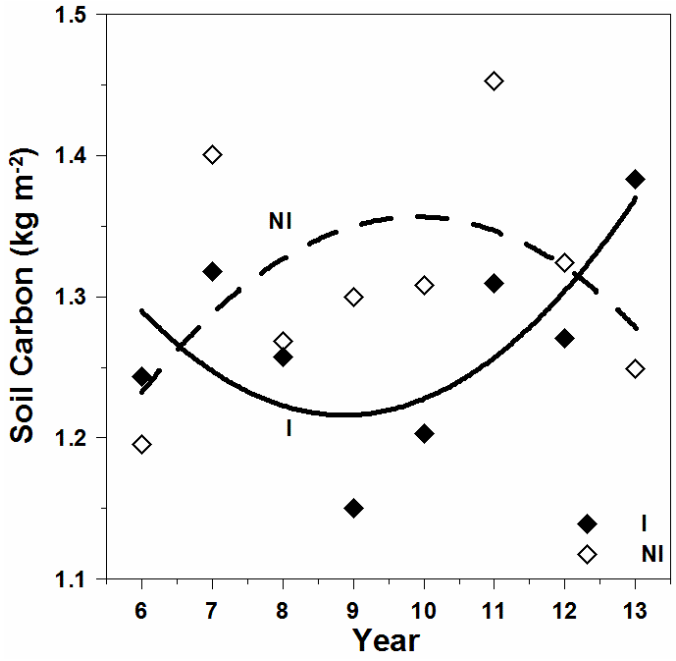

Fig. 2. Soil C content trends over time from year 6 to year 13 averaged across tillage, burning, and residue level to show trends in irrigated (I) and non-irrigated (NI) treatments.

Validation of Soil-Test-Based Fertilizer Recommendations for Irrigated Soybean

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ABSTRACT

Crop yield response to fertilization does not always agree with the soil-test report interpretation. Validation of P and K fertilizer recommendations is needed to determine the accuracy of existing fertilizer recommendations. This report communicates soybean yield responses and seed nutrient concentrations as affected by P and K fertilization in 2013. Yield increases at sites having Very Low, Low, or Medium soil-test levels were expected from P and K fertilization at six and five sites, respectively. Yield increases occurred at two sites from P fertilization and four sites from K fertilization. Soybean seed-P and -K concentrations were affected by fertilizer treatments at five and three sites (of nine), respectively. Seed-K concentration increased as K rate increased only at sites that responded positively to K fertilization. Seed-P concentration was most affected at the site that showed the greatest yield increase to P fertilization.

INTRODUCTION

Soil-testing is the most accepted and best available science for soil and plant nutrient management. Variable rate fertilization technologies require soil-test information to be accurately interpreted. Unfortunately, crop yield response to fertilization does not always agree with the soil-test report interpretation. The main objective of this project is to validate the accuracy of the existing soil-test-based fertilizer P and K recommendations for irrigated soybean. A secondary objective was to examine how P and K fertilization influences the harvested soybean seed-P and -K concentrations. Seed accumulation of P and K from fertilization practices that do not increase yield represents inefficient use of fertilizer inputs. This report summarizes the primary and secondary objectives of examining how P and K fertilization influences yield and soybean seed-P and -K concentrations.

PROCEDURES

Nine trials were established in University of Arkansas System Division of Agriculture's Experiment Station fields across eastern Arkansas in 2013 (Table 1). Composite soil samples (0-4 inch depth) were collected in spring 2013 from each field as a guide for defining the recommended P and K fertilizer rates. Additional soil samples from the 0-4 inch (all sites) and 0-12 inch (clayey sites) or the 0-18 inch (loamy sites) samples were taken from the no-fertilizer control in each replicate (n = 3-6) when the research plots were established. Only the 0-4 inch samples will be presented in this report. All soil samples were oven-dried, crushed, and analyzed for soil pH (1:2 soil weight:water volume mixture) and the Mehlich-3 extractable nutrients by inductively coupled plasma spectroscopy (ICPS). Crop management practices such as seeding rate, irrigation, and pest control closely followed recommendations from the University of Arkansas System Division of Agriculture's Cooperative Extension Service. Soybean was furrow or flood irrigated as needed.

Each trial contained six treatments that involved four K_2O rates and two P_2O_5 (0 and 60 lb P_2O_5/ac) rates including 1) the recommended P rate plus 0 lb K_2O/ac, 2) the recommended P rate plus 60 lb K_2O/ac, 3) the recommended P rate plus 120 lb K_2O/ac, 4) the recommended P rate plus 160 lb K_2O/ac, 5) the recommended K rate plus the alternate P rate (0 or 60 lb P_2O_5/ac), and 6) no P and K fertilizer (control). Arkansas research has shown that the correlation between crop yield and soil-test P is weak ($r^2 < 0.40$), so only two P_2O_5 rates were used. Plots at each site were 20- to 26-ft long by 10- to 13-ft wide. Muriate of potash (60% K_2O) and triple superphosphate (46%P_2O_5) were the nutrient sources used.

Trifoliate leaves were collected from the interior rows of every plot at the R1-R2 stage, dried, ground, digested, and analyzed for nutrient concentrations. A plot combine harvested a 16-to 22-ft long section from the middle of each plot. The harvested seed from each plot was homogenized and a 50-gram subsample was stored for analysis. The subsample was dried for 3 days, ground, and analyzed for elemental concentrations by ICPS.

Each trial included six treatments and six blocks except Newport (three blocks), which were arranged as a randomized complete block design. The ANOVA was conducted by site with the MIXED procedure in SAS V. 9.4 (SAS Institute, Inc., Cary, N.C.). Yield response to fertilization was performed using specific single-degree-of-freedom contrasts using significance levels of 0.05, 0.10, and 0.25. Seed P and K concentration means were separated using Fisher's protected least significant difference and interpreted as significant when $P < 0.10$.

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RESULTS

By soil-test level definition, positive and significant yield responses are expected the majority of the time on soils categorized as having Very Low and Low P and K levels and no yield change from fertilization is expected on soils having Optimum and Above Optimum levels. Reponses may or may not occur on soils with Medium levels. In 2013, yield increases (Very Low, Low, or Medium soil-test levels) were expected from P and K fertilization at six and five sites, respectively (Table 2). Yield increases were recorded at PTRS-D2 site with Very Low P at all significance levels and RRS-Loam with Medium P at the 0.10 and 0.25 levels. The RRS-Loam site also had rather large standard deviation (12 ppm) indicating substantial variation in soil-test P within the research area. Sites with Optimum and Above Optimum soil-test P did not respond to fertilization. Soybean yields were increased by K fertilization at 4 of 5 sites with suboptimal soil-test K levels and 1 of 4 sites with Optimal or Above Optimal soil-test K (Table 2). The significance level influenced the interpretation of results for PTRS-C4 and RRS-Loam sites, both of which had relatively small (2 bu/ac) yield increases from K fertilization (Table 4).

Soybean seed-P (Table 3) and -K (Table 4) concentrations were affected by fertilizer treatments at 5 and 3 sites (out of nine, $P < 0.10$), respectively. Application of P fertilizer at PTRS-D20, one of two sites that responded to P fertilization, increased seed-P concentration compared to seed from soybean fertilized with only K (Treatment 5), but not soybean that received no fertilizer (Table 3). The response at PTRS-C4 was the same as for PTRS-D2. The other three sites showed no clear seed-P concentration trend among treatments. Seed removal of P ranged from 0.55 to 0.82 lb P_2O_5/bu but most seed P values would remove closer to 0.62 lb P_2O_5/bu.

Seed K concentrations were increased at PTRS-C4, PTRS-D20, and PTRS-D2, which showed positive and significant yield increases from K fertilization (Table 4). In general, treatments 1 through 4 received 0, 60, 120 and 160 lb K_2O/ac and the same P rate and showed a trend for seed-K concentration to increase as K rate increased from 0 to 120 lb K_2O/ac. Sites that had Optimal or Above Optimal soil-test K values clearly showed no trend for seed-K to change as K rate changed. The Marianna and RREC sites also had Low or Medium, respectively, soil-test K but showed no yield or seed-K change among K rates. Mean seed-K concentrations of most treatments ranged from 1.53-1.66% K, which would equal removal rates of 1.11 to 1.20 lb K_2O/bushel. The greatest seed-K concentration of 1.95 (Marianna) corresponds to a removal rate 1.41 lb K_2O/bushel.

PRACTICAL APPLICATIONS

Soil-test P and K were not completely accurate in identifying sites that would or would not respond to P and K fertilization, but additional sites are needed to draw conclusions. This one year of results suggest that our interpretation of soil-test P needs to be revised to make fertilizer recommendations more accurate. Seed nutrient concentration suggests that i) seed-P and -K concentrations vary numerically from site-to-site and ii) seed-K concentration increases as K fertilizer rate increases on fields that require K to maximize yield.

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Table 1. Selected agronomic and soil chemical property means (n = 3-6) of nine P and K fertilization trials conducted during 2013.

Site	Soil Chemical Properties, 4-inch sample depth							Soil series	Cultivar	Previous crop
	pH	P[a]	K[a]	Ca	Mg	Mn	Zn			
		ppm	ppm	ppm	ppm	ppm	ppm			
Marianna	5.6	23(4)	83(6)	758	143	196	1.5	Convent	Armor 55-R22	Soybean
Newport	5.5	118(19)	131(28)	973	102	15	4.3	Foley-Calhoun	Armor 47-R13	Rice
NEREC	6.4	25(3)	330(16)	4315	898	70	4.1	Sharkey-Steele	Armor 47-R13	Soybean
PTRS-C4	6.9	18(3)	88(5)	1487	224	445	2.3	Calloway	Armor 48-R40	Soybean
PTRS-D2	7.2	43(9)	96(10)	1988	293	228	5.4	Calloway	Armor 47-R13	Rice
PTRS-D20	7.0	8(2)	94(12)	1542	326	445	2.4	Calloway	Armor X1316	Soybean
RREC	6.4	21(1)	102(5)	981	152	295	0.6	Dewitt	Armor 55-R22	Soybean
RRS-Clay	7.5	64(2)	353(17)	4527	847	172	3.7	Sharkey-Desha	Armor 55-R22	Soybean
RRS-Loam	7.2	29(12)	157(10)	2110	544	165	2.1	Desha	Armor 55-R22	Soybean

[a] Numbers in ( ) indicate the standard deviation of the mean. NEREC = Northeast Research and Extension Center. PTRS = Pine Tree Research Station. RREC = Rice Research and Extension Center. RRS = Rohwer Research Station.

Table 2. Summary of soybean yield responses to P and K fertilization at three levels of significance (0.05, 0.10, and 0.25) as categorized by soil-test P and K level.

Soil Test Level	Soil Test Value		Phosphorus response			Potassium response		
	P	K	0.05	0.10	0.25	0.05	0.10	0.25
	ppm	ppm	Sites with yield differences / total number of sites					
Very Low	≤15	≤60	1/1	1/1	1/1	--	--	--
Low	16-25	61-90	0/4	0/4	0/4	0/2	0/2	2/2
Medium	26-35	91-130	0/1	1/1	1/1	2/3	2/3	2/3
Optimum	36-50	131-175	0/1	0/1	0/1	0/2	1/2	1/2
Above Optimum	≥51	≥176	0/2	0/2	0/2	0/2	0/2	0/2

Table 3. Soybean yield response summary and seed-P concentrations as affected by P and K fertilization.

Site-Year	Control Yield [a]	Yield Response [b]	STP[c] Level	Treatment Number[d] 1	2	3	4	5	6	*P*-value	$LSD_{0.10}$
	bu/ac (P-value)	bu/ac (*P*-value)		----------Seed-P Concentration (%)----------							
Marianna	58	+2 (0.77)	L	0.589	0.554	0.573	0.597	0.566	0.561	0.0057	0.019
NEREC	75	-2 (0.39)	L	0.507	0.488	0.487	0.472	0.475	0.487	0.1007	0.021
PTRS-C4	50	-1 (0.64)	L	0.455	0.461	0.453	0.455	0.440	0.453	0.0997	0.012
PTRS-D20	44	+6 (0.02)	VL	0.437	0.435	0.425	0.433	0.398	0.433	0.0529	0.022
PTRS-D2	79	-1 (0.70)	O	0.466	0.467	0.459	0.450	0.477	0.469	0.0694	0.015
RREC	62	+1 (0.85)	L	0.442	0.454	0.464	0.458	0.441	0.454	0.1562	NS[e]
RRS-Clay	75	0 (0.64)	AO	0.444	0.430	0.442	0.442	0.450	0.446	0.4683	NS
RRS-Loam	80	+2 (0.08)	M	0.432	0.441	0.422	0.437	0.426	0.420	0.1868	NS
Newport	79	-3 (0.59)	AO	0.490	0.499	0.506	0.507	0.491	0.486	0.3455	NS

[a] Control yield is the yield of the plots that received no fertilizer.
[b] All yield responses are to P fertilizer only compared to the no fertilizer control except for PTRS-D2 which is in response to P with the same K rate.
[c] Soil-test P (STP) Level abbreviations: L, Low (61-90 ppm K); M, Medium (91-130 ppm K); O, Optimum (131-175 ppm K); and AO, Above Optimum (>175 ppm K).
[d] Treatment definitions: Trt 1) the recommended P rate plus 0 lb K_2O/acre; Trt 2) the recommended P rate plus 60 lb K_2O/acre; Trt 3) the recommended P rate plus 120 lb K_2O/acre; Trt 4) the recommended P rate plus 160 lb K_2O/acre; Trt 5) the recommended K rate plus the second P_2O_5 rate; and Trt 6) no P and K fertilizer (control). If STP level is VL, L, or M, 60 lb P_2O_5/acre is recommended and 0 lb P_2O_5/acre is recommended if STP is O or AO. STK recommendations: VL = 160 lb K_2O/acre, L = 120 lb K_2O/acre, M = 60 lb K_2O/acre, and O or AO = 0 lb K_2O/acre.
[e] NS, not significant ($P > 0.10$).
NEREC = Northeast Research and Extension Center. PTRS = Pine Tree Research Station. RREC = Rice Research and Extension Center. RRS = Rohwer Research Station.

Table 4. Soybean yield response summary and seed-K concentrations as affected by P and K fertilization.

Site-Year	Control Yield [a]	Yield Response [b]	STK[c] Level	Treatment Number[d] 1	2	3	4	5	6	*P*-value	$LSD_{0.10}$
	bu/ac	bu/ac (*P*-value)		----------Seed-K Concentration (%)----------							
Marianna	58	+7 (0.15)	L	1.91	1.89	1.93	1.95	1.94	1.85	0.1320	NS
NEREC	75	+1 (0.68)	AO	1.73	1.66	1.65	1.63	1.63	1.65	0.1333	NS[e]
PTRS-C4	50	+2 (0.23)	L	1.47	1.53	1.57	1.60	1.52	1.47	<0.0001	0.038
PTRS-D20	44	+7 (0.01)	M	1.52	1.57	1.65	1.63	1.55	1.49	0.0143	0.081
PTRS-D2	79	+5 (<0.001)	M	1.54	1.58	1.59	1.56	1.52	1.51	0.0963	0.054
RREC	62	0 (0.99)	M	1.64	1.66	1.66	1.65	1.62	1.66	0.8285	NS
RRS-Clay	75	+1 (0.32)	AO	1.64	1.61	1.64	1.66	1.64	1.64	0.7475	NS
RRS-Loam	80	+2 (0.07)	O	1.56	1.60	1.58	1.59	1.61	1.55	0.3083	NS
Newport	79	-4 (0.28)	O	1.61	1.66	1.65	1.68	1.62	1.61	0.5080	NS

[a] Control yield is the yield of the plots that received no fertilizer.
[b] All yield responses are to K fertilizer only compared to the control yield except for NEREC and RRS-Loam which is the response to K with the same P rate. The number in () is the *P*-value of the yield response.
[c] Soil-test K (STK) Level abbreviations: L, Low (61-90 ppm K); M, Medium (91-130 ppm K); O, Optimum (131-175 ppm K); and AO, Above Optimum (>175 ppm K).
[d] Treatment definitions: Trt 1) the recommended P rate plus 0 lb K_2O/acre; Trt 2) the recommended P rate plus 60 lb K_2O/acre; Trt 3) the recommended P rate plus 120 lb K_2O/acre; Trt 4) the recommended P rate plus 160 lb K_2O/acre; Trt 5) the recommended K rate plus the second P_2O_5 rate; and Trt 6) no P and K fertilizer (control). If STP level is VL, L, or M, 60 lb P_2O_5/acre is recommended and 0 lb P_2O_5/acre is recommended if STP is O or AO. STK recommendations: VL = 160 lb K_2O/acre, L = 120 lb K_2O/acre, M = 60 lb K_2O/acre, and O or AO = 0 lb K_2O/acre.
[e] NS, not significant ($P > 0.10$).
NEREC = Northeast Research and Extension Center. PTRS = Pine Tree Research Station. RREC = Rice Research and Extension Center. RRS = Rohwer Research Station.

Soybean Yield as Affected by Phosphorus Fertilization Source and Foliar Application of Selected Products

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ABSTRACT

Preplant fertilization of soybean [*Glycine max* (L.) Merr.] with phosphorus (P) and potassium (K) fertilizers is a common practice. Application of fertilizer solutions to soybean foliage is less common, but is being aggressively marketed as a means of increasing soybean yield. This report summarizes four P rate × P source experiments conducted from 2012-2014 and a single foliar-feeding trial conducted in 2014. Averaged across four trials, P source had no effect on soybean yield and application of 80 and 120 lb P_2O_5/ac increased soybean yield minimally (1.7 to 1.9 bu/ac) but significantly. Foliar-feeding had no benefit to soybean yield, but preplant application of 60 lb P_2O_5 plus 80 lb K_2O/ac increased soybean yield by nearly 11 bu/ac.

INTRODUCTION

The frequency and magnitude of soybean yield response to preplant P fertilization and foliar application of solutions that contain nutrients or growth-stimulating substances are important questions since they represent economic inputs. Phosphorus fertilization is usually performed based on soil-test results which are assumed to be accurate. Unfortunately, soil-test P is not a highly accurate indicator of soybean yield response to P fertilization. Examination of soybean yield response to different fertilizer sources and rates is of interest to ensure that the lack of consistent response is not due to the use of a particular fertilizer (e.g., triple superphosphate).

The number of solutions available to farmers for foliar application has increased in recent years. These solutions are often marketed as having the potential to increase yield. Although a substantial amount of research has been performed on foliar feeding with various fertilizer solutions and application times (Haq and Mallarino, 1998, 2000), new products continue to be developed and marketed, requiring continual research to investigate their potential benefit. In this report we summarize trials investigating i) soybean yield response to multiple P sources applied at different rates and ii) the benefit of two preplant P and K rates and multiple foliar-applied solutions.

PROCEDURES

The Pine Tree Research Station (PTRS), near Colt, was the location of all trials conducted from 2012 to 2014, except for one trial which was conducted in Cross County (CRCO12) (Table 1). The trials were established and managed using University of Arkansas System Division of Agriculture's Cooperative Extension Service guidelines for irrigated-soybean production. Depending on the site-year, individual plots were 6.5-to 13-ft wide and 20-to 30-ft long. Soybeans at the PTRS were planted in 15-inch wide rows and flood irrigated as needed. At CRCO12, soybeans were drilled in 7-inch wide rows and flood irrigated as needed.

For the P trials, triple superphosphate (46% P_2O_5) and MicroEssentials (MESZ, 12-40-0-10S-1Zn; The Mosaic Company, Plymouth, Minn.) were applied at 0, 40, 80, and 120 lb P_2O_5/ac. Phosphorus fertilizers were applied to the soil surface 0 (2012 to 2014) to 17 (2014) days before planting along with a uniform application of 80-90 lb K_2O/ac. The differences in N, S, and Zn application between the MESZ and TSP were not equalized. Differences in soybean yield response to P source could therefore be attributed to factors other than P. Trifoliate leaf samples were collected at the R2 stage, dried to a constant moisture, ground to pass a 2-mm sieve, digested with concentrated nitric acid and 30% H_2O_2, and analyzed for elemental concentrations including P. Grain yield was measured at maturity by harvesting the middle rows with a plot combine.

Each P trial was a randomized complete block design and contained 4 (CRSO12), 5 (PTRS12 and PTRS13), or 6 (PTRS14) blocks. Analysis of variance was performed using the Mixed procedure of SAS V. 9.4 using a 2 (source) by 4 (rates) factorial treatment structure (fixed effects). Location and replicate were considered random effects in the model. Means were separated when appropriate using Fisher's method of least significant difference at a significance level of 0.10.

The foliar-feeding experiment consisted of two soil-applied fertilizer treatments of no fertilizer (0 lb P_2O_5 and 0 lb K_2O/ac) and 60 lb P_2O_5 plus 80 lb K_2O/ac applied as triple superphosphate and muriate of potash. Five foliar-applied treatments were made including 0.25 lb Boron/ac at V4 stage (the standard control), 32 oz Foliar Blend/ac (Agri-Gro Marketing, Inc., Doniphan, Mo.) applied at the V4 and R2 stages, 24 oz Over-the-Top for Soybeans/ac (3% N, 1% Mg, 0,2% B, 0,05% Cu, and 3% Mn, Agro Logic, LLC, Seneca, S.C.) applied at R2, 2 gal KA24/ac at R2 stage (2.54% K_2O, NACHURS Alpine Solutions, Marion,

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Ohio), and 1.5 gal 3-18-18/ac at R2 stage (NACHURS Alpine Solutions, Marion, Ohio). All applications were made with a CO_2 backpack sprayer calibrated to deliver 10 gal/ac at 3 mph. The V4 and R2 applications were made on 25 June (V4) and 16 July (R2). Trifoliate leaf samples were collected before the second foliar application was applied to evaluate the effect of the V4 application on leaf nutrient concentration. The trial was a randomized complete block with a 2 × 5 factorial treatment arrangement and six blocks using the same statistical methods described for the P trial.

RESULTS AND DISCUSSION

Phosphorus fertilizer source (P = 0.1053, < 1 bu/ac difference) and the P rate by source interaction (P = 0.1475) had no significant influence on soybean yield. When averaged across P sources and compared to the no-P control, soybean yields were increased significantly by application of 80 and 120 lb P_2O_5/ac (Table 2). The yield difference was only 1.7 to 1.9 bu/ac, making application of these rates uneconomical at soybean prices of $12.00/bushel and P fertilizer prices of $0.65/lb P_2O_5. The lack of differences between P sources suggests that the N, S, and Zn added with the MESZ did not benefit soybean yield. Tissue P concentration increased as P rate increased (Table 2). Tissue P concentrations of soybean receiving no P were considered adequate (> 0.30%).

Neither foliar-applied product (P < 0.1495) nor the foliar-applied product by preplant fertilizer interaction (P < 0.4010, Table 3) had a significant effect on soybean yield. Preplant fertilizer rate, averaged across foliar-applied products, did influence yield (P < 0.0001). Averaged across foliar-applied treatments, soybean receiving 60 lb P_2O_5 plus 80 lb K_2O/ac (62.6 bu/ac) produced 10.9 bu/ac greater yield than soybean receiving no preplant P and K (51.7 bu/ac). Trifoliate leaf samples (data not shown) collected before foliar applications made at the R2 stage showed soybean receiving no preplant fertilization was K deficient (1.19% K). This suggested that the yield increase from preplant fertilization was likely due to K.

PRACTICAL APPLICATIONS

Years of field research show that positive soybean yield responses to P fertilization occur infrequently on Arkansas silt loam soils. The lack of response is unlikely due to fertilizer source and highlights the need for a soil-test method that better characterizes soil-P availability. Foliar application of various fertilizer solutions failed to increase soybean yields in 2014 but preplant application of 60 lb P_2O_5 and 80 lb K_2O increased yields by nearly 11 bu/ac with the yield increase attributed primarily to K fertilization. Growers should be aware of the strengths and weaknesses of soil-testing and ask about the expected frequency of yield increase, the magnitude of yield increase, and long- and short-term benefits from each crop input.

ACKNOWLEDGMENTS

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Table 1. Selected agronomic and soil-test information for five experiments conducted from 2012-2014.

Objective	Site-Year†	Cultivar	Plant date Mo/day	Soil pH	Soil-test P‡ ppm	Soil-test K‡ ppm
P Source	CRCO12	Armor 53-Z5	May 18	7.0	30	76
P Source	PTRS12	Armor 53-R15	April 24	7.1	10	70
P Source	PTRS13	Armor 48-R40	June 13	7.2	22	91
P Source	PTRS14	Armor 49-R56	May 23	7.3	14	59
Foliar	--	Armor 49-R56	May 23	7.2	16	58

†Site-year abbreviations: CRCO12, Cross County in 2012; PTRS12-14, Pine Tree Research Station, 2012-2014.
‡Soil-test was Mehlich-3 with concentrations in extracts analyzed by inductively coupled plasma atomic emission spectroscopy.

Table 2. Soybean yield and trifoliate leaf P concentration means as affected by P rate, averaged across two P sources, in four trials conducted from 2012 to 2014.

P Application Rate	Trifoliate Leaf P	Grain Yield
lb P_2O_5/ac	**% P**	**bu/ac**
0	0.336	64.7 b†
40	0.343	65.7 ab
80	0.352	66.4 a
120	0.357	66.6 a
P-value	<0.0001	0.0951

†Means followed by the same letter (within a column) are not different based on Fisher's method of least significant difference (α = 0.10).

Table 3. Soybean seed yield as affected by P and K fertilization rate and foliar-applied treatments at the Pine Tree Research Station (PTRS) during 2014.

	Preplant Fertilizer Treatment	
	0-0-0	0-60-80
Foliar Treatment†	bu/ac	
Control	49.7	63.2
Over-the-Top	52.8	64.3
Foliar Blend	52.9	63.3
NACHURS KA-24	51.3	59.2
NACHURS 3-18-18	51.7	62.8
LSD 0.10	NS	

†Foliar treatments: Control, 0.25 lb B/ac at V3-4; Over-the-Top, 24 oz/ac at R2; Foliar Blend, 32 oz/ac at the V3 and R2 stages; NACHURS KA-24, 2 gal/ac at R2, NACHURS 3-18-18, 1.5 gal/ac at R2.

Soybean Plant Structure Chloride Concentration as Affected by Chloride Rate and Cultivar Chloride Includer/Excluder Rating

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ABSTRACT

Chloride (Cl) toxicity or 'leaf scorch' of [*Glycine max* (L.) Merr.] soybean is a frequent problem on many irrigated and poorly drained soils. Our research objective was to examine Cl accumulation at the R5 growth stage in two representative soybean cultivars subjected to two different Cl levels. Two Pioneer cultivars, P94Y82, a Cl includer, and P49T80R, a Cl excluder, were planted in plots that received 0, 250, 500, and 750 lb Cl/ac in five applications. Whole plants were collected at R5 stage, separated into plant parts, and analyzed for dry matter and Cl concentration. Dry matter was not affected by Cl rate, but tissue Cl concentration increased as Cl rate increased. In general, the results showed that Cl concentrations i) for each plant part were greatest in the middle one-third, intermediate in the bottom one-third, and lowest in the top one-third of soybean plants and ii) within each plant position followed the order of petioles ≥ stems = leaves > pods. Collecting trifoliate leaves (no petiole) from the upper one-third of the plant may be the most practical sampling protocol and is likely sufficient to diagnose potential Cl problems.

INTRODUCTION

Chloride (Cl) toxicity or 'leaf scorch' of [*Glycine max* (L.) Merr.] soybean is a frequent problem on many irrigated and poorly drained soils in the southeast U.S. Information that can be used to diagnose Cl toxicity from plant tissue analysis is scarce. Most of the published research concerns rapid screening techniques for cultivar classification as a Cl includer or excluder. Fully developed trifoliate leaves are recommended for sampling at the R1-2 stage to diagnose deficiencies and toxicities of other nutrients; but Cl concentrations that are considered deficient and toxic could not be found in the published literature. Although Cl is an essential element, Cl deficiencies occur infrequently and toxicity is the more common problem. Knowledge of Cl accumulation in soybean plants would be useful to ensure that the most sensitive plant tissues are sampled for diagnostic purposes. Our research objective was to examine Cl accumulation at the R5 growth stage in two representative soybean cultivars subjected to two different Cl levels. A more detailed report that includes yield results and preliminary toxic tissue Cl concentrations from 2014 research was published by Slaton et al. (2015).

PROCEDURES

Trials were established at the Pine Tree Research Station (PTRS) and Rohwer Research Station (RRS) during 2014. Management with respect to seeding rate, irrigation, and pest control closely followed recommendations from the University of Arkansas System Division of Agriculture's Cooperative Extension Service. In each trial, soybean was furrow-irrigated as needed (Table 1).

Six cultivars were seeded in random positions within each of 16, 180-ft long strips that included four replications of four Cl rates. Individual plots were 30-ft long and 4-rows wide. Only two of the cultivars used in the primary experiment including P94Y82, a Cl includer, and P49T80R, a Cl excluder, were used for this objective. Each Cl rate was separated by four border rows to ensure Cl from one strip did not influence growth in the adjacent treatment. Chloride treatments were made using a combination of $CaCl_2 \cdot 2H_2O$ and $MgCl_2 \cdot 5H_2O$ salts (Bulk Reef Supply Co., Golden Valley, Minn.) applied in a 3:1 molar ratio, which approximated the molar ratio of Mehlich-3 exchangeable Ca and Mg in the soils common to each experiment station. Four Cl rates (0, 250, 500, and 750 lb Cl/ac) were applied in a total of five separate applications (Table 1). The Ca and Mg salts for each rate were preweighed for each replicate and Cl rate, dissolved in 3 gallons of deionized water (57 gal/ac at PTRS and 73 gal/ac at RRS), and applied to the plots on the dates indicated in Table 1. The salt solution was delivered using a 4-nozzle boom with drop nozzles (Teejet XR8004VS at the PTRS and the Teejet XR8006VS at the RRS; Teejet Technologies, Wheaton, Ill.) or a single-nozzle boom that allowed the spray to be directed onto the side of each bed.

Whole plants (4/plot at RRS and 6/plot at PTRS) were collected on 5 August at RRS and 6 August at PTRS to assess the plant part and location of Cl accumulation. The whole plants contained 14-16 nodes and were divided into thirds (upper, middle and lower) and subsequently partitioned into leaves, petioles, pods, and stems. All plant samples were oven-dried, weighed,

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ground, extracted with water (Kalra, 1998), and the extracts were analyzed for Cl concentration by inductively coupled plasma spectroscopy. The total dry weight and Cl uptake of the sampled plants was summed to compare total aboveground Cl content per 4 (RRS) or 6 plants (PTRS).

Each experiment was a randomized complete block design with three (PTRS) or four (RRS) blocks. The analysis of variance (ANOVA) model used a split-plot treatment structure where i) Cl rate was the whole plot and cultivar was the subplot (Table 2) or ii) plant position was the whole plot and plant part was the subplot (Tables 3 and 4). The ANOVA was performed by site, cultivar, and/or Cl rate using the MIXED procedure in SAS (SAS Institute, Inc., Cary, N.C.). When appropriate, mean separations were performed using Fisher's protected least significant difference method with an alpha level of 0.10.

RESULTS AND DISCUSSION

Total dry matter at the R5 stage following four Cl applications (0, 200, 400, or 600 lb Cl/ac) was not affected by the main effects (cultivar or Cl rate) or their interaction at either site (Table 2). Dry weight accumulation, assuming 130,000 plants per ac, corresponded to 4968 lb/ac for PTRS and 4451 lb/ac for RRS. The interaction between main effects was significant for whole-plant Cl concentration at both sites. Plant Cl concentration rank at both sites followed the general order of Cl-Includer 750 lb Cl/ac > Cl-Includer 0 lb Cl/ac ≥ Cl-Excluder 750 lb Cl/ac ≥ Cl-Excluder 0 lb Cl/ac. Aboveground Cl content (uptake) at R5 stage ranged from 3 to 51 lb Cl/ac at PTRS and 2 to 25 lb Cl/ac at RRS.

The plant position × plant part interaction significantly influenced tissue Cl concentrations for six of the eight cultivar and Cl rate combinations (Tables 3 and 4). In general, the results showed that Cl concentrations i) for each plant part were greatest in the middle one-third, intermediate in the bottom one-third, and lowest in the top one-third of soybean plants and ii) within each plant position followed the order of petioles ≥ stems = leaves > pods. The significant interactions for most situations occurred because the magnitude of Cl concentration differences varied among plant parts and positions. For example, pod Cl concentrations were uniform across plant positions.

PRACTICAL APPLICATIONS

Chloride salt addition had no detrimental effect on soybean dry matter accumulation but increased Cl uptake. Chloride concentrations tended to be greatest in the middle one-third and lowest in the top one-third of the plant and within each position followed the order of petioles ≥ stems = leaves > pods. Although Cl concentrations differed among plant parts and locations, collecting trifoliate leaves (no petiole) from the upper one-third of the plant may be the most practical and is likely sufficient to differentiate between Cl-includer and -excluder cultivars and diagnose potential Cl problems. The Cl concentration ratio (Includer/Excluder) of trifoliate leaves from the top one-third of the plant ranged from 3.5 to 8.0 at PTRS and 10.5 to 11.6 at RRS. This information suggests that new soybean cultivars can be categorized in most field environments by leaf analysis for Cl and greenhouse screening may not be needed.

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Table 1. Selected soil and agronomic management information for soybean Cl fertilization trials conducted in 2014 in Arkansas.

Information or Event	Pine Tree Research Station	Rohwer Research Station
Soil series	Calloway silt loam	Desha silt loam
Previous crop	Soybean	Soybean
Bed width (inches)	30	38
Seed rate (seed number/ac)	155,000	150,000
Seeding Date	May 23	May 21
Chloride Application Dates		
1	June 25 (first bloom)†	June 26 (first bloom)
2	July 3	July 2
3	July 9 (R2)	July 9 (R2)
4	July 24 (R3)	July 23 (R3/R4)
5	August 6 (R5)	August 5 (R5)

† Date and (growth stage) of Cl solution application or tissue sample collection.

Table 2. Whole, aboveground plant dry matter, Cl content, and Cl concentration means for each cultivar and Cl rate combination for trials conducted in 2014 at the Pine Tree (PTRS) and Rohwer (RRS) Research Stations. Means within each column followed by different lowercase letters indicate significant differences at the 90% level.

		Pine Tree Research Station		Rohwer Research Station	
Cultivar†	Cl Rate‡	Dry matter	Cl Concentration	Dry matter	Cl Concentration
	lb Cl/ac	g/6 plants	ppm	g/4 plants	ppm
P49T80R	0	106 a	667 c	69 a	434 c
P94Y80	0	106 a	3,497 b	65 a	3394 b
P49T80R	750	107 a	2,328 bc	59 a	850 c
P94Y80	750	99 a	10,773 a	56 a	6222 a
P-values					
Cl rate		0.789	0.036	0.076	0.010
Cultivar		0.624	<0.001	0.538	<0.001
Interaction		0.604	0.004	0.871	0.021

† Pioneer 49T80R is a Cl excluder and Pioneer 94Y82 is a Cl includer.

‡ Plant samples were collected at the R5 stage following application 0 or 600 lb Cl/ac. The Cl rate shown is the total Cl rate applied during the season.

Table 3. Chloride concentration means for each plant part and position combination for each cultivar and Cl rate for the trial conducted in 2014 at the Pine Tree Research Station.

		Cl Excluder (P49T80R) †		Cl Includer (P94Y82) †	
Position‡	**Part §**	**0 lb Cl/a**	**750 lb Cl/a**	**0 lb Cl/a**	**750 lb Cl/a**
		ppm	**ppm**	**ppm**	**ppm**
Bottom	Leaves	454	1991	2255	7887
Middle	Leaves	680	2511	5009	13460
Top	Leaves	466	2227	2680	7860
Bottom	Petioles	726	2204	3009	14150
Middle	Petioles	1032	3399	6700	22505
Top	Petioles	861	2449	3154	11925
Bottom	Pods	128	215	241	1247
Middle	Pods	147	205	409	1937
Top	Pods	86	231	236	1046
Bottom	Stems	976	3829	4086	11625
Middle	Stems	889	3169	4715	13640
Top	Stems	719	2516	2535	9690
LSD0.10¶		131	1362	769	2566
LSD0.10#		179	2011	1119	3851
Position (POS)		0.216	0.886	0.014	0.068
Part (PAR)		<0.001	<0.001	<0.001	<0.001
POS×PAR		0.014	0.6291	<0.001	0.005

† Pioneer 49T80R cultivar is a Cl excluder and Pioneer 94Y82 is a Cl includer.
‡ Plant sections are defined as follows: Bottom was the lower one-third, middle was the middle one-third, and top is the upper one-third of nodes.
§ Plant samples were collected at the R5 stage following application 0 or 600 lb Cl/ac. The Cl rate shown is the total Cl rate applied during the season.
¶ Fisher's least significant difference (LSD) test was used to compare means of plant parts within the same plant position.
# LSD was used to compare any two means between plant positions.

Table 4. Chloride concentration means for each plant part and position combination for each cultivar and Cl rate for the trial conducted in 2014 at the Rohwer Research Station.

		Cl Excluder (P49T80R) †		Cl Includer (P94Y82) †	
Position ‡	**Part §**	**0 lb Cl/a**	**750 lb Cl/a**	**0 lb Cl/a**	**750 lb Cl/a**
		ppm	**ppm**	**ppm**	**ppm**
Bottom	Leaves	395	942	3383	7323
Middle	Leaves	449	1024	4968	8655
Top	Leaves	277	421	2898	4892
Bottom	Petioles	600	1279	4572	10309
Middle	Petioles	791	1459	5571	12004
Top	Petioles	545	879	3374	5955
Bottom	Pods	137	171	299	709
Middle	Pods	120	165	406	868
Top	Pods	115	139	263	434
Bottom	Stems	614	1293	3860	6473
Middle	Stems	634	1234	4508	8546
Top	Stems	469	886	3614	7047
LSD0.10 ¶		98	139	1144	1311
LSD0.10 #		111	153	1968	1677
Position (POS)		0.021	<0.001	0.440	0.009
Part (PAR)		<0.001	<0.001	<0.001	<0.001
POS×PAR		0.074	<0.001	0.343	<0.001

† Pioneer 49T80R is a Cl excluder and Pioneer 94Y82 is a Cl includer.
‡ Plant sections are defined as follows: Bottom was the lower one-third, middle was the middle one-third, and top is the upper one-third of nodes.
§ Plant samples were collected at the R5 stage following application 0 or 600 lb Cl/ac. The Cl rate shown is the total Cl rate applied during the season.
¶ Fisher's least significant difference (LSD) test was used to compare means of plant parts within the same plant position.
# LSD was used to compare any two means between plant positions.

Seasonal Variation of Trifoliolate Leaf Potassium Concentration in Soybean Genotypes Differing in Maturity Group

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ABSTRACT

The trifoliolate leaf potassium (K) concentration of soybean [*Glycine max* (L.) Merr.] at blooming (R1-2) is used to monitor plant-K status. Improved diagnostics for interpreting leaf-K concentration across a range of growth stages would enable us to assess the K nutritional status of soybean. We evaluated season-long dynamics of trifoliolate leaf-K concentration in three glyphosate-resistant soybean cultivars of different maturity groups. Trifoliolate leaf-K concentration peaked (1.99-2.10%) at blooming (R1-2) for all three cultivars and then declined linearly at the same rate (0.0245% K/day) until leaf senescence (R7). Results suggest that interpreting soybean trifoliolate leaf-K concentration at growth stages beyond R1-2 may be possible.

INTRODUCTION

Understanding the change of soybean trifoliolate leaf-K concentration across time is required to develop diagnostic information to assess a plant's K health. The K concentration of a recently matured trifoliolate leaf at the R1-2 stage is a good predictor of soybean yield response to K fertilization (Yin and Vyn, 2004; Slaton et al., 2010; Clover and Mallarino, 2013). The relationship between soybean trifoliolate leaf-K concentration and seed yield may be different for determinate and indeterminate soybean cultivars. The critical leaf-K concentration and the best plant development stage for sample collection could differ between growth habits. Additional research is needed to evaluate how maturity group (MG) and K availability influence the trifoliolate leaf-K concentration of determinate and indeterminate glyphosate-resistant soybean cultivars. Our objective was to evaluate season-long dynamics of trifoliolate leaf-K concentration in representative determinate and indeterminate glyphosate-resistant soybean cultivars of different MG under the same growing condition.

PROCEDURES

A field experiment was conducted at the Pine Tree Research Station (near Colt, Ark.) on a Calhoun silt loam (Typic Glossaqualfs) in 2014. A composite soil sample from the 0-to 4-inch soil depth was collected from each of four blocks before fertilizer application. The soil samples were oven-dried, crushed, extracted with Mehlich-3 solution, and the extract was analyzed by inductively coupled plasma atomic emission spectroscopy (ICP-AES). Soil pH was determined in a 1:2 v:v (soil:water) mixture. Soil organic matter content was determined using the weight loss-on-ignition method. Selected soil chemical property means include a pH of 7.1, organic matter of 2.6%, and Mehlich-3 nutrient availability indices of 13 ppm P [2 ppm standard deviation (SD)], 68 ppm K (13 ppm SD), 1628 ppm Ca, 263 ppm Mg, 7 ppm S, 230 ppm Mn, and 1.8 ppm Zn.

The research area consisted of four adjacent blocks that accommodated three, 35-ft long strips of each soybean cultivar with each strip containing 20, 15-inch wide rows. Three glyphosate-resistant soybean cultivars having different maturity were selected for this study and were randomized within each block. The cultivars included Asgrow 3934, Armor 47-R13, and Armor 55-R22 to represent an indeterminate MG 3.9, an indeterminate MG 4.7, and a determinate MG 5.5, respectively. The trial was fertilized with 80 lb P_2O_5/ac as triple superphosphate, 120 lb K_2O/ac as muriate of potash, and 0.5 lb B/ac as solubor to ensure these nutrients were not yield limiting. The seeding rate, irrigation, and pest management practices closely followed the recommendations of the University of Arkansas System Division of Agriculture's Cooperative Extension Service.

After soybean emergence, a fully-expanded trifoliolate leaf from one of the top three nodes of 15 plants was collected 10-12 times every 6-8 days beginning 27 days after emergence (DAE; Fig. 1). The average plant development stage as described by Fehr et al. (1971) was recorded at each sample time. Leaf samples were processed and analyzed for K concentration by ICP-AES. A 140 ft^2 to 150 ft^2 area within each block was harvested with a small plot combine. Seed yield was adjusted to 13% seed moisture before yields were calculated.

The seed yield data were statistically analyzed by analysis of variance and means were separated by Fisher's protected least significant difference (LSD) test ($\alpha = 0.05$) using the Fit Model of JMP Pro 11 (SAS Institute, Inc., Cary, N.C.). Trifoliolate leaf-K concentration data were regressed against DAE using a non-linear Gaussian peak model. In the Gaussian model, the coefficient 'A' is the peak value (%K), 'B' is the critical point (DAE), and 'C' is the value (DAE) that controls the width of the bell shaped Gaussian curve (Archontoulis and Miguez, 2013). A linear model was used to predict the decline rate in trifoliolate leaf-K concentration after K concentration peaked.

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The growing season (emergence to maturity) was 115 days for the MG 3.9, 120 days for the MG 4.7, and 128 days for the MG 5.5 cultivar. The entire reproductive period (R1-8) lasted 80-85 days for all three cultivars. Blooming, the first reproductive stage (R1) started at 30, 35, and 48 DAE for the MG 3.9, 4.7, and 5.5 cultivars, respectively and lasted 12 days for both the MG 3.9 and MG 4.7 cultivars and 8 days for the MG 5.5 cultivar. Soybean seed yield was statistically different among soybean cultivars (Table 1). The MG 5.5 cultivar yield was 14-76% greater than the MG 4.7 and 3.9 cultivars. The yield of the MG 4.7 cultivar was intermediate and 55% greater than the MG 3.9 cultivar.

The Gaussian model showed that regardless of soybean MG group or growth habit, the trifoliolate leaf-K concentration gradually increased from the vegetative stage to the early reproductive stage (R1-2), peaked at the R1-2 stage, and then declined gradually towards maturity (Fig. 1; Table 1). The peak trifoliolate leaf-K concentration was similar (1.99-2.10%) for all three cultivars but occurred at different DAE. The trifoliolate leaf-K concentration peaked at the R2 stage for the MG 3.9 (37 DAE) and 4.7 (43 DAE) cultivars and at the R2 stage for the MG 5.5 (42 DAE). The linear model showed that after peak K concentrations were reached at the R1-2 stage, the trifoliolate leaf-K concentration declined linearly with plant age at the same rate of 0.0245% K/day until leaf senescence (R7 stage) for all three cultivars (Fig. 2).

PRACTICAL APPLICATIONS

Trifoliolate leaf-K concentration peaked during early reproductive growth and declined linearly at a constant rate irrespective of MG or growth habit, suggesting that critical leaf-K concentrations can be developed for growth stages after blooming. This would expand our ability to interpret leaf-K concentrations at growth stages other than R1-2. Additional research is needed to assess whether K availability level influences the time that leaf-K peaks and the rate of decline.

ACKNOWLEDGMENTS

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Table 1. Soybean seed yield means and trifoliate leaf-K concentration regression coefficients and estimated parameter values as predicted by the Gaussian model for three soybean cultivars belonging to different maturity groups (MG) during the 2014 growing season.

		Gaussian model parameters†			
Cultivar MG	**Seed yield**	**A**	**B**	**C**	r^2
	bu/ac	**%**	**days after emergence**		
MG 3.9	38 c ‡	2.04 a	37 b	38.3 a	0.90
MG 4.7	59 b	1.99 a	43 a	38.7 a	0.90
MG 5.5	67 a	2.10 a	42 a	38.7 a	0.90
P-value	<0.001		<0.001		

†In Gaussian model [Y= A*Exp(-0.5*((X-B)/C)^2)], the coefficient ‘A’ is the peak value, ‘B’ is the critical point, and ‘C’ is the value that controls the width of the bell shaped Gaussian curve.

‡ Similar letters in a column do not differ significantly at 5% level of probability.

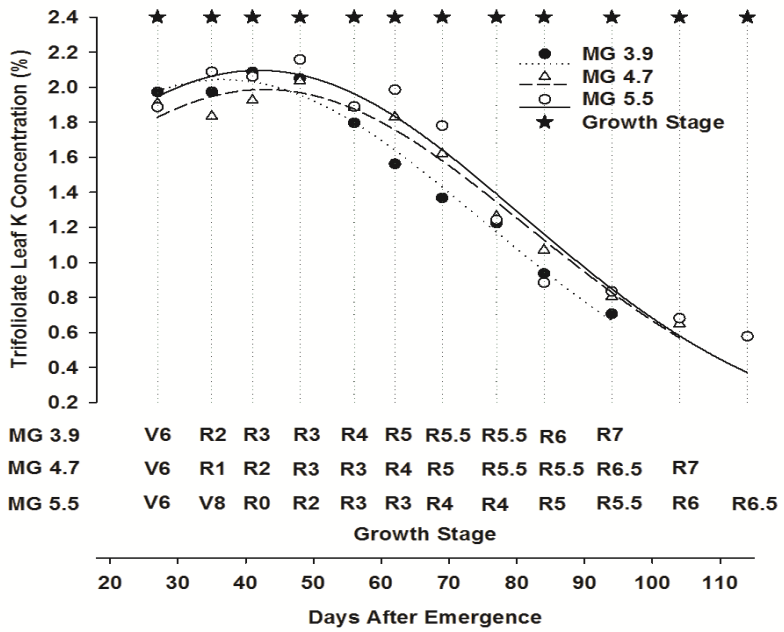

Fig. 1. Trifoliolate leaf-K concentration across time (and growth stage) of three soybean cultivars belonging to different maturity groups (MG) as predicted with a Gaussian peak model. Coefficient and estimated parameter values are listed in Table 1.

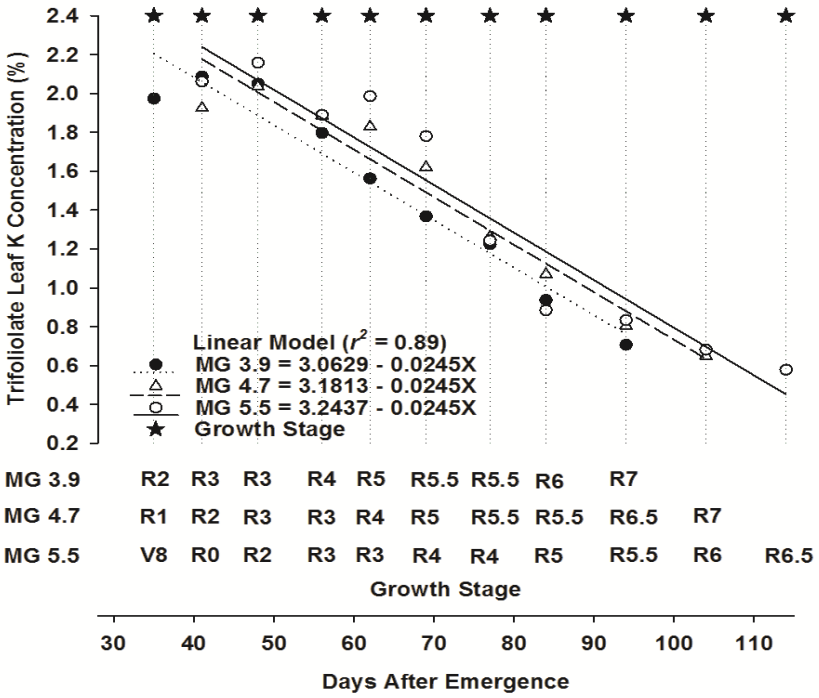

Fig. 2. Trifoliolate leaf-K concentration change across time (and growth stage) of three soybean cultivars belonging to different maturity groups (MG) as predicted with linear model after the peak K concentration is reached at the R1-2 stage.

Arkansas Discovery Farms: Monitoring Nutrient Loss in Runoff from Soybean Fields

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ABSTRACT

The Arkansas Discovery Farm program works with agricultural producers to monitor impacts of farming practices on natural resources and the environment. Nutrient losses in runoff from real soybean production fields are monitored using state-of-the-art, automated samplers. Four fields in rice-soybean rotations were monitored for nitrogen and phosphorus loss in runoff. Nitrate-N ranged from 0.048 to 0.975 mg/l (milligrams/liter), which is well below the national drinking water standard of 10 mg/l. Total nitrogen ranged from 0.860 to 1.938 mg/l, while soluble P ranged from 0.012 to 0.183 mg/l. Total P ranged from 0.126 to 0.554 mg/l. In all cases, mean concentrations of Nitrate-N, Total N, soluble P and Total P were relatively small compared with national averages in streams in agricultural watersheds from across the United States.

INTRODUCTION

Arkansas row-crop farmers are under increasing pressure to operate with environmental sustainability. The U.S. Environmental Protection Agency (USEPA) considers agriculture as a leading source of water quality degradation. Within the Mississippi River drainage basin, large–scale, basin-wide, water quality modeling efforts by the United States Geological Service projects agriculture in States along the Mississippi River corridor as the leading source of nitrogen and phosphorus delivery to the Gulf of Mexico, where excessive nutrients are thought to be the cause of a large hypoxic (waters with low dissolved oxygen) zone within the Gulf. In addition, several streams in eastern Arkansas have been declared by the Arkansas Department of Environmental Quality (ADEQ) as being impaired due to high turbidity levels thought to be caused by sediment delivery from row crop agriculture and are in need of Total Maximum Daily Loads determinations as required by the Clean Water Act.

These issues have been defined by in-stream or in-body water quality monitoring or by modeling stream systems based on water quality data from in-stream monitoring. While in-stream monitoring can define elevated nutrient or turbidity levels, it does not by itself clearly identify the source. Often agriculture has been targeted based on data generated by modeling. However, little data exists that quantifies edge-of-field losses from agricultural operations and tracks these losses through drainage pathways to streams and rivers. Edge-of-field data are needed to truly determine agriculture's impact on these issues. This need has been recognized by the USDA-NRCS, as it now provides financial assistance to eligible agricultural producers to conduct edge-of-field monitoring through Conservation Activities 201 and 202.

The overall goal of the Arkansas Discovery Farm program is to document sustainable and viable farming systems that remain cost-effective in an environmentally sound manner. The specific objective for this paper was to monitor and quantify any nutrient losses from a range of soybean production systems.

PROCEDURES

In 2011, the University of Arkansas System Division of Agriculture, along with its partners, established Discovery Farms for row crop operations in Cross and Arkansas Counties (Fig. 1). Instruments were installed at five fields where soybeans are rotated with rice to collect runoff samples. At the lower end of each field, automated, runoff water quality monitoring stations (Fig. 2) were established to: 1) measure runoff flow volume, 2) collect samples of runoff for water quality analysis, and 3) measure precipitation. The ISCO 6712 automated portable water sampler (Teledyne Isco, Lincoln, Neb.) was utilized to interface and integrate all the components of the flow station. Runoff flow volume was collected with either flumes or open-channel pipes. An ISCO 720 flow module equipped with a submerged pressure transducer was used to measure the hydraulic head at a flow-calibrated measurement point within the flumes, while a 750 flow module with an area velocity meter was used to measure flow velocity as well as head. Hydraulic head data and runoff discharge data was downloaded into the ISCO Flowlink software where discharge curves integrated over time (hydrographs) were used to calculate total discharge for a single runoff event. Discharge data were utilized to trigger flow-paced, automated collection of up to 100, 100-mL subsamples which were composited into a

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single 10 L sample. Flow pacing was used to ensure that subsamples were collected along both the rising and falling limbs of the hydrograph. At the completion of sampling for a given event, a text message was sent to cell phones via a wireless modem to indicate that a sample was ready for collection. A subsample of the 10 L sample was collected, processed in the field for preservation and shipped in insulated shipping vessels to keep samples chilled to meet EPA guidelines for prepping and handling samples. Samples were shipped to the University of Arkansas' Water Quality Lab (certified by the Arkansas Department of Environmental Quality) to determine concentration of soluble phosphorus, nitrate-Nitrogen, total nitrogen (N), total phosphorus (P) and total solids according to handling, prepping and analytical methods outlined by the EPA.

RESULTS AND DISCUSSION

The mean concentrations of nitrogen and phosphorus in runoff were similar across years and cultural practices from five soybeans fields (Table 1). Nitrate-N ranged from 0.048 to 0.975 mg/l (milligrams/liter), which is well below the national drinking water standard of 10 mg/l. Total nitrogen ranged from 0.860 to 1.938 mg/l, while soluble P ranged from 0.012 to 0.183 mg/l. Total P ranged from 0.126 to 0.554 mg/l. In all cases, mean concentrations of Nitrate-N, Total N, soluble P and Total P were relatively small. Nitrate-N is highly soluble and can move readily with surface runoff or downward movement with water through the soil profile. The range of mean Nitrate-N and total N concentrations in runoff from these fields is smaller than nearly 80% of mean concentrations from 130 reference streams in agricultural watersheds around the country (Fig. 3). Soluble P can move from application sites in runoff waters. It is also readily absorbed by soils, but the vulnerability of soluble P loss may increase if soil-test P values are high. Soluble P levels in the L'Anguille River just upstream and downstream of our Discovery Farms location in Cross County were observed to be 0.06 mg/l, while the average of soluble P leaving soybeans in fields next to the L'Anguille is 0.07 mg/l. This comparison may indicate that that runoff water quality in terms of soluble P is very similar to the water quality in the river.

PRACTICAL APPLICATIONS

Documenting environmental impacts of Arkansas farming systems, as well as evaluating the efficacy and cost-effectiveness of alternative practices, will bridge a knowledge gap that now keeps farmers, natural resource managers and decision-makers alike from confidently taking effective actions that ensure both economic and environmental sustainability. This program, as well as the formation of strong partnerships, has the potential to affect millions of agricultural acres across the state. These results indicate that soybean production in Arkansas may be losing small concentrations of N and P in runoff that are low or similar to observed in-stream values.

ACKNOWLEDGMENTS

The authors would like to thank the United Soybean Board, the Arkansas Soybean Promotion Board, the Arkansas Rice Research and Promotion Board, USDA-NRCS, the Arkansas Natural Resources Commission, EPA, and the University of Arkansas System Division of Agriculture for the funding required to conduct this work.

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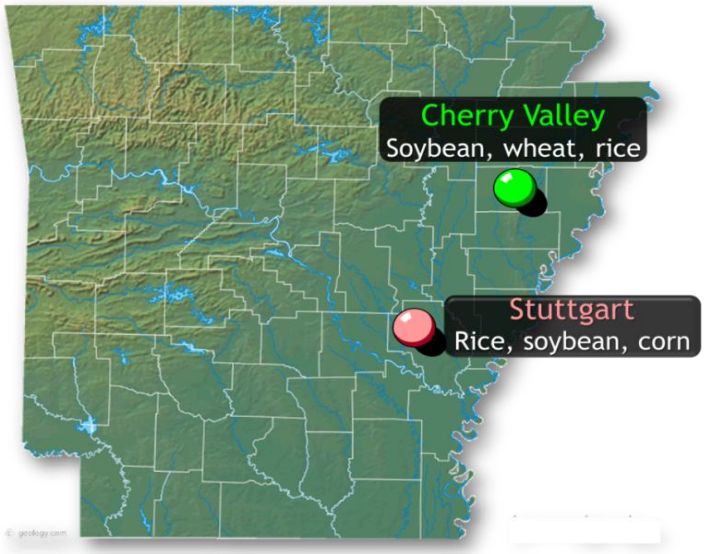

Fig. 1. Location of Arkansas Discovery Farms where soybeans are produced.

Fig. 2. An automated edge-of-field runoff monitoring station.

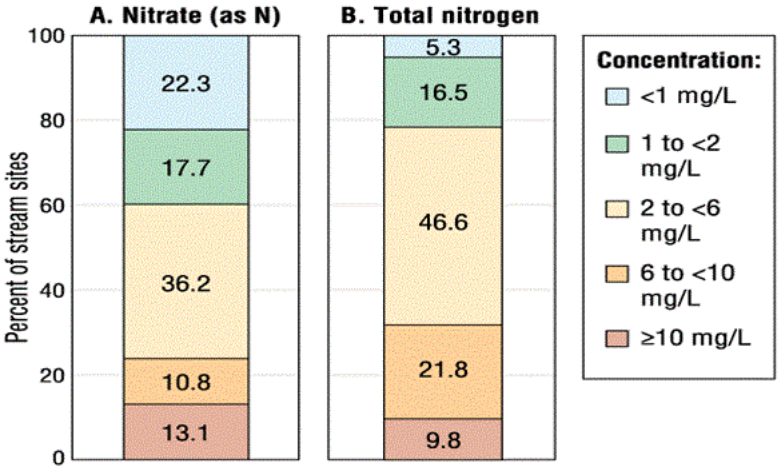

Fig. 3. Nitrogen concentrations in streams draining agricultural watersheds from around the United States. (A) Coverage: Nitrate data from 130 stream sites; total nitrogen data from 133 stream sites. Stream sites are in watersheds where agriculture id the predominant land use. These watersheds are within 36 major river basins studies by the United States Geological Survey National Water Quality Assessment. (B) Totals may not add to 100% due to rounding. Data source: Mueller and Spahr, 2005.

Table 1. Nutrient concentrations in runoff from Soybean fields located on Arkansas Discovery Farms.

Location	Field	Year	Tillage	Crop Rotation	Irrigation	Number of Runoff Events	Nitrate mg/L	Total N mg/L	Soluble P mg/L	Total P mg/L
Cross County	W1	2012	Cons.[a]	Following Soybeans	Flood	4	0.655	1.65	0.064	0.745
Cross County	W1	2014	Cons.	Following Rice	Flood	4	0.318	1.890	0.056	0.765
Cross County	W2-West	2012	Cons.	Following Rice	Furrow using ET Gage to schedule	7	0.343	1.210	0.081	0.344
Cross County	W2-West	2014	Cons.	Following Rice	Furrow using Pipe Planner Design and Surge Valve	13	0.975	1.938	0.078	0.232
Cross County	W2-East	2012	Cons.	Following Rice	Furrow using Computerized Scheduler	8	0.754	1.854	0.183	0.554
Cross County	W2-East	2014	Cons.	Following Rice	Furrow without Pipe Planner Design or Surge Valve	11	0.476	1.482	0.040	0.126
Cross County	C1	2012	Conv.[b]	Following Rice	Flood	7	0.318	1.200	0.055	0.503
Cross County	C1	2014	Conv.	Following Rice	Flood	2	0.800	1.480	0.015	0.437
Arkansas County	STG2	2012	Conv.	Following oats	Furrow with two rows on 36-inch beds	7	0.048	0.860	0.012	0.415
Arkansas County	STG2	2014	Conv.	Following soybeans	Furrow with two rows on 36-inch beds	8	0.700	1.810	0.037	0.240

[a]Conservation tillage.
[b]Conventional tillage.

ECONOMICS

Soybean Enterprise Budgets and Production Economic Analysis

A. Flanders[1]

ABSTRACT

Crop enterprise budgets are developed that are flexible for representing alternative production practices of Arkansas producers. Interactive budget programs apply methods that are consistent over all field crops. Production practices for base budgets represent University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations from the Soybean Research Verification Program. Unique budgets can be customized by users based on either Extension recommendations or information from producers for their production practices. The budget program is utilized to conduct economic analysis of field data in the Soybean Research Verification Program.

INTRODUCTION

Technologies are continually changing for soybean production. Simultaneously, volatile commodity prices and input prices present challenges for producers to maintain profitability. Producers need a means to calculate costs and returns of production alternatives to estimate potential profitability. The objective of this research is to develop an interactive computational program that will enable stakeholders of the Arkansas soybean industry to evaluate production methods for comparative costs and returns.

PROCEDURES

Methods employed for developing crop enterprise budgets include input prices that are estimated directly from information available from suppliers and other sources, as well as costs estimated from engineering formulas developed by the American Society of Agricultural and Biological Engineers. Input costs for fertilizers and chemicals are estimated by applying prices to typical input rates. Input prices, custom hire rates, and fees are estimated with information from industry contacts. Methods of estimating these operating expenses presented in crop enterprise budgets are identical to producers obtaining costs information for their specific farms.

Ownership costs and repair expenses for machinery are estimated by applying engineering formulas to representative prices of new equipment (Givan, 1991; Lazarus and Selly, 2002). Repair expenses in crop enterprise budgets should be regarded as value estimates of full service repairs. Repairs and maintenance performed by hired farm labor will be partially realized as wages paid to employees. Machinery performance rates of field activities utilized for machinery costs are used to estimate time requirements of an activity which is applied to an hourly wage rate for determining labor costs (USDA-NASS, 2014). Labor costs in crop enterprise budgets represent time devoted to specified field activities.

Ownership costs of machinery are determined by the capital recovery method which determines the amount of money that should be set aside each year to replace the value of equipment used in production (Kay and Edwards, 1999). This measure differs from typical depreciation methods, as well as actual cash expenses for machinery. Amortization factors applied for capital recovery estimation coincide with prevailing long-term interest rates (Edwards, 2005). Interest rates in this report are from Arkansas lenders as reported in November 2014. Representative prices for machinery and equipment are based on contacts with Arkansas dealers and industry list prices (Iron Solutions, 2014). Revenue in crop enterprise budgets is the product of expected yields from following Extension practices under optimal growing conditions and projected commodity prices.

RESULTS AND DISCUSSION

The University of Arkansas' Department of Agricultural Economics and Agribusiness (AEAB) develops annual crop enterprise budgets to assist Arkansas producers and other agricultural stakeholders in evaluating expected costs and returns for the upcoming field crop production year. Production methods analyzed represent typical field activities as determined by consultations with farmers, county agents, and information from Crop Research Verification Program Coordinators in the Department of Crop, Soil, and Environmental Sciences. Actual production practices vary greatly among individual farms due to management preferences and between production years due to climatic conditions. Analyses are for generalized circumstances

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with a focus on consistent and coordinated application of budget methods for all field crops. This approach results in meaningful costs and returns comparisons for decision making related to acreage allocations among field crops. Results should be regarded only as a guide and basis for individual farmers developing budgets for their production practices, soil types, and other unique circumstances.

Table 1 presents a summary of 2015 costs and returns for Arkansas irrigated soybeans. Costs are presented on a per-acre basis and with an assumed 1000 acres. Program flexibility allows users to change total acres, as well as other variables to represent unique farm situations. Returns to total specified expenses are $190.50/acre. The budget program includes similar capabilities for center pivot irrigated and non-irrigated soybean production.

Crop insurance information in Table 1 associates input costs with alternative coverage levels for insurance. For example, with an APH yield of 54.0/acre and an assumed projected price of $10.00/bu, input costs could be insured at selected coverage levels greater than 52%. Production expenses represent what are commonly termed as "out-of-pocket costs," and could be insured at coverage levels greater than 57%. Total specified expenses could be insured at coverage levels of 75%.

PRACTICAL APPLICATIONS

The crop enterprise budget program has a state level component that develops base budgets. County extension faculty can utilize base budgets as a guide to developing budgets that are specific to their respective counties, as well as customized budgets for individual producers. A county delivery system for crop enterprise budgets is consistent with the mission and organizational structure of the Arkansas Cooperative Extension Service.

The benefits provided by the economic analysis of alternative soybean production methods provide a significant reduction in financial risk faced by producers. Arkansas producers have the capability with the budget program to develop economic analyses of their individual production activities. Unique crop enterprise budgets developed for individual farms are useful for determining credit requirements. Flexible crop enterprise budgets are useful for planning that determines production methods with the greatest potential for financial success. Flexible budgets enable farm financial outlooks to be revised during the production season as inputs, input prices, yields, and commodity prices change. Incorporating changing information and circumstances into budget analysis assists producers and lenders in making decisions that manage financial risks inherent in agricultural production.

ACKNOWLEDGMENTS

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Table 1. 2015 summary of revenue and expenses, furrow irrigated soybeans, per acre and 1000 acres.

Summary of Revenue and Expenses			Crop Insurance Information	
Revenue	**Per Acre**	**Farm**		**Per Acre**
Acres	1	1000		
Yield (bu)	60.0	60,000	APH Yield	54.0
Price ($/bu)	10.00	10.00	Projected Price	10.00
Grower Share	100%	100%		
Total Crop Revenue	**600.00**	**600,000**	**Revenue**	**540.00**
Expenses			**Percent of Revenue**	
Seed	90.00	90,000		17%
Fertilizers & Nutrients	43.40	43,400		8%
Chemicals	68.98	68,984		13%
Custom Applications	14.00	14,000		3%
Diesel Fuel, Field Activities	17.92	17,919		3%
Irrigation Energy Costs	40.39	40,395		7%
Other Inputs	3.45	3,450		1%
Input Costs	**278.15**	**278,148**		**52%**
Fees	0.00	0		0%
Crop Insurance	0.00	0		0%
Repairs & Maintenance, Includes Employee Labor	21.68	21,680		4%
Labor, Field Activities	10.30	10,299		2%
Production Expenses	**310.13**	**310,127**		**57%**
Interest	7.37	7366		1%
Post-harvest Expenses	18.00	18,000		3%
Custom Harvest	0.00	0		
Total Operating Expenses	**335.49**	**335,493**		
Returns to Operating Expenses	**264.51**	**264,507**		
Cash Land Rent	0.00	0		0%
Capital Recovery & Fixed Costs	74.00	74,004		14%
Total Specified Expenses	**409.50**	**409,497**		
Returns to Specified Expenses	**190.50**	**190,503**		

Economic Contribution of the Soybean Industry to the Delta, Arkansas River Valley, and Red River Valley Regions of Arkansas in 2012

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ABSTRACT

The soybean industry is a key component of Arkansas's economy. Since most soybeans and edamame (vegetable soybeans) are grown in the Delta, Arkansas River Valley, and Red River Valley regions of the state, these regions receive the greatest economic benefit from the soybean industry. The contributions of soybean farming and processing are magnified and many non-agriculture businesses in these regions benefit when the multiplier effects are included in the analysis.

INTRODUCTION

The soybean industry, which includes the production and processing of soybeans, is a key component of Arkansas agriculture and the state and some regional economies. However, some local and state leaders may be unaware of the contribution in terms of jobs, income and value added. This article summarizes the findings of a study which estimates the economic contribution of the soybean industry to the major growing regions of the state: the Delta, Arkansas River Valley and Red River Valley (Fig. 1).

PROCEDURES

The soybean industry contributes to the economy through the production and processing of soybeans (direct effect) and through multiplier effects (indirect and induced effects). The indirect effects include purchases made by soybean farmers and processing plants that are needed to grow, harvest, market and process soybeans. The induced effects occur when owners and employees of the soybean and supplying industries use their income to purchase goods and services from businesses in the region. Combined, these three effects are the measure of the soybean industry's total economic contribution to a region.

A region can only have direct effects within its own region (intraregional). However, indirect and induced effects can occur both within (intraregional) and outside (interregional) the region. Here we present only the intraregional contributions, which account for over 90% of total contributions to the state. See publication CED118 (Kemper et al., 2014) for the interregional and total contributions statewide.

The economic contributions are estimated using the IMPLAN System (MIG, 2012) input-output (IO) modeling software. The model estimates the direct, indirect and induced effects using the value of soybean production and processing that we enter into the model. Three separate models were developed, one for each of the three regions. The soybean value of production data and acreage planted and harvested are for 2011-2012 and from the United States Department of Agriculture, National Agricultural Statistics Service (USDA-NASS, 2013). The 2011 acreage data were used to adjust the 2011 employment data from IMPLAN to 2012 jobs estimates. The 2012 value of production data were converted to 2011 dollars to be consistent with the latest IMPLAN data, using deflators provided in the model. Once the estimates were generated, all values were adjusted and are reported in 2012 dollars. For the vegetable soybean industry, both 2012 jobs and output data were available. The economic contributions of the soybean industry are reported in terms of jobs, income and value added within each of the three regions.

RESULTS AND DISCUSSION

The Delta Region is the major soybean growing area in Arkansas and the soybean industry contributes greatly to this regional economy. Soybean production in the Delta Region is dominated by traditional soybean farming, although there is also a small amount of edamame production. The total intraregional economic contributions of the Arkansas Soybean Industry in the Delta in 2012 were 18,977 jobs, $698.6 million in income and $1.3 billion in value added (Table 1), representing 5 percent of the jobs in the Delta and 6 percent of the value added. The soybean industry generates 8 percent of jobs and 11 percent of the value added in the Central Delta sub-region, a significant share of this regional economy (Fig. 2).

Although the majority of the soybean industry's contribution to the Delta is in the form of direct contributions (soybean farming and processing) the industry generates considerable indirect and induced effects which add substantially to the regional economy. These indirect and induced contributions are generated in many sectors. The top five non-agriculture industries in terms of value added were: 1) Real Estate and Rental ($84.8 million), 2) Finance and Insurance ($70.3 million), 3) Health and Social Services ($36.0 million), 4) Manufacturing ($35.4 million), and 5) Retail Trade ($32.0 million). The contribution of the soybean industry to these five industries represents over 60% of the total contribution to value added outside of the soybean industry (Fig. 3).

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Although not as large, the soybean industry also contributes substantially to the Arkansas River Valley (ARV) and Red River Valley (RRV) regions of the state. Soybean production in the ARV is primarily traditional soybean farming but includes the majority of the edamame production in the state and the only edamame processing facility. The contributions of the edamame production and processing sectors are included in these results. The total intraregional economic contributions in the ARV in 2012 were 1,072 jobs, $10.4 million in income and $18.7 million in value added (Table 2). This represents approximately 1% of the jobs and value added in the ARV. The top five non-agriculture industries benefiting from the soybean industry in terms of value added were: 1) Real Estate and Rental ($1.3 million), 2) Finance and Insurance ($1.0 million), 3) Wholesale Trade ($686,100), 4) Health and Social Services ($604,900), and 5) Retail Trade (485,200). Outside of agriculture, the Real Estate and Rental industry represented the largest beneficiary of the soybean industry in the ARV region, representing 16% of the indirect and induced contributions (Fig. 4).

The soybean industry in the RRV region is comprised primarily of traditional soybean production. Therefore, most of the economic contribution to the region was captured as part of the direct effect of the soybean industry. The soybean industry generated 427 jobs, $4.9 million in income and $9.9 million in value added for the RVV regional economy in 2012 (Table 3). The non-agriculture industries that benefited most from the soybean industry in the RRV region in 2012 in terms of value added were: 1) Real Estate and Rental ($908,600), 2) Finance and Insurance ($434,900), 3) Retail Trade ($198,300), 4) Health and Social Services ($143,400), and 5) Construction ($113,800). The contribution of the soybean industry in these five industries represents over 70% of the total contribution outside of agriculture (Fig. 5).

PRACTICAL APPLICATIONS

The results clearly show that the Arkansas soybean industry generated considerable economic activity in the three soybean-producing regions of the state in 2012 (Fig. 6). It is also noteworthy that many industries which benefitted from soybean production and processing may not commonly be associated with the soybean industry or agriculture in general. However, without the economic engine of soybean farming and processing, many of these connected businesses would suffer losses in jobs, income, and value added, thus reducing the size of the regional economies.

ACKNOWLEDGMENTS

This study was funded by the Arkansas Soybean Promotion Board and their support is sincerely appreciated. Support was also provided by the University of Arkansas System Division of Agriculture. The authors also acknowledge and thank all those who provided information and helped undertake this study. American Vegetable Soybean and Edamame Inc. based in Mulberry, Arkansas, provided information on edamame production and processing as did the authors of the UA Division crop budgets. We appreciate the assistance provided by Lanny Ashlock, project manager, Arkansas Soybean Promotion Board, who was helpful (as always) answering any and all questions related to soybean production and processing.

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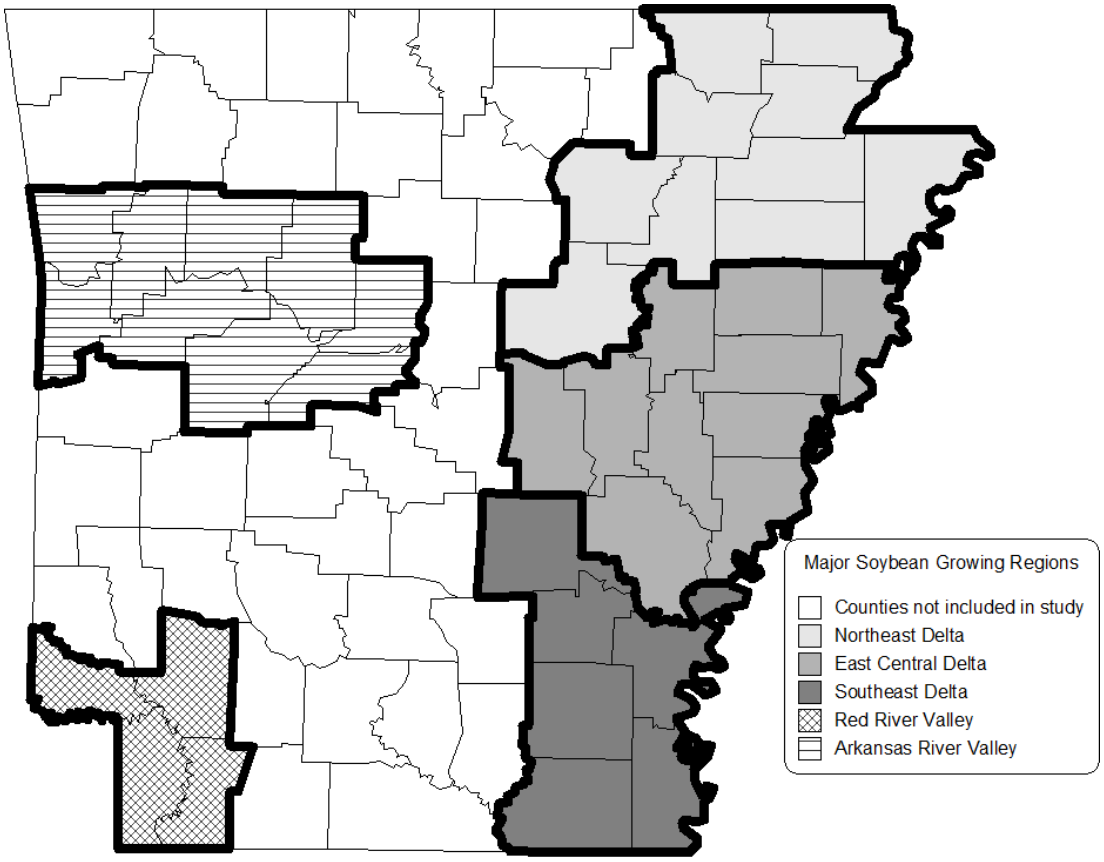

Fig. 1. Major Soybean Regions in Arkansas

Table 1. Intraregional economic contributions of the Arkansas soybean industry in the Delta region.

Region	Contribution Type	Jobs	Income[a]	Value Added[a]
Delta Region	Direct	12,527	463,493	870,488
	Indirect	3,740	151,657	271,545
	Induced	2,710	83,471	165,470
	Total	18,977	698,620	1,307,504

[a] Thousands of Dollars

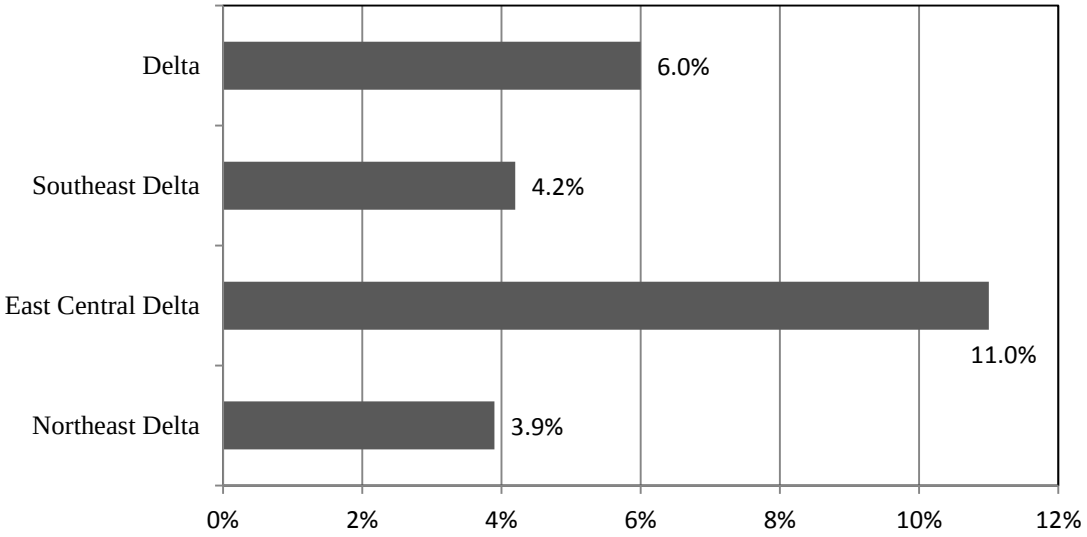

Fig. 2. Soybean industry intraregional contributions as percent of delta and delta subregions total value added.

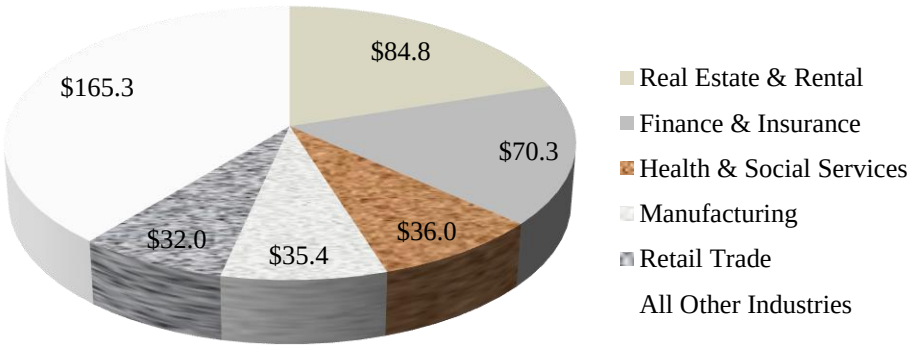

Fig. 3. Value added generated by the soybean industry in non-agriculture industries in the Delta region (in millions of dollars).

Table 2. Intraregional economic contributions of the Arkansas soybean industry in the Arkansas River Valley region.

Region	Contribution Type	Jobs	Income[a]	Value Added[a]
Arkansas River Valley	Direct	962	6,529	12,053
	Indirect	70	2,373	3,893
	Induced	40	1,465	2,756
	Total	1,072	10,366	18,703

[a] Thousands of Dollars

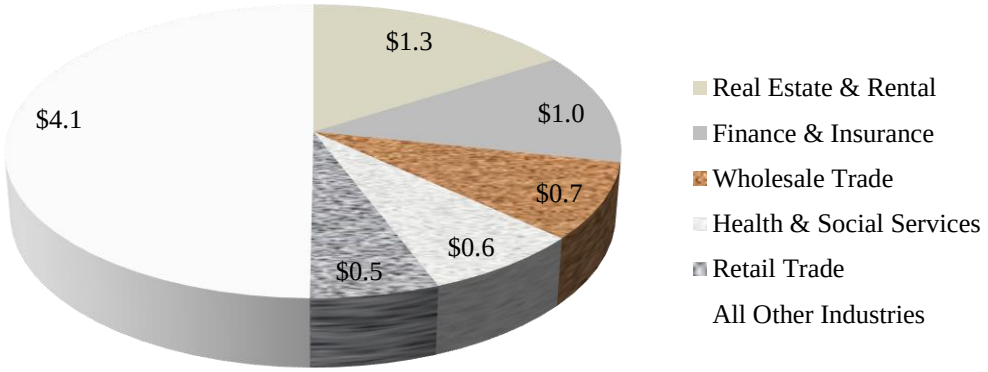

Fig. 4. Value added generated by the soybean industry in non-agriculture industries in the Arkansas River Valley region (in millions of dollars).

Table 3. Intraregional economic contributions of the Arkansas soybean industry in the Red River Valley region.

Region	Contribution Type	Jobs	Income[a]	Value Added[a]
Red River Valley	Direct	367	3,834	7,405
	Indirect	40	686	1,511
	Induced	20	448	1,027
	Total	427	4,967	9,943

[a] Thousands of Dollars

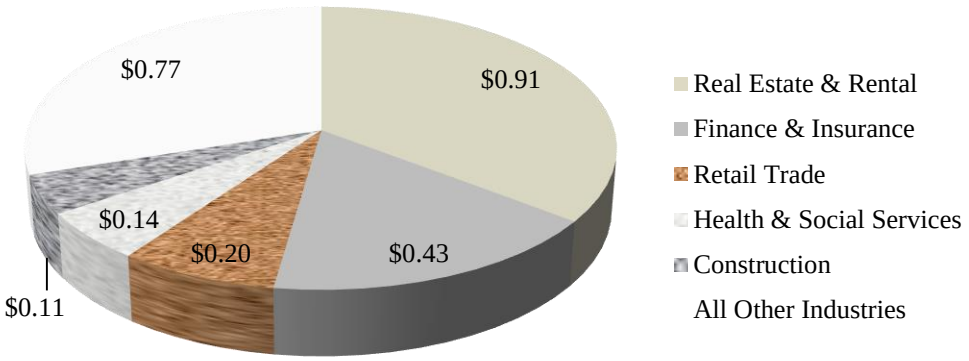

Fig. 5. Value added generated by the soybean industry in non-agriculture industries in the Red River Valley region (in millions of dollars).

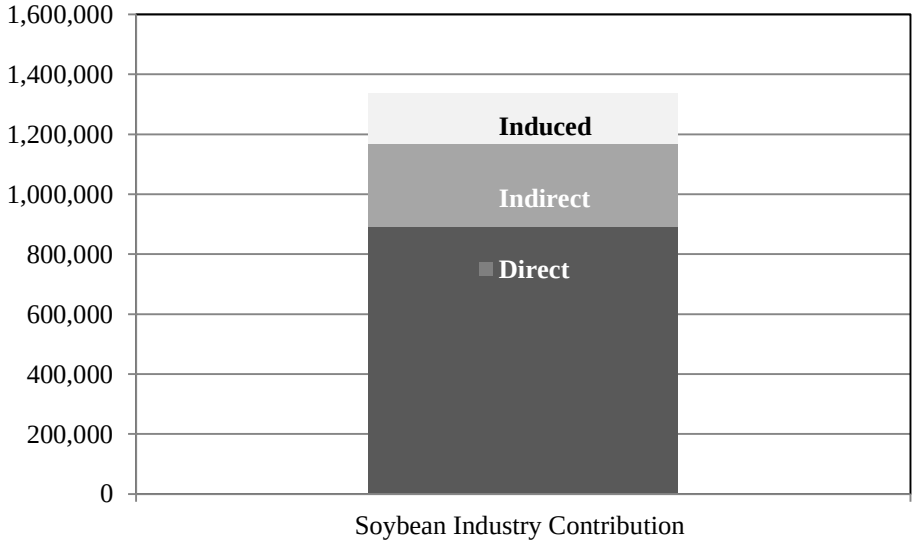

Fig. 6. Soybean industry generated value added in the three major soybean regions.

Economic Analysis of the 2014 Arkansas Soybean Research Verification Program

C.R. Stark Jr[1], C. Grimes[2], C. Norton[3], and W.J. Ross[4]

ABSTRACT

Economic and agronomic results of a statewide soybean research verification program can be a useful tool for producers making production management decisions prior to and within a crop growing season. The 2014 season results indicate that yields can be increased approximately 50% by the use of irrigation. A Roundup Ready/furrow irrigation system generated the highest average revenue. Center Pivot systems had the lowest average Variable Costs and highest average Fixed Costs. Returns to Land and Management were much higher for the fields using a Roundup Ready/furrow irrigation system.

INTRODUCTION

The Arkansas Soybean Research Verification Program (SRVP) originated in 1983 with a University of Arkansas System Division of Agriculture's Cooperative Extension Service study consisting of four irrigated soybean fields. Records have been compiled each succeeding year from the fields of participating cooperators until over 500 individual fields now comprise the state data set. Among other goals, the program seeks to validate state extension service standard soybean production recommendations and demonstrate their benefits to state producers. Studies of the annual program reports have shown that SRVP producers consistently exceed the state average soybean yields, even as both measures have trended upward (Stark et al., 2008). Specific production practice trends have also been identified using the SRVP database such as herbicide use rates (Stark et al., 2011). Cooperating producers in each yearly cohort are identified by their county extension agent for agriculture. Each producer receives timely management guidance from state SRVP coordinators on a regular basis and from state extension specialists as needed. Economic analysis has been a primary focus of the program from the start. Coordinators of the SRVP record input rates and production practices throughout the growing season including official yield measures at harvest. A state extension economist compiles the data into an Excel spreadsheet used for annual cost of production budget development. Measures of profitability and production efficiency are calculated for each cooperator's field and grouped by soybean production system.

PROCEDURES

Sixteen cooperating soybean producers from across Arkansas provided input quantities and production practices utilized in the 2014 growing season. A state average soybean market price was estimated by compiling daily forward booking and cash market prices for the 2014 crop. The collection period was 1 January through 31 October for the weekly soybean market report published on the Arkansas Row Crops Blog (Stark, 2014). Data were entered into the 2014 Arkansas soybean enterprise budgets for each respective production system (Flanders, 2014). Input prices and production practice charges were primarily estimated by the Flanders budget values. Missing values were estimated using a combination of industry representative quotes and values taken from the Mississippi State Budget Generator program for 2014 (Laughlin and Spurlock, 2014). Summary reports, by field, were generated and compiled to generate system results.

RESULTS AND DISCUSSION

The sixteen fields in the 2014 Arkansas Soybean Research Verification Program spanned six different production/irrigation systems (Table 1). Half of the system combinations utilized Roundup Ready (RR) technology seed. Two systems used Liberty Link (LL) seed and the final system had conventional seed. Half of the fields were grown under a Roundup Ready system with furrow irrigation. Four other fields employed furrow irrigation, two fields had center pivot irrigation, and two fields were non-irrigated. The small numbers of fields represented in this study do not permit standard statistical analysis. Yield and economic results are presented by grouping only for discussion purposes.

Yields by system ranged from 34.4 to 68.9 bu/ac. Weighted average yield per field across all systems was 59.4 bu/ac. Irrigation was clearly a differentiating factor with the irrigated fields averaging 62.0 versus non-irrigated averaging 41.3 bu/ac.

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Highest system yield was 68.9 bu/ac for the Roundup Ready/furrow irrigation system. All yields were standardized to 13% moisture content.

Soybean forward book and cash market price for the 2014 crop averaged $11.21/bu over the period of 1 January - 31 October 2014. Market price multiplied by yield gave field revenues. No grade reductions or premiums were included. Highest average revenue per acre was $771.88 for the Roundup Ready/furrow irrigation system.

Variable Costs across all systems had a weighted average of $277.22 and ranged from $183.77 to $311.17/ac. Lowest Variable Cost totals were seen in the Center Pivot systems. Fixed Costs across all systems had a weighted average of $60.40 and ranged from $50.73 to $82.43/ac. Highest Fixed Costs, as expected, were found in the Center Pivot systems.

Combination of the Variable Costs and Fixed Costs with Revenue values allowed calculations of Returns to Land and Management. The weighted average of Returns to Land and Management across all fields was $328.08/ac. The Roundup Ready/furrow irrigation system generated a Return to Land and Management that was much higher than other system combinations with an average of $431.71/ac. The two non-irrigated fields had an average Return to Land and Management of only $109.76/ac.

PRACTICAL APPLICATIONS

The results of state research verification programs can provide valuable information to producers statewide. Illustration of the returns generated when optimum management practices are applied can facilitate the distribution of new techniques and validate the standard recommendations held by state row-crop production specialists. Adoption of these practices can benefit producers currently growing soybeans and those contemplating production.

ACKNOWLEDGMENTS

The authors wish to thank the Arkansas Soybean Promotion Board and the University of Arkansas at Monticello School of Agriculture who provided funding and other support for this research project. Appreciation is also extended to Chris Grimes and Chad Norton, Arkansas Soybean Research Verification Program Coordinators, and Jeremy Ross, Arkansas Soybean Research Verification Program Director, without whom this research would not have been possible. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Soybean Research Verification Program economic results by production/irrigation system, 2014.

Production System	**Roundup Ready**	**Roundup Ready**	**Roundup Ready**	**Liberty Link**	**Liberty Link**	**Conventional**
Irrigation System	**Furrow**	**None**	**Center Pivot**	**Furrow**	**Center Pivot**	**Furrow**
# Fields	**8**	**2**	**1**	**2**	**1**	**2**
			Averages per acre			
Yield (bu)	68.9	41.3	34.4	56.4	59.0	55.3
Revenue ($)	771.88	462.98	385.62	631.69	661.39	619.92
Total Variable Costs ($)	281.07	302.49	183.77	311.17	229.45	273.23
Total Fixed Costs ($)	59.10	50.73	72.91	63.71	82.43	54.66
Total Costs ($)	340.17	353.22	256.68	374.88	311.88	327.89
Returns to Land & Management ($)	431.71	109.76	128.94	256.81	349.52	292.03

Source: 2014 Arkansas Soybean Research Verification Program Report.

Consumer Preferences and the Market for Non-Genetically Modified Food

N. Kemper [1], R. Rainey[2], and D. Rainey [1]

ABSTRACT

Studies have found U.S. consumers to be more accepting of genetically modified (GM) food products than consumers in Europe. However, American consumers also consistently express a willingness to pay (WTP) a premium to avoid GM products. Despite the apparent demand, non-GM products have not had the same market penetration as organic or natural products in the U.S. Interest of farmers in growing specialty and conventional varieties also appears to be on the rise. The goal of the consumer phase of this project is to better understand the demand for non-GM food products to assess the opportunities for Arkansas soybean farmers.

INTRODUCTION

There are increasing signals that enhanced market opportunities for non-GM crop products are increasing in the U.S. In fact, recent surveys have shown that about half of American consumers are willing to pay substantial premiums for non-GM foods and these premiums appear to be trending upward (Dannenberg, 2009). Fig. 1 shows the upward trend of premiums for non-GM foods in the U.S. and Europe. Two meta-analyses estimated that U.S. consumers were willing to pay, on average, 42% and 45% premiums for non-GM foods, respectively (Lusk et al., 2005; Dannenberg, 2009). Consumer demand is stronger for non-GM meat products than for non-GM processed products or oils (Fig. 2). In June of 2013 the USDA's Food Safety and Inspection Service approved the first non-GM labelling language to be used on meat and liquid egg products. A 2013 survey found 71% of U.S. food manufacturers and 64% of retailers in favor of mandatory GM labeling (Gallagher, 2013).

Despite consumer demand for non-genetically modified (non-GM) food there are few products marketed as such in the U.S. One explanation of this gap between consumer demand and the limited supply of products from industry may be the hypothetical methods used to elicit willingness to pay (WTP). It is well established that consumers tend to overstate WTP in hypothetical settings (List and Gallet, 2001); however, it is still unclear as to why this is the case and how best to adjust hypothetical methods to reduce this bias. There is a distinct need to conduct more studies using *non-hypothetical* and *incentive compatible* approaches to elicit WTP for non-GM foods.

Our primary goal is to better understand the demand for non-GM food products and assess the opportunities for Arkansas soybean and grain farmers to supply the non-GM market. To accomplish this goal four objectives will be carried out: 1) estimate consumer preferences for non-GM food using a hypothetical choice experiment; 2) evaluate the hypothetical results with a non-hypothetical, incentive compatible real choice experiment using real money and products; 3) estimate the market segmentation and better understand the "non-GM consumer" and; 4) assess the value of the Non-GMO Verified Product label on a poultry product fed a non-GM feed ration. One additional "methods" objective will test a new method to reduce hypothetical bias in choice experiments and contribute to more reliable WTP estimates using hypothetical methods.

PROCEDURES

The product selected for evaluation is fresh boneless skinless chicken breast. American consumers frequently purchase this product, and poultry and livestock producers are the single largest consumer of soybeans grown in Arkansas. The new USDA non-GM labeling language for meat products increases the attractiveness of this product. Several attributes and levels will be tested in the experiment. Table 1 lists the tentative attributes and levels.

The data for the hypothetical experiment will be collected through a national, web-based survey. The methods selected focus on the effectiveness of emphasizing attribute-level pricing in a hypothetical experiment to mitigate hypothetical bias. Adaptive Choice-Based Conjoint (ACBC) analysis was selected for use. This method represents an extension of one of the most widely used in marketing research and involves giving subjects tasks that appear to mimic what real buyers do more closely than ranking or rating products. Our study will implement four different treatments where respondents will only participate in one of the treatments. The first and second treatments will employ the standard Choice-Based Conjoint (CBC) method and the ACBC method, respectively. The third treatment (new method) will modify the ACBC method to include the price effects of selecting preferred attributes to further emphasize the need for respondents to consider price and return more reliable WTP estimates. The fourth treatment will be a Real Choice Experiment (non-hypothetical) involving real products and purchases.

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RESULTS AND DISCUSSION

Information plays an important role in consumers' choices to purchase non-GM products; however, most U.S. consumers (75%) are under the impression that they have never consumed GM food products (Pew, 2006). The difference in informed and uninformed consumers may explain some of the differences in consumer studies and the actual market. If this is the case, then food companies could use advertising to help transform an uninformed consumer into an informed one. However, large food processors have established product lines that rely on GM inputs and may be hesitant to aggressively promote non-GM food products at the risk of jeopardizing existing product lines. Providing reliable and accurate estimates of WTP premiums for non-GM foods is a critical part of evaluating market opportunities. Our project aims to better understand the non-GM market by exploring methods to reduce hypothetical bias in an effort to provide more accurate WTP estimates of non-GM premiums.

PRACTICAL APPLICATIONS

Estimating accurate price premiums for non-GM protein products can yield valuable information for farmers, processors and retailers. The price available at the retail level is ultimately what pushes economic incentives (or disincentives) back down the supply chain. Examining non-GM labeled and branded protein products using non-hypothetical incentive compatible approaches would provide market knowledge that currently does not exist.

ACKNOWLEDGMENTS

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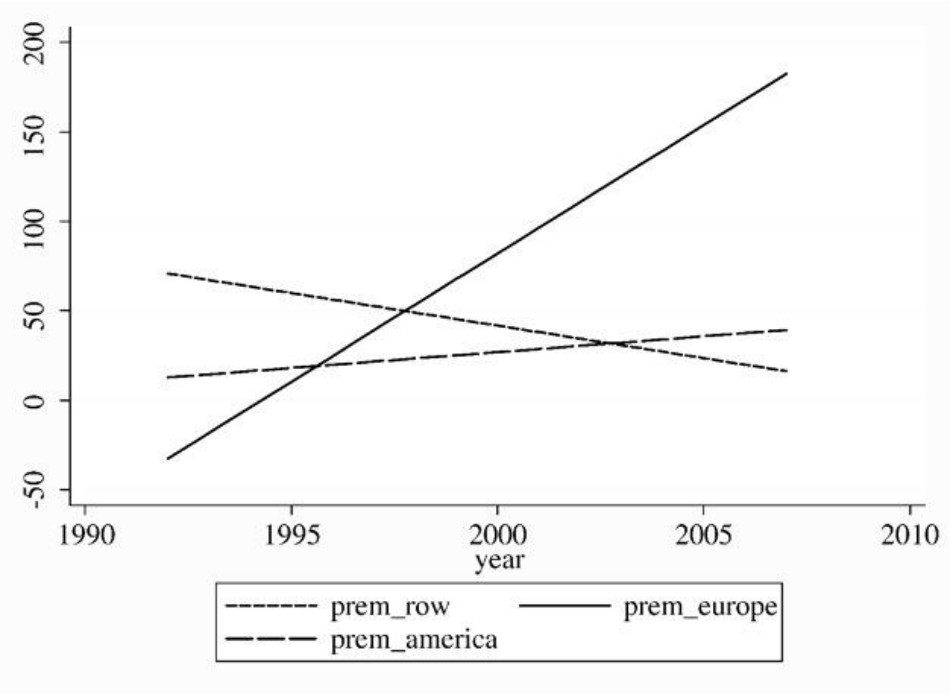

Fig. 1. Aversion to genetically modified food from the literature in percent (%) premium for non-genetically modified Information from a meta-analysis by Dannenberg, 2009.

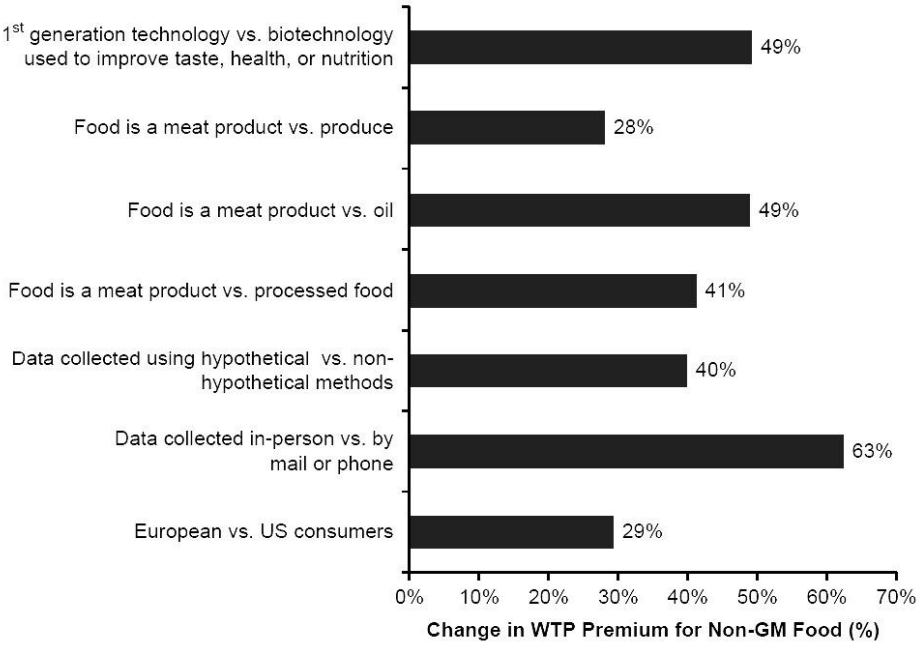

Fig. 2. Willingness to pay for non-genetically modified foods summarized from 57 studies. Data is from a meta-analysis by Lusk et al., 2005.

Table 1. Choice Experiment Product Attributes and Levels[a]

Attributes		Levels
1.	Price (12)	$5.99 (base), $6.59, $6.29, $6.09, $6.39, $6.19, $6.69, $6.79, $6.89, $6.99, $7.09, $7.19
2.	Production (3)	USDA organic ($0.60), all Natural ($0.30), none
3.	GM Labeling (3)	non-GMO verified ($0.30), may contain GM ingredients ($0.10), none
4.	Animal welfare (2)	cage free ($0.10), none
5.	Antibiotics (2)	antibiotics free ($0.10), none
6.	Diet (2)	fed no animal byproducts ($0.10), none

[a] attributes and levels tentative and subject to change.

Characterization of the Functionality of Soybean Seed Coats and Evaluation of Novel Prebiotic Fibers from Soy in Humans

S-O. Lee [1], P. Crandall[1], P. Chen[2], and S. Ricke[1]

ABSTRACT

Pectin is a soluble fiber with demonstrated health benefits such as the ability to lower blood glucose and cholesterol, increased satiety leading to lower caloric intake and improved insulin resistance. These benefits suggest that pectin may help in prevention and treatment of diseases such as diabetes and obesity. Soybean seed coats, a co-product of soybean processing, are a good source of fiber (pectin) and show potential as a value-added product. The objective of this study is to examine the effects of soy pectin on blood glucose and insulin responses in humans. Using a randomized-crossover design, fifteen healthy men were randomly assigned to two groups (control and soy pectin). Fasting finger-stick blood samples were collected at 15 minutes before and 0, 15, 30, 45, 60, 75, 90, 120, and 180 minutes after consumption of a control solution with added soy pectin or a control solution. Although no specific time interval was significantly different, a reduction in plasma glucose and insulin concentrations was observed. Compared with the control, mean glucose iAUC (incremental area under the curve) for the soy pectin treatment was lowered by ~13.2% from 5059 $\pm$ 506 to 4390 $\pm$ 387 mg × (~3 h) dL^{-1}. The soy pectin treatment also reduced the mean insulin iAUC to 26% compared with the control treatment. Results suggest soy pectin has a potential for use as a functional food ingredient to improve human health.

INTRODUCTION

Soybean seed coats are a good source of fiber and minerals. Soybean seed coats (hulls), a co-product of soybean processing are usually viewed as waste, but represent 8% to 10% of the weight of a bushel of soybeans (Sessa and Wolf, 2001). Soybean seed coats are used mostly in livestock and poultry feeds with a tiny percentage used to produce the enzyme soybean peroxidase. The seed coat, removed during soybean crushing, can be converted into value-added products with nutraceutical and pharmaceutical properties. Research suggests that dietary fiber has many health benefits including positive effects on controlling glucose and blood lipids. It may also influence satiety, by decreasing hunger, prolonging satiation, and/or increasing satiety signals from the gut.

If consuming soy soluble fibers during a meal could be shown to decrease the amplitude of the blood glucose peak following the meal, then this fiber could help diabetics control their blood sugar. Diabetes mellitus continues to be one of the leading and rapidly growing U.S. public health concerns. The Centers for Disease Control and Prevention estimates that more than 29 million people, over 9.3% of the U.S. population, have been diagnosed or have un-diagnosed diabetes (CDC, 2014). Diabetics are at increased risk for many serious health conditions including hypertension, heart disease, stroke, blindness, amputations, nervous system diseases and kidney failure.

The objectives of this study were to characterize and produce functional fiber fraction, pectin, from soybean seed coats and assess the functionality of consuming soybean pectin to improve blood glucose and insulin responses in humans.

PROCEDURES

Soy pectin from soybean seed coats was prepared using the method of Crandall and McCain (2000). A human study was approved by the Institute of Research Board (IRB) at the University of Arkansas and conducted to investigate plasma glucose and insulin responses. A randomized-crossover design was implemented and responses were analyzed after two 3-h periods over 2 wks. Healthy, nonsmoking male subjects with age range of 18-45 y not taking medication were recruited to participate in the study. Healthy male subjects were recruited to minimize metabolism variability, in addition all subjects' fasting blood glucose levels were < 100 mg/dL. After fasting 10-12 h, subjects consumed a solution with added soy pectin or a control solution (Azer Scientific, Pa.) along with 250 mL of water. Subjects were not allowed to drink additional water during testing.

[1] University of Arkansas System Division of Agriculture, Department of Food Science Department, Fayetteville, Ark.
[2] University of Arkansas System Division of Agriculture, Department of Crop, Soil and Environmental Sciences, Fayetteville, Ark.

About 0.4 mL of finger-stick blood sample was collected as a baseline measurement 15 min prior to each treatment as a reference. Plasma was collected and stored at -20 °C until analysis. Plasma glucose concentrations were measured using ACE® Glucose Reagent from Alfa Wassermann Diagnostic Technologies, LLC with Alfa Wassermann Clinical Analyzer (West Caldwell, N.J.). Plasma insulin concentrations were measured using the Human Ultrasensitive Insulin ELISA kit from Mercodia, Inc. (Uppsala, Sweden). Incremental area under the curve (AUC) was calculated by the trapezoidal rule (Whittaker and Robinson, 1967) for each individual and averaged for treatment responses from the group.

Incremental plasma glucose and insulin changes based on differences after the baseline measurement were averaged and mean in addition incremental AUCs were analyzed using analyses of variance (ANOVA) with SAS V. 9.4 (SAS Institute, Cary, N.C). Mean differences at each time point and iAUC were evaluated by a *t*-test using Tukey's adjustment with a significance level at $P < 0.05$.

RESULTS AND DISCUSSION

Table 1 illustrates the participant profile of the study group. Participants represented the normal BMI (Body Mass Index) category. Although no specific time interval was significantly different, incremental glucose response of the soy pectin was lower at 30-120 min intervals compared to the control reference drink (Fig. 1A). Also, while observing the group response, the mean incremental AUC for the control was significantly different at 5059 ± 506 mg × (~3h)/dL compared to the soy pectin incremental AUC of 4390 ± 387 mg × (~3h)/dL as shown in Fig. 2A ($P < 0.05$). A reduction in plasma insulin concentrations was also observed in participants for the soy pectin treatment (Fig. 1B). The mean incremental AUCs for treatments reflected a strong, similar trend as observed in the glucose response for the participant group. Fig. 2B shows that incremental AUC response to the control treatment was 3696 ± 495 µU × (~3h)/L compared to 2733 ± 372 µU × (~3h)/L of the soy pectin, an average 26% less response compared to the control treatment. Additional studies investigating long-term effects of regular consumption of products with the soy pectin from soybean seed coats may offer benefits for blood glucose and insulin control. Our study suggests soy pectin has a potential for use as functional food ingredient to improve human health such as lowering blood glucose and decreasing insulin release.

PRACTICAL APPLICATIONS

The market for functional foods as a health beneficial product with nutrition value is rapidly expanding. A wide variety of applications could utilize soy pectin for future product use and provide a healthy, value-added, and cost effective product.

ACKNOWLEDGMENTS

We appreciate the support provided by Arkansas soybean producers through check-off funds administered by the Arkansas Soybean Promotion Board. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Male participant information including age, body mass index, and screened fasting blood glucose.

Participant	Fasting blood glucose
Age (y)	25.9 ± 1.2
Body Mass Index (BMI, kg/m^2)	23.6 ± 2.0
Fasting Blood Glucose (mg/dL)	86.9 ± 0.7

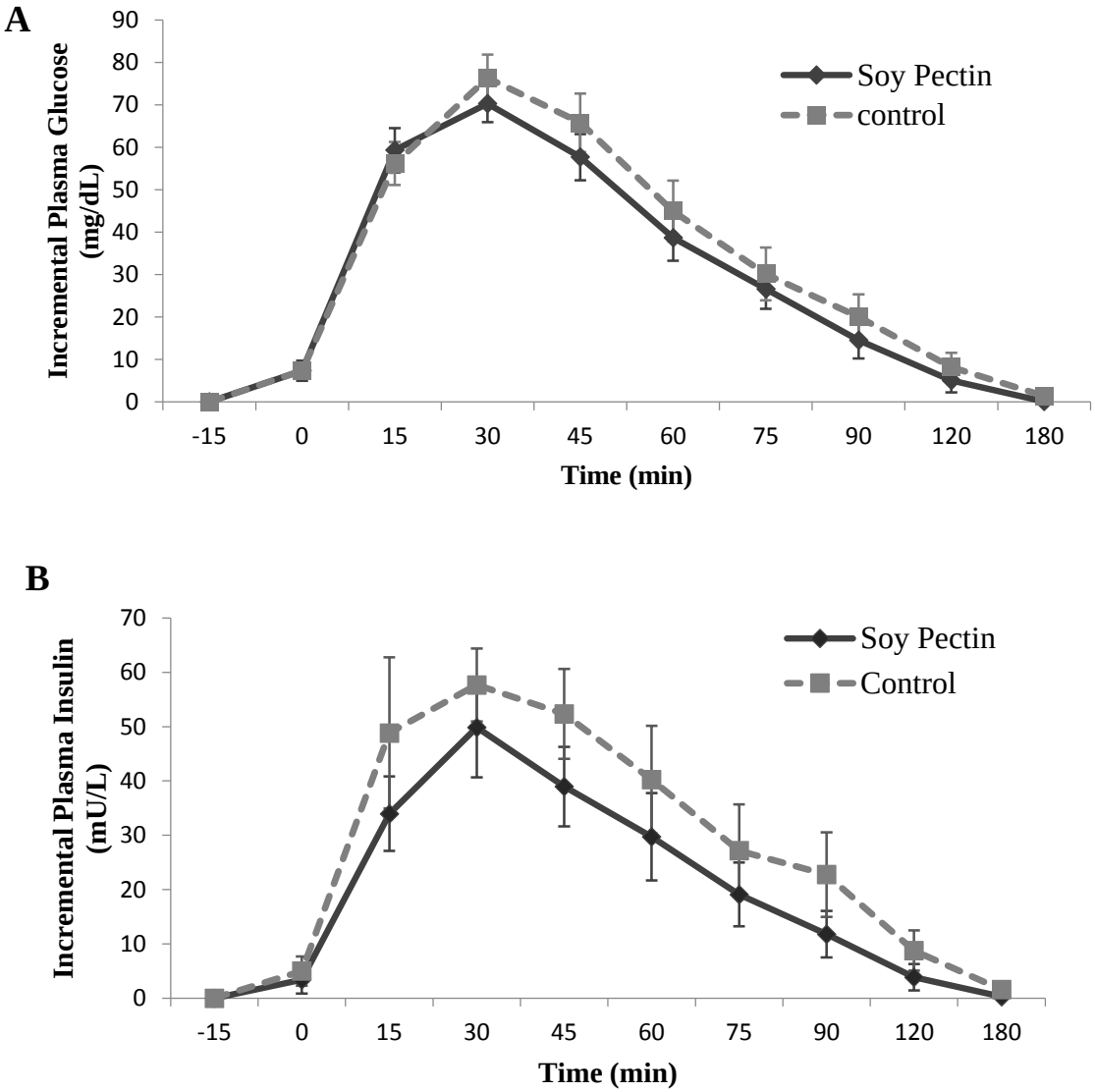

Fig. 1. Mean incremental plasma glucose response (A), 15 min before consumption to 180 min after consumption. Mean incremental plasma insulin response (B) from 0 min to 180 min after consumption displays reduced response. Each value represents the mean ± SEM.

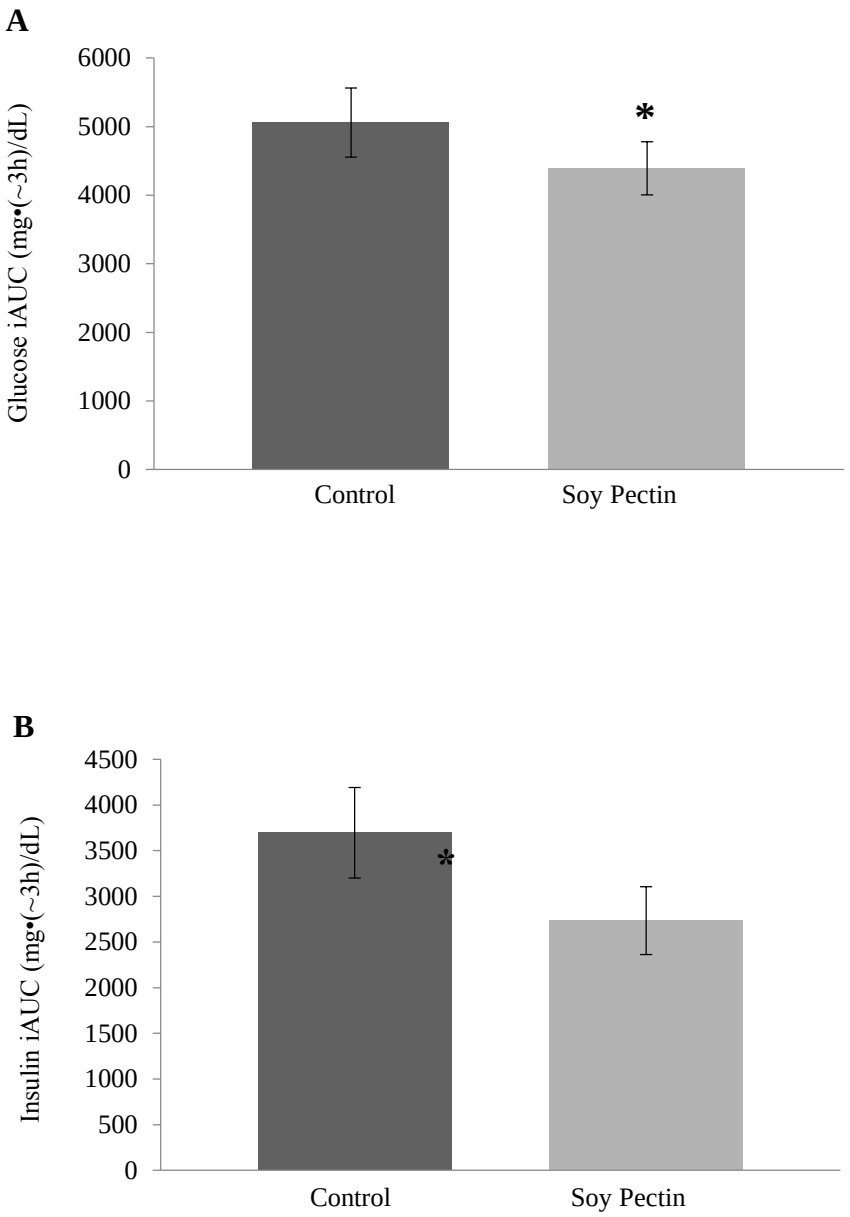

Fig. 2. Mean iAUC (incremental area under the curve) plasma glucose response with SEM (A). Mean iAUC plasma insulin response with SEM (B). * indicates significant difference *P* < 0.05.

Innovative and Value-Added Products from Arkansas Grown Non-Genetically Modified Soybeans for Patent and Potential Commercialization

N. Hettiarachchy[1], S. Rayaprolu[1], R. Horax[1], P. Chen[2], and H.S. Seo[1]

ABSTRACT

Non-genetically modified (GM) cultivars of soybeans have become commercially popular in the United States with excellent economic benefits to the growers and food industry. The nutrient loss due to the removal of by-products or residue during processing is more significant when non-GM soybean cultivars are used, since they are valuable in terms of high consumer preference and health perspectives. Hence, in this research the objective was to utilize whole soybean seeds to prepare nutritionally potent food products/snacks with sound science including freeze-dried and roasted soy snack, frozen dessert, dip/paste/hummus and snack chips. Four non-GM cultivars—Osage, R95-1705, R08-4004, and R05-4969—are included in this study along with two GM cultivars—UA Kirksey and JYC-2 (dried edamame) for comparison. The optimized conditions of processing created soy-based products with excellent physical and textural properties obtaining the best results in terms of appearance, taste, and nutritive quality. Tasty and nutrient-dense snack products prepared using non-GMO soy cultivars have the potential for commercialization and contribute to enhancement in economic growth.

INTRODUCTION

Soybean has been one of the key vegetables in Asia since the beginning of civilization. The intake of soy products has increased substantially over the past two decades in the United States (Sullivan, 2005). Soybean has been recognized as a wonder bean with health promoting nutrients including protein, dietary fiber, and isoflavones with no cholesterol and is considered a better choice as a vegetable protein source (Friedman and Brandon, 2001). There has been a recent trend for increased production of non-genetically modified (non-GM) soybeans among growers due to a major shift in consumer behavior (Ernst, 2013; Roseboro, 2014). Arkansas has the potential to become the leading state in the production of non-GM soybeans, and, hence, there is a need to develop new, innovative food products using Arkansas grown non-GM soybeans. The objective of this research was to develop protein-rich food products with significant eating quality using non-GM soybean cultivars: Osage, R95-1705, R08-4004, and R05-4969. Two genetically modified soy cultivars: UA Kirksey and JYC-2 (dried edamame) were used for comparison. The products prepared include: (i) roasted and freeze-dried snack, (ii) frozen dessert, (iii) snack chips and (iv) hummus-like dip. A protein energy drink, and Greek-style yogurt with probiotics for gastrointestinal health are in progress in addition to other products' optimization.

PROCEDURES

Roasted and Freeze-Dried Snack. The raw seeds of all the 6 cultivars were soaked in water overnight before the preparation of the snack products. Soaked seeds were cooked in 1% brine for 30 minutes before blast freezing (-25 °C) and freeze drying (3 days) under optimal conditions. To achieve optimal conditions for the roasted snack, the cooked seeds were tested under various time-temperature processing conditions. The color (L*, a*, and b* values), water activity, texture (compression force), and water absorption capacity (for inclusion in a breakfast cereal) were measured for both freeze-dried and roasted soybean seeds (Chen et al., 2005; HunterLab, 2008).

Preparation of Frozen Dessert with Edamame. The frozen dessert was prepared using both R08-4004 (non-GM and high protein) and JYC-2 (GM and edamame) cultivars due to their inherent color differences, yellow and green respectively. Whole seeds were pressure-cooked (15 PSI for 10 minutes), homogenized with gluten-free and dairy-free cheese/gum for mouthfeel, spinach, soy milk and low calorie sweetener was added to prepare a frozen dessert formulation. The product contained three different flavors: Vanilla (JYC-2), Chocolate-chip Mocha (R08-4004), and Pistachio (JYC-2 and R08-4004).

Snack Chips Preparation. The dried seeds of soybean cultivars R08-4004 and JYC-2 were ground to flour, and boiling water was added to prepare a dough. The dough was passed through a pasta maker to prepare a sheet which was cut to shape and roasted in a convection oven. The time and temperature conditions for the roasting were optimized to prepare the soybean chips with bland flavor, garlic flavor and sweet cinnamon flavor.

Development of Soybean Dip/Hummus. The soybean seeds from R08-4004 and JYC-2 cultivars were pressure-cooked in water at 15 PSI for 10 minutes. Ingredients, including olive oil, garlic powder, lime juice, tahini (sesame paste), and ground jalapenos were added. The contents were homogenized to an optimum hummus texture by varying the ingredient quantities and the time of processing. The color, viscosity, texture and water activity attributes were measured and used for comparison between the two cultivars.

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RESULTS AND DISCUSSION

Development of Creative Freeze-Dried and Roasted Snack. Figures 1 and 2 show the roasted and freeze-dried products. The results from all the physico-textural tests for the quality attributes showed that the freeze-dried products have brighter color, better water absorption characteristics (Fig. 3), significant textural character and lowest water activity (predicts extended shelf life, Table 1). The seeds roasted at 180 °C for 40 minutes showed the optimal textural and physical properties (Rayaprolu et al., 2015).

Preparation of New and Novel Frozen Dessert with Edamame. Utilization of whole seeds was the significant aspect during the preparation of the frozen dessert with three flavors: Chocolate-chip Mocha, Vanilla, and Pistachio. The textural and nutritional quality demonstrated that sugar and dairy-free frozen dessert can be prepared using non-GM soybeans that can be targeted towards diabetics, vegans and lactose intolerant individuals. Figure 4 shows frozen desserts—Mocha flavor with chocolate chips and vanilla flavor with spinach.

Creation of Soybean Snack Chips. The unflavored (Fig. 5), garlic, and cinnamon flavored snack chips were prepared under optimized conditions with the suitable color and texture comparable with other chips in the market. Additional flavors can be added as needed. They are healthy, nutritious and guilt-free snack products ready to be consumed.

Development of Soybean Dip/Hummus with Innovation. The whole soybean seeds were used to develop soy-based hummus (dip) with enhanced protein content and texture attributes comparable to a regular chick-pea hummus (Fig. 6). Color, viscosity and water activity were used as optimizing parameters for preparing the dip/hummus. The physiochemical and rheological characteristic analyses showed superior attributes to regular chick-pea hummus.

PRACTICAL APPLICATIONS

This research is the first of its kind using Arkansas-grown Non-GMO soybean cultivars for preparing novel food products. Other products like Greek-style soy yogurt for intestinal health and a protein-rich sports drink are also in progress due to their commercial appeal in the U.S. The outcome of this study will result in the development of tastier and healthier food products that can claim: gluten, corn, dairy and egg free; Non-GMO; no trans-fat and cholesterol; vegan; protein and dietary fiber rich. A patent has been filed (Hettiarachchy and Chen, 2012) on the frozen dessert formulation, and the edamame snack chips product has drawn the attention of Arkansas Vegetable Soybean and Edamame Company, Mulberry, Arkansas for potential commercialization.

ACKNOWLEDGMENTS

The authors would like to thank the Arkansas Soybean Promotion Board for providing the funds to conduct this project. Support was also provided by the University of Arkansas System Division of Agriculture.

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Fig. 1. Roasted snack prepared with R08-4004 seeds.

Fig. 2. Freeze-dried snack prepared with R08-4004 (left) & JYC-2 (right).

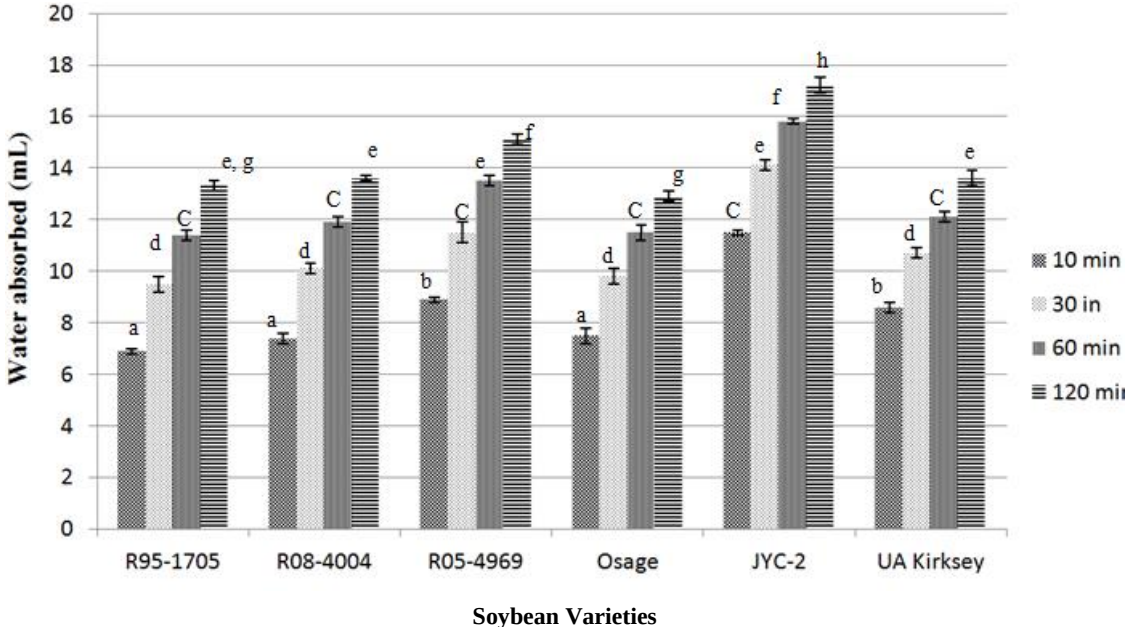

Fig. 3. Amount of water absorbed by the freeze-dried soybeans (GM and non-GM) seeds at various soaking times. Bars represent mean values of water absorbed (in mL) over soaking time (10, 30, 60 and 120 min) and the error bars represent the standard deviations. Bars connected by same letter are not significantly different from each other ($P < 0.05$). Non-GM: R95-1705, R08-4004, R05-4969, Osage; GM: JYC-2, UA Kirksey. (Rayaprolu et al., 2015). Better water absorption capacity can have potential impact when the product is used as an ingredient in breakfast cereals.

Table 1. The water activity of roasted soybean at varying roasting temperatures and time combinations.

Treatments† ➔	*140 - 20*	*140 - 40*	*140 - 60*	*160 - 20*	*160 - 40*	*160 - 60*	*180 - 20*	*180 - 40*	*180 - 60*
R95-1705	0.9 ± 0.0^{a}	0.8 ± 0.0^{ab}	0.3 ± 0.0^{a}	0.8 ± 0.0^{a}	0.3 ± 0.0^{a}	0.3 ± 0.0^{a}	0.5 ± 0.0^{a}	0.2 ± 0.0^{a}	0.2 ± 0.0^{a}
R08-4004	0.9 ± 0.0^{a}	0.8 ± 0.0^{ab}	0.4 ± 0.0^{a}	0.9 ± 0.0^{a}	0.5 ± 0.0^{b}	0.3 ± 0.0^{a}	0.8 ± 0.0^{b}	0.2 ± 0.0^{a}	0.2 ± 0.0^{a}
R05-4969	0.9 ± 0.0^{a}	0.7 ± 0.0^{a}	0.3 ± 0.0^{a}	0.9 ± 0.0^{a}	0.3 ± 0.0^{a}	0.3 ± 0.0^{a}	0.7 ± 0.0^{b}	0.2 ± 0.0^{a}	0.2 ± 0.0^{a}
Osage	0.9 ± 0.0^{a}	0.7 ± 0.0^{a}	0.3 ± 0.0^{a}	0.9 ± 0.0^{a}	0.2 ± 0.0^{a}	0.2 ± 0.0^{a}	0.9 ± 0.0^{bc}	0.2 ± 0.0^{a}	0.2 ± 0.0^{a}
JYC-2	0.9 ± 0.0^{a}	0.9 ± 0.0^{b}	0.4 ± 0.0^{a}	0.9 ± 0.0^{a}	0.3 ± 0.0^{a}	0.5 ± 0.1^{b}	0.9 ± 0.0^{bc}	0.2 ± 0.0^{a}	0.4 ± 0.0^{b}
UA- K‡	0.9 ± 0.0^{a}	0.9 ± 0.0^{b}	0.4 ± 0.0^{a}	0.9 ± 0.0^{a}	0.4 ± 0.1^{ab}	0.6 ± 0.1^{b}	0.9 ± 0.0^{bc}	0.2 ± 0.0^{a}	0.2 ± 0.0^{a}

† Treatments: Temperature in °C – Time in minutes.

‡ UA-K = UA Kirksey. Values presented are means ± standard deviations and those connected by same letter in each column are not significantly different ($P < 0.05$). Low water activity (<0.6) of the roasted product represents longer shelf life and keeping quality.

Fig. 4. Prototypes of soybean frozen dessert formulations. (The white spots seen in the pictures are reflections of light.) Left: mocha flavor with chocolate chips. Right: vanilla flavor with spinach.

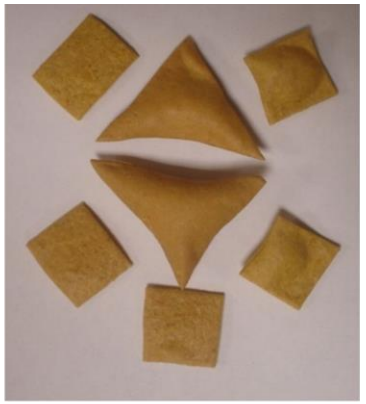

Fig. 5. Prototype of the soybean 'snack chips' (Contains over 90% soybean).

Fig. 6. Edamame hummus with jalapeno flavor.

Soybean Science Challenge

K. Ballard[1] and L. Wilson[1]

ABSTRACT

Arkansas' future policy makers are sitting in urban and rural high school science classes across our state. This generation is the first to have unlimited access to digital information about agriculture, but there are few resources to help them filter accurate from inaccurate information. The Soybean Science Challenge (SSC) responded to a growing disconnect between good science and the eroding public perception of farming. The anticipated impact of this program is already coming to fruition as students in schools across Arkansas are learning about the science undergirding sustainable agriculture. The goal of the SSC was not to teach the answers, but to help Arkansas youth formulate questions and develop a research-based understanding and appreciation of complex sustainability issues. The first Soybean Science Challenge student research award winners, Katie and Will Welch (a brother and sister team from Alpena High School), represented Arkansas at the international level with their project, *Stress Signals: Evaluating Cellular Signaling in Cotton, Soybeans, and Corn by Colorimetric Means as an Inexpensive Method of Crop Monitoring*. Will and Katie's project was recognized, at the 2014 Intel International Science and Engineering Fair in May, as one of the top 50 projects representing North, Central, and South America. The Welch's selection came from a total of 1015 projects and was based upon the potential economic and social impact of the student research. We believe well-informed and engaged youth will help ensure the viability of Arkansas agriculture for generations to come.

INTRODUCTION

A recently published educational study from ACT, Inc. (2014), reported on Arkansas high school student interest in STEM (Science, Technology, Engineering, Mathematics) -related fields. The 1846 Arkansas high school student respondents indicated a low overall interest in science majors and fields, particularly in the areas of agronomy and science, ecology, environmental science, food sciences and technology, horticulture science and science education. The 2014 STEM report identifies the critical challenge we face in engaging and inspiring Arkansas youth regarding the value and relevance of science to their lives (ACT, 2014).

Prior to 2014, Arkansas high school science classes did not have access to grade-appropriate core curriculum to support the study of agricultural sustainability. Student research recognition and incentives in the form of special awards at the annual state science fair numbered over 50; sadly, not one award related to the support of Arkansas production agriculture. The *Soybean Science Challenge* set out to change all of this.

Soybean production and commerce play a key role in the state's agricultural industry and overall economy. Ironically, Arkansas young people currently have little first-hand knowledge about soybean production. Some of these academically gifted students will be future leaders and decision makers. The *Soybean Science Challenge* was developed to support the Arkansas Soybean Promotion Board (ASPB) educational goals through filling a void in Arkansas high school science curriculum related to soybean production and providing incentives and support for applied student research in topics that support the sustainability of Arkansas soybean production.

PROCEDURES

The SSC educational program was managed through a project investigator and a part-time educational project manager. Management strategies included: teacher/curriculum needs assessment, creation of grade-appropriate educational curriculum (aligned with Arkansas Department of Education (ADE) Common Core), multi-agency/university partner development, planning and teaching face-to-face labs, synchronous distance and asynchronous online education, and ongoing process and outcome evaluation to inform and shape the project (Table 1). A needs assessment process revealed that Arkansas teachers are required to complete 60 hours of ADE approved in-service training annually. The University of Arkansas System Division of Agriculture's

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Cooperative Extension Service became an approved provider. Instructional tools/programs including Articulate, Moodle, Zoom, and Survey Monkey were utilized to create, deliver, evaluate, and manage SSC educational products and processes. Student research was supported through the creation of soybean research evaluation criteria and incentivized through establishment of *Soybean Science Challenge* research awards at the Intel International Science and Engineering Fair (ISEF) regional and state science fairs (Fig. 1). An online "Seed Store" was opened with the help of our UA Division of Agriculture research partners in Fayetteville to support student research. During 2014 the SSC developed and delivered two online courses, six online teacher curriculum resource modules, SSC High School Curriculum Resource Guide (publication), two Virtual Field Trips, six hands-on educational labs, student mentoring, a *Soy What's Up* web page, ADE approved in-service credit for teachers, sponsorships of ISEF regional and state science fairs, and cash awards for student researchers to start the process of changing the status quo.

RESULTS AND DISCUSSION

Teacher and student engagement in learning was a key SSC strategy and targeted outcome. Active engagement of partners was integral to our ability to effectively leverage resources to accomplish statewide outreach and educational goals. External partners included: ADE, STEM center directors, science specialists and teachers, ISEF Science Fair Directors, ASPB board members, USB, Blake Bennett (youth educator and soybean farmer), The Communications Group, and multi-state soybean promotion board educators.

Valuation of UA Division of Agriculture salary and technology contributions to this project exceeded $200,000 during 2014, including donated faculty/staff time, instructional design programs and systems, equipment and supplies. Soybean Science Challenge program evaluation data reflects that 485 Arkansas youth from diverse backgrounds gained valuable knowledge about soybean production and potential careers in agriculture through direct education.

Seven curriculum products were created and over 50 resources were peer reviewed, edited and incorporated in support of the online courses for students and teachers. Over 4000 marketing flyers and brochures were disseminated to Arkansas students and teachers. Soybean Science Challenge communicated with 142 public and private schools, 544 teachers, and over 1000 contacts were made with Arkansas state and regional education leaders. The virtual field trips, *Soybean Bugnados!* broadcast on 7 August 2014 involved 28 4-H youth and *Nematode Nemesis*, broadcast on 30 September 2014 involved 15 schools and 432 total participants (Fig. 2).

The media response was significant. The *Soybean Science Challenge* had 21 news placements (Table 2), including a feature in Delta Farm Press and two national radio and TV features on RFD-TV. Approval as an ADE in-service provider and alignment of *SSC* curriculum with ADE Common Core standards demonstrated our commitment to the rigor of the educational products we produced (Fig. 3). The establishment of SSC research awards and partnerships with four ISEF Science Fairs demonstrated a commitment to student engagement in applied research and the creation of new knowledge.

PRACTICAL APPLICATIONS

Arkansas youth, even just one or two generations removed from the farm, know little about the science and values that undergird Arkansas agricultural production. The Soybean Science Challenge leveraged partnerships to grow student knowledge and inquiry in meaningful ways.

ACKNOWLEDGMENTS

This education project was supported by the Arkansas Soybean Promotion Board. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Soybean Science Challenge products/outputs.

Product	Target Audience	Distribution
Soybean Science Challenge Online Course – Student (6 ½ hours of instruction)	9-12 grade	courses@uaex.edu
Soybean Science Challenge Online Course – Teacher In-Service (7 hours)	Science Teachers	courses@uaex.edu
Soybean Science Challenge Teacher Resources	Science Teachers	courses@uaex.edu
Soybean Science Challenge High School Science Curriculum Resource Guide – Curriculum Guide to the Teacher In-Service and Teachers Resources Courses with ADE Core Science Standards	Science Teachers/Students	ASTA List Serve; Arkansas Educational Cooperatives, personal emails; mailed to 285 Arkansas high school science teachers
It's Never Too Early to Plant the Seeds of Science Education – Soybean Science Challenge Announcement Flyers (2)	Science Teachers/Students	Released multiple times to ASTA List Serve, Arkansas Educational Cooperatives, personal emails; mailed to 285 Arkansas high school science teachers
Take Your Science Class on a Virtual Field Trip to an Arkansas Farm – Soybean Science Challenge Announcement (1)	Science Teachers/Students	Released multiple times to ASTA List Serve, Arkansas Educational Cooperatives, personal emails
Soybean Bugnados! Insects and Agriculture – Virtual Field Trip, 7 August 2014	4-H High School Students	28 students participated over Zoom
Nematode Nemesis? UA Virtual Trip to Davis Farm Video and Teacher Discussion Guide & Key, 30 Sept. 2014 Agriculture Cooperative Extension Service	High School Students/Teachers	Over 400 Hundred Students/Teachers from 15 Arkansas Schools; *SOY What's UP* CES web page; themiraclebean.com Miraclebean.com
Soybean Science Challenge Teacher Discussion Guide and Answer Key – Virtual Field Trip, 30 Sept. 2014	High School Students/Teachers	18 Arkansas High Schools; *SOY What's UP* CES web page; themiraclebean.com; mailed to 285 Arkansas high school science teachers Science Teachers
2015 Soybean Science Challenge Brochure	High School Students/Teachers	ASTA List Serve; Arkansas Educational Cooperatives; personal emails; *SOY What'sUP* CES web page; themiraclebean.com; conferences; mailed to 285 Arkansas high school science teachers
Soybean Science Challenge Seed Store announcement	High School Students/Teachers	ASTA List Serve; Arkansas Educational Cooperatives; personal emails; *SOY What's UP* CES web page; themiraclebean.com; conferences; mailed to 285 Arkansas high school science teachers
Soybean Science Challenge Banners	High School Teachers	Arkansas Curriculum Conference & the 2014 Arkansas State Science Fair
Soy Science Explosion Booklet – Soybean Science Challenge Program Evaluation Report	ASPB & CES	Mailed to ASPB and CES
Soybean Science Challenge Winners Video (In Production)	Video	Will be available on CES & themiraclebean.com websites/pages

Soybean science challenge

Our Soy Checkoff™ Progress Powered by U.S. Farmers

Cultivating Arkansas' student scientists to change the world.

Soybean Science Challenge Judge's Scoring Sheet

_____ **Science Fair**

Date: _____

Student Name(s): _____

Project Title: _____

Project Elements			Possible Score	Score
Presentation (Oral & Display): • **Neatness** • **Clarity of Text & Presentation** • **Use of images, graphics, tables, and graphs for display and in discussion with judges**			5	
Hypothesis or Testable question references a cause and effect relationship and a measureable change.	OR	Proposed solution/invention references a specific outcome and a measureable change.	5	
Background Research is diverse, multiple sources, complete citations.			5	
Variables are clearly defined (independent, controlled, dependent).			5	
Procedure is sequential and describes the investigation clearly (can be easily replicated).			10	
Collection & Use of Data: Systematic collection of key data with defined characteristics and clear documentation to insure data integrity. Data type(s) can include: Quantitative data: numbers, standard metric units, and/or Qualitative Data: words, observations, descriptions of physical or behavioral changes.			10	
Analysis: describes the trends or patterns found in the data; may have comments on reasons for trends or patterns. Conclusion: based on analysis of the data; acceptance or rejection of hypothesis or success of invention/solution; suggestions for further efforts.			10	
Social and/or Commercial Value to the Soybean Industry: Has the student or team made a viable correlation between their research and a key issue related to the production, marketing, consumption, or sustainability of soybean production? Is there a clear strategy related to the practical application of their research to the soybean industry? What is the potential for the application of this research?			25	
Marketability and Sustainability of Product, Process, and/or Strategy for the Soybean Industry: Is the target market clearly identified? Has the student/team considered how this concept/application could be utilized on a large commercial scale? Will the product/ process/strategy have a long-term impact on production, the environment and/or consumers? How easily could this product/ process/strategy be introduced to the marketplace?			15	
Total Score			**100**	

Fig. 1. Student research criteria.

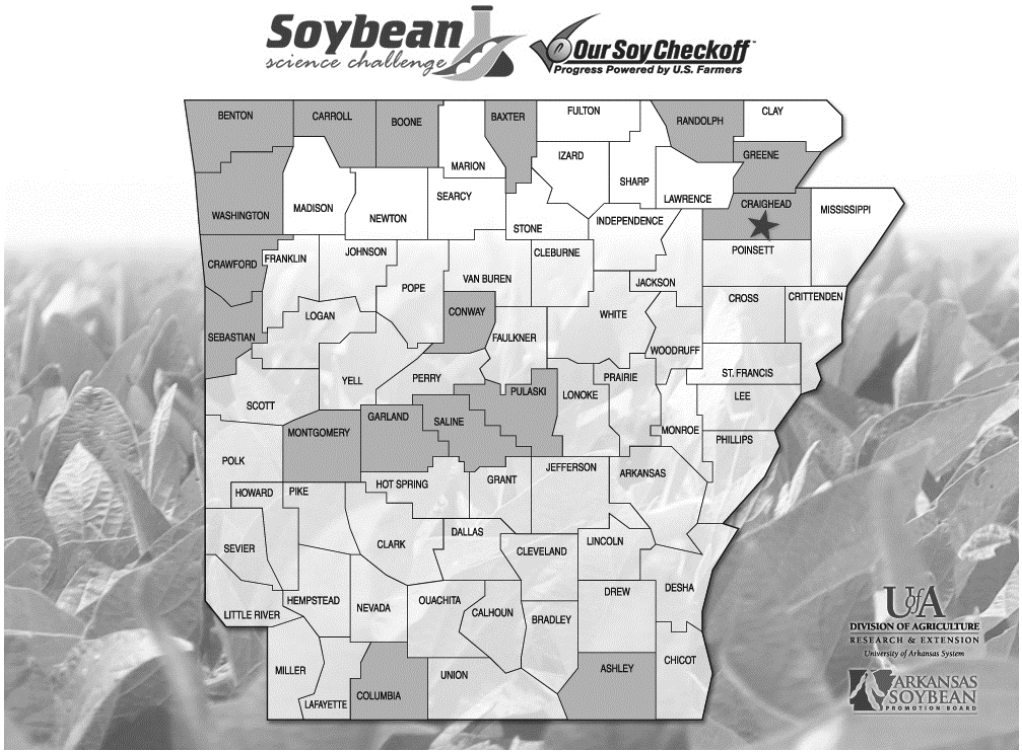

Fig. 2. Map – 30 September 2014 virtual field trip statewide school locations.

Table 2. Soybean Science Challenge media placement, type and reach.

Title and Media Outlet	Media Type	Distribution/Reach
Brother-sister team wins first Soybean Science Challenge – Arkansas Agriculture News, Division of Agriculture	News Feed	200 media outlets/county agents
Alpena team wins first-ever Arkansas Soybean Science Challenge in Conway – Carroll County News, Berryville, Ark.	Newspaper	8768
Ark. Brother-sister team win soy award (with photo) – FarmTalkNewspaper.com	Online Newspaper	10,000
Brother/sister team wins statewide Soybean Science Challenge – High Plains Midwest AG Journal	Periodical	100,000
Photo with cutline on Will and Katie Welch and Rick Cartwright with check for winning Soybean Science Challenge award – Farm Bureau Arkansas Press	Online Newspaper	2800
Breaking new ground: virtual field tour broadcast from a soybean farm (two photos) – Blue Letter, UA System Division of Agriculture Cooperative Extension Service	Newsletter	862
Phone Interview with Karen Ballard, video footage sent; package aired week of Sept. 30, 2014 – RFD TV	Cable TV Network	60 million households
Virtual field trip brings science behind soybeans from farms to high schools – Pine Bluff Commercial	Newspaper	26,788
Taylor School to Participate in Virtual field trip – Magnolia Banner News	Newspaper	9062
Students take part in virtual field trip – Advance Monticellonian	Newspaper	3940
High School Students learn about agriculture through virtual reality (two photos) – Jonesboro Sun	Newspaper	20,054
ASMSA student takes virtual field trip – Sentinel-Record, Hot Springs	Newspaper	38, 665
Recent virtual field day reaches science students across Arkansas – Delta Farm Press	Newspaper	26,201
Virtual Field Tour Broadcast From a Soybean Field (with photo) – Arkansas 4-H Outlook	State Newsletter	7722
Virtual field trip brings soybean science to the classroom – Blue Letter, UA Div. of Ag Cooperative Extension Service	Newsletter	862
Nematode Nemesis? UA Virtual Trip to Davis Farm Video and Teacher Discussion Guide & Key – Cooperative Extension Service	VFT Zoom	1200
Soybean Science Challenge Virtual Field Trip – Video News Monthly Update – Arkansas Farm Bureau	Online	450
Two national radio features on the Virtual Field Trip- RFD Radio SiriusXM Satellite Network	Radio	22 million subscribers
Using their (soy) bean: Student join virtual field trip connecting science and ag Arkansas Land and Life, UofA Division of Agriculture	Periodical	13,000
SOY in the SKY – Blue Letter, UA Div. of Ag Cooperative Extension Service	Newsletter	862
Soybean Science Challenge Winners Video – UofA Division of Agriculture Cooperative Extension Service (In Production)	Video	Will be available on CES & TCG websites/pages

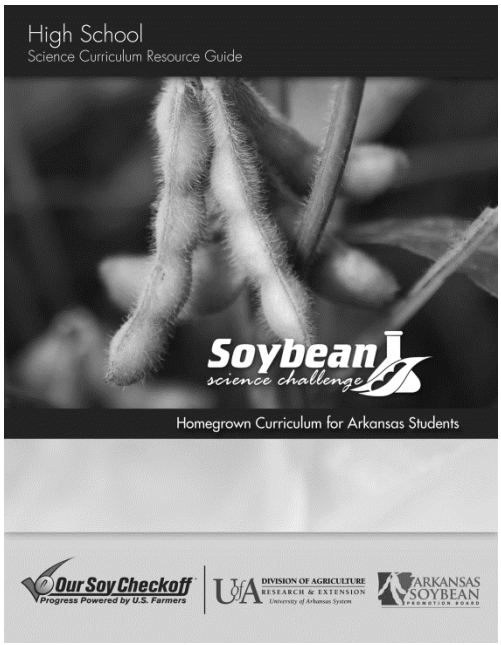

Fig. 3. Soybean Science Challenge Arkansas curriculum resources (sample).

Development of an Online Course: Future of Biotechnology Crops

J.C. Robinson[1] and H.G. Jernigan[1]

ABSTRACT

Global scrutiny of biotechnology in agriculture has created a need for educational components on the subject of biotechnology. With little to no biotechnology educational materials available to the general public produced by research institutions, adult learners have few reliable fact-based sources on the science of biotechnology. Adult learners increasingly seek information via the Internet, so by developing an online course we are providing material in the most palatable form for a large majority of adults. The development of the *Future of Biotechnology Crops* online course covers basic terminology, science, the abilities of biotechnology, and the impact it can have on the Arkansas and global soybean industry. Online components were developed, peer-reviewed, pilot-tested, and an online course was launched to the general public.

INTRODUCTION

Biotechnology, sometimes referred to as genetically modified organisms (GMO) or genetically engineered (GE), is defined as the application of molecular biology techniques to identify genes responsible for particular traits. Biotechnology in the United States and Arkansas has become a fact of life for modern soybean production, and our agricultural systems are now more dependent on genetic biotechnology for rapid improvement of varieties. At the same time, there are widely held concerns about the safety and appropriateness of biotechnology crops in Europe and these concerns appear to be growing in the U.S. In the last two years, emerging markets for non-GMO baby foods, cereals, produce and meats have increased substantially in the U.S. among major food retailers and suppliers. These markets even offer premiums for non-GMO grains including corn and soybean to growers. The belief that biotechnology crops, including soybean, are somehow bad or less safe than non-GMO crops is not based on science but is encouraged by the lack of public education resources about this topic.

In 2013, 83.8% of U.S. households reported computer ownership, with 78.5% of all households having a desktop or laptop computer, and 63.6% having a mobile device or tablet (U.S. Census Bureau, 2014). In 2013, 74.4% of all households reported Internet use, with 73.4% reporting a high-speed connection (U.S. Census Bureau, 2014). Fifty percent of Americans now cite the Internet as a main source for national and international news, 71% of those 18-29 years old cite the Internet as a main news source, and of those 30-49 years old, 63% say the Internet is where they go to get most of their news (Pew Research Center, 2014).

Most of the current outreach effort about biotechnology is provided by companies who profit from it, so many people consider this effort untrustworthy. While university faculty members teach biotechnology concepts in formal classroom settings, outside the classroom most public universities and extension services have largely avoided the topic. The current interest in online information by the public and the growing popularity of free online courses offer an opportunity to teach a large lay audience the facts about biotechnology crops; so, it seems timely to develop an online extension course.

PROCEDURES

A one-hour interactive modular course was developed using accepted adult-learning methods and format (Fig. 1). The course was hosted on a Moodle platform accessible via the Internet. Content was provided by our science cooperators, who currently teach biotechnology principles and facts at the University of Arkansas. We modified the content for the general public and adult learner understanding. In order to appeal and engage all learning types (visual, auditory, and kinesthetic), interactive narrated lessons, videos, and print materials were developed to be used throughout the course (Fig. 2). The modules developed, cover biotechnology in the field, nutrition and food safety information, as well as future trends in biotechnology crops—using soybean as the model crop.

Persons completing the course were challenged by appropriate exercises to test knowledge gained during the course and overall understanding at completion. A certificate was issued upon successful completion. The beta version of the course was peer-reviewed, then pilot-tested by selected individuals who mirror the target audience. Feedback was used to modify the course as needed, and then a final version was launched.

RESULTS AND DISCUSSION

The course is hosted on the University of Arkansas System Division of Agriculture's Cooperative Extension Services online learning management system, Moodle. Moodle is an online learning platform accessible via the Internet. Persons

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completing the course will have the opportunity to test their knowledge gain by completing interactive exercises throughout the course. This course is second in a biotechnology series, and is more extensive than the introductory course.

Course evaluations are a completion requirement for learners who wish to successfully complete the course and print a course completion certificate. Course evaluations ask learners about the content, perceived knowledge gain, probability of completing more courses about the same or similar topic, technical issues, and any other comments they may have about the course. These evaluations are frequently collected and analyzed. Course analytics will be collected and analyzed periodically after launch for at least 2 years and reported to the Arkansas Soybean Promotion Board. After the launch year, Extension will monitor and assess the course annually in case modifications are needed.

PRACTICAL APPLICATIONS

An educated consumer is a powerful resource for agriculture. One can look at Europe and see the result of the lack of factual education about biotechnology, that is, unfounded concerns that have cost European and U.S. agriculture untold millions. If this trend continues to grow in the U.S., what will be the outcome here with regard to continued science-based progress in agriculture? Not good, especially considering the future challenge of feeding the world that is coming within many of our lifetimes. Regardless, progress will ultimately rest in the minds of the consuming public, and we believe there is great value in those minds knowing the facts.

ACKNOWLEDGMENTS

This research was supported by the Arkansas Soybean Promotion Board. Support was also provided by the University of Arkansas System Division of Agriculture.

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Course Objectives

Upon completion of this course, students will:

- *Explain components of biotech field production in the United States*
- *Understand the cultivation process of biotech crops*
- *Discuss GMO labeling and related concepts*
- *Summarize the basic principles, safeguards, benefits and risks of biotech crop production and consumption in the future*
- *Understand how biotech crop production benefits farmers and communities worldwide*
- *Determine exportation and importation processes for biotech crops*
- *Recall the importance of biotech crops to the growing world population*

Tentative Course Outline

Module 1: *In the Field*
Total Module Length: 20 Minutes

Objectives Covered:

- *Explain components of biotech field production in the United States*
- *Understand the cultivation process of biotech crops*

Lesson 1: Soil and Water
**8 Minutes Total*

*Specifically discuss aspects of biotech soybean production.
- Why soybeans are excellent biotech crops
- Biotech effects on soil
- Water conservation efforts and biotech efficiency in production and cultivation

*Interactions Planned:
- Video of biotech field photos
- Interactive buttons to move between slides
- Interactive quiz

Lesson 2: Seeds
**7 Minutes Total*

*Specifically discuss famous soybean seed breakthroughs
- Increasing yields
- Quality of products
- Safe for soil, humans and animals

Fig. 1. Course outline.

*Interactions Planned:

- Interactive buttons to move between slides
- Possible newscast video or sound clip
- Interactive quiz

Lesson 3: Disease Prevention
**5 Minutes Total*

*Specifically discuss soybean disease-prevention breakthroughs

- How they came about
- Why there is a need for these breakthroughs
- How biotechnology has been instrumental in the development of US agriculture (give some stats- Commodity Board websites)

*Interactions Planned:

- Interactive buttons to move between slides
- Interactive quiz
- Video from CommonGround

Module 2: *At the Store*
Total Module Length: 20 minutes

Objectives Covered:

- *Discuss GMO labeling and related concepts*
- *Summarize the basic principles, safeguards, benefits and risks of biotech crop production and consumption in the future*

Lesson 1: Food Labels
**7 Minutes Total*

*Specifically discuss the following:

- Define GMO and illustrate
- Define GMO labeling and illustrate
- Demonstrate labeled and unlabeled food

*Interactions Planned:

- Interactive buttons to move between slides
- Interactive nutrition label
- Interactive quiz at the end of the lesson

Fig. 1. Continued.

Lesson 2: Risks and Benefits
**7 MinuitesTotal*

*Specifically discuss the following:

- Risks and benefits of biotech crops in the future
- Any risks or benefits of using soybeans in production

*Interactions Planned:

- Interactive buttons to move between slides
- Interactive quiz

Lesson 3: The Feed Store- Animal Ag Consumption
**6 Minutes Total*

*Specifically discuss the following:

- Discuss how biotech crops enhance animal feed
- Nutritional benefits
- Animal health as related to consumption by humans

*Interactions Planned:

- Interactive buttons to move between slides
- Interactive quiz
- Videos from National Geographic and CommonGround

Module 3: *Around the World*
Total Module Length: 20 Minutes

Objectives Covered:

- *Understand how biotech crop production benefits farmers and communities worldwide*
- *Determine exportation and importation processes for biotech crops*
- *Recall the importance of biotech crops to the growing world population*

Lesson 1: Biotech Crops in Other Countries
**6 Minutes Total*

*Specifically discuss the following:

- World-wide access to biotech crops
- Reasons other countries are producing biotech crops

*Interactions Planned:

- Interactive buttons to move between slides
- Interactive Infographic
- Interactive quiz

Fig. 1. Continued.

Lesson 2: Exports

**7 Minutes Total*

*Specifically discuss the following:

- Exporting biotech crops
- Importing biotech crops

*Interactions Planned:

- Interactive buttons to move between slides
- Interactive world map
- Interactive quiz

Lesson 3: Feeding a Growing World Population

**7 Minutes Total*

*Specifically discuss the following:

- Video- one farmer's story
- Benefiting the world
- Population numbers and food increases through biotech breakthroughs

*Interactions Planned:

- Interactive buttons to move between slides
- Interactive quiz
- Videos

Fig. 1. Continued.

Fig. 2. Course introduction graphic.

Growth Performance, Fatty Acid Composition, and Consumer Preference Scores for Channel Catfish Fed Diets with Regular Soybean Oil, Soybean Oil Enhanced With Conjugated Linoleic Acids, Menhaden Fish Oil, or an Algal Docosahexaenoic Acid Source

J. Faukner[1], S.D. Rawles[2], A. Proctor[3], T.D. Sink[4], R. Chen[5], H. Phillips[5], and R.T. Lochmann[5]

ABSTRACT

Fish consumption is a common way to obtain beneficial n-3 fatty acids, but increased use of plant oils in fish diets causes a reduction in fillets of long-chain n-3 fatty acids. Conjugated linoleic acids (CLA) are also beneficial for human health. We investigated four different lipid sources in channel catfish (*Ictalurus punctatus)* diets for their ability to enhance fatty acid profiles of fillets to benefit human health while maintaining fish performance. Channel catfish were fed a commercial 32% protein diet with 2% added lipid from: soybean oil (SBO), soybean oil enhanced with conjugated linoleic acids (CLA), menhaden fish oil (MFO), or an algal supplement of *Schizochytrium* sp. high in 22:6n-3 (DHA) for 25 weeks. There were no differences in fish growth performance. Fish fed the MFO or algal DHA diets had more 22:6n-3 in the muscle than fish fed SBO or CLA diets. Consumer preference scores were higher for fillets from fish fed SBO or CLA diets than from fish fed MFO or algal DHA diets. In addition, the CLA diet produced beneficial increases in fillet CLA concentrations.

INTRODUCTION

Channel catfish raised in the United States generated 500 million dollars in revenue during 2000 and 423 million dollars in 2011 (USDA-NASS, 2012). Despite recent setbacks with global competition from other catfish species and rising feed costs, channel catfish (*Ictalurus punctatus)* is still the most important aquaculture finfish species in the United States. Feed ingredients for commercial fish production are selected not only for their nutrient content, but also for economics and availability. The influence of dietary ingredients on product quality is also important, and the lipid composition of the fish is relatively easy to manipulate through the diet.

There are numerous human health benefits associated with n-3 long-chain polyunsaturated fatty acids (LC-PUFA, such as 20:5n-3 and 22:6n-3) including the reduction of cardiovascular disease, arthritis, atherosclerosis, diabetes, and cancer (Simopoulos, 2008). The ability to market catfish enriched with n-3 or other healthy fatty acids as a functional food could be a key factor in restoring the competitiveness of the industry. Fish are the most common source of n-3 LC-PUFAs in most human diets (Tocher, 2003), but cultured channel catfish are low in these fatty acids due to minimal use of marine fish meals and oils in their diets.

Conjugated linoleic acids (CLA) also produce human health benefits such as reduced incidence of cardiovascular problems and some cancers (Benjamin and Spener, 2009). The CLA are n-6 trans fatty acids that have been incorporated into fillets of many cultured fish species to improve the fatty acid profile, and several CLA products have been tested in channel catfish (Manning et al., 2006). However, standard soybean oil, CLA-soybean oil, algal DHA, and menhaden oil have not been evaluated as dietary lipid sources in channel catfish in the same study. Therefore, we investigated the use of these lipids in channel catfish diets to enhance fatty acid profiles of fillets for human health while maintaining growth, survival, feed conversion, and consumer acceptability of the fillets.

PROCEDURES

Diets were prepared as described previously (Faukner et al., 2012) from a commercial extruded catfish feed with 32%-protein and 5% lipid. Supplemental lipid sources were standard soybean oil (SBO, control), soybean oil enhanced with conjugated linoleic acids (CLA), an algal source of DHA (*Schizochytrium* sp.) combined with soybean oil, and refined menhaden

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[4] Texas A&M University, Texas A&M AgriLife Extension, College Station, Tx.
[5] University of Arkansas Pine Bluff, Department of Aquaculture and Fisheries, Pine Bluff, Ark.

fish oil (MFO). Standard soybean oil was used as a control because it contains non-conjugated linoleic acids or n-3 long-chain polyunsaturated fatty acids (LC-PUFA) and has a similar fatty acid profile to commercial catfish diets. Soybean oil enhanced with CLA (Jain and Proctor, 2008) contained 12% total CLA isomers. The DHA algal supplement contained 19% 22:6n-3. Refined menhaden fish oil contained 28% n-3 LC-PUFA and 9% 22:6n-3. Lipid extracts were transesterfied with 14% boron trifluoride to obtain fatty acid methyl esters (FAMEs), which were analyzed by gas chromatography and quantified using reference standards.

For the 25-week feeding trial, fifty stocker (71 grams) channel catfish were placed into each of 16 outdoor 1600-L tanks. Each diet was assigned to four tanks supplied with well water and air stones. Fish were fed a fixed rate of 1.9% of body weight per day. At harvest (week 25), final fish weights and numbers in each tank were determined, and fillets from 3 fish per tank were frozen for later fatty acid analysis. Additional subsamples of fish from each tank were filleted and individual fillets were sealed in a plastic bag and frozen at -20 °C. Fillets were sent to the Sensory Service Center at the University of Arkansas at Fayetteville for consumer preference testing by trained panelists using a modified Sensory Spectrum Method (Meilgaard et al., 1999). Data were analyzed with mixed-model analysis of variance (ANOVA) and a probability level of $P \leq 0.05$ was considered significant.

RESULTS AND DISCUSSION

There were no differences in weight gain, feed conversion ratio, or survival among treatments (Table 1). Recommendations for daily intake of CLA for human health benefits are extremely variable, and range from 61.3 to 3000 mg (Brownbill et al., 2005). Muscle lipid from fish fed the CLA diet contained 178.7 mg of CLA per 85 g of fillet. A more concentrated CLA supplement would increase fillet content of CLA in less time, but at a higher cost.

Fatty acid composition of muscle is shown in Table 2. The total n-3 LC-PUFA concentration was highest in the muscle of fish fed the MFO diet, followed by the DHA diet, and lowest in SBO or CLA diets. The total n-6 LC-PUFA concentration was similar in muscle of fish fed the SBO, CLA or DHA diets, but lower in muscle of fish fed the MFO diet than those fed the SBO diet. The ratio of n-3 to n-6 fatty acids was highest in the muscle of fish fed the MFO diet and lowest in fish fed the SBO or CLA diets. As expected, the fatty acid composition of the fish muscle closely mirrored that of the diets (Tocher, 2003).

Consumer preference scores for flavor were lower in the MFO and DHA treatments than in the SBO and CLA treatments (Table 3). Fillets from the MFO and DHA treatments had more total n-3 LC-PUFA than fillets from CLA and SBO treatments. The number of double bonds in a fatty acid determines its susceptibility to attack from free radicals. Fatty acid peroxidation products contribute to rancid flavor in fish (Gray, 1978). Although thiobarbituric-acid-reactive substances (TBARS) were not statistically different among diets in this study (data not shown; Faukner et al., 2012), other products that were not measured might have affected fish flavor.

PRACTICAL APPLICATIONS

In summary, target fatty acids (n-3 LC-PUFA, CLA) increased in catfish in response to dietary lipids. The CLA content in fillets was much higher than levels found in pasture-fed beef or milk from pasture-fed cows. The soybean oil with CLA isomers was also high in CLA trans isomers, which may reduce cholesterol more than other CLA isomers. In addition, only the CLA diet enhanced the health value of the catfish fillet without reducing flavor scores.

ACKNOWLEDGMENTS

This study was funded by the Arkansas Soybean Promotion Board. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Mean weight gain, feed conversion, and survival of channel catfish fed a 32% protein diet supplemented with 2% of either soybean oil (SBO), conjugated linoleic acid (CLA)-enriched soybean oil, algal (DHA), or menhaden fish oil (MFO) for 25 weeks. Means within columns are not significantly different ($P \leq 0.05$).[a]

Diet and statistics	Weight gain (g)[b]	FCR[c]	Survival
SBO	358.4	1.3	96
CLA	347.5	1.3	99
DHA	375.2	1.2	95
MFO	323.5	1.4	89
PSE[d]	23.7	0.1	2.2
Pr > F	0.84	0.51	0.07

[a] Values are means of 3-4 replicate tanks per treatment.
[b] Weight gain = (final individual mean weight – mean individual initial weight)/number. Mean (± SE) initial individual weight was 71.4 ± 0.1 g.
[c] Feed conversion ratio = feed weight/fish weight gain.
[d] Pooled standard error.

Table 2. Mean fatty acid composition (percentage of total fatty acids by weight) of channel catfish muscle from fish fed a 32% protein diet supplemented with 2% (by weight) of either soybean oil (SBO), conjugated linoleic acid (CLA)-enriched soybean oil, algal (DHA), or menhaden fish oil (MFO) for 25 weeks. Means within rows with different letters are significantly different ($P \leq 0.05$).

		Muscle[a]					
Fatty acids	Initial fish[b]	SBO	CLA	DHA	MFO	PSE[c]	Pr > F
Saturates[d]	25.8	23.9y	25.8x	25.0x	25.7x	0.2	0.001
Monounsaturates[e]	51.5	49.8x	48.0y	50.5x	50.8x	0.4	0.006
18:2n-6	15.3	19.4w	17.8x	16.7y	14.8z	0.1	< 0.001
CLA – 9c,11t	0.0	0.0y	0.1x	0.0y	0.0y	0.01	< 0.001
CLA – 10t,12c	0.0	0.0y	0.1x	0.0y	0.0y	0.01	< 0.001
∑ CLA trans isomers[f]	0.0	0.0y	1.1x	0.0y	0.0y	0.02	< 0.001
∑ CLA isomers[g]	0.0	0.0y	1.6x	0.0y	0.0y	0.06	< 0.001
18:3n-3	1.2	1.7x	1.4y	1.4y	1.3z	0.3	< 0.001
20:4n-6	1.6	0.9	0.8	0.8	0.8	0.05	0.234
20:5n-3	0.2	0.1y	0.1y	0.1y	1.0x	0.03	< 0.001
22:6n-3	1.1	0.5y	0.6y	2.4x	2.3x	0.1	< 0.001
∑n-3[h]	2.8	2.5y	2.3z	4.1x	5.3w	0.1	< 0.001
∑n-6[i]	17.6	20.8w	19.1x	17.9y	15.8z	15.8	< 0.001
∑n-3 LC-PUFA[j]	1.7	0.7z	0.9z	2.6x	4.0w	0.1	< 0.001
∑n-6 LC-PUFA[k]	1.8	1.0y	0.9yz	0.9yz	0.8z	0.05	< 0.001
n-3/n-6 ratio	0.15	0.11z	0.11z	0.22y	0.32x	0.006	< 0.001

[a] Muscle data are means of 3-4 replicate tanks per treatment analyzed in duplicate.
b Initial data are means of two pooled muscle samples analyzed in duplicate.
[c] Pooled standard error.
[d] Saturates included 14:0, 16:0, 18:0, and 20:0.
[e] Monounsaturates included 14:1, 16:1, 18:1, 20:1, 22:1, and 24:1.
[f] Total trans CLA isomers included 9t, 11t; 10t, 12t; and 11t, 13t.
[g] Total CLA isomers included 9c,11t; 10t,12c; 9c,11c/10c, 12t; 9t, 11t; 10t,12t; and 11t, 13t.
[h] Total n-3 fatty acids included 18:3n-3, 20:5n-3, 22:5n-3, and 22:6n-3.
[i] Total n-6 fatty acids included 18:2n-6 (excluding CLA isomers), 18:3n-6, 20:4n-6, and 22:4n-6.
[j] Total n-3 LC-PUFA included 20:5n-3, 22:5n-3 and 22:6n-3.
[k] Total n-6 LC-PUFA included 20:4n-6 and 22:4n-6

Table 3. Means of consumer preference testing scores from fillets of channel catfish fed a 32% protein commercial catfish diet supplemented with 2% (by weight) of either soybean oil (SBO), conjugated linoleic acid (CLA)-enriched soybean oil, algal DHA (DHA) or menhaden fish oil (MFO) for 25 weeks. Means within columns with different letters are significantly different ($P \leq 0.05$).[a,b]

Diet and Statistics	Overall Impression	Flavor	Aroma	Texture	Appearance
SBO	6.3	6.3x	6.1	6.3	6.3
CLA	6.1	6.1x	6.2	6.3	6.4
DHA	5.9	5.5y	6.0	5.9	6.2
MFO	5.8	5.5y	6.0	6.0	6.0
PSE[c]	0.22	0.23	0.17	0.21	0.19
Pr > F	0.41	0.02	0.99	0.32	0.66

[a] Values are means of scores given by 75 individual participants. Each participant tasted one fillet sample from each treatment.
[b] The following response scale was used: 1 = dislike extremely, 2 = dislike very much, 3 = dislike moderately, 4 = dislike slightly, 5 = neither like nor dislike, 6 = like slightly, 7 = like moderately, 8 = like very much, 9 = like extremely.
[c] Pooled standard error.

Effect of *trans, trans* Conjugated Linoleic Acid (CLA) Egg Enrichment from CLA-Rich Soybean Oil on Yolk Fatty Acid Composition, Viscosity and Physical Properties

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ABSTRACT

Recent *cis, trans* (*c,t*) conjugated linoleic acid (CLA) egg accumulation studies have been effective, but these isomers also cause adverse egg quality. While *trans, trans* (*t,t*) CLA isomers have shown superior nutritional benefits in rodent studies, reports of *t,t* CLA-rich yolks are limited. The objective of this research was to determine the effect of *t,t* CLA-rich soybean oil in feed on egg yolk viscosity and yolk quality during 30 d refrigeration. Yolk fatty acids, viscosity, weight, index, moisture, pH, and vitelline membrane strength (VMS) were determined at 0, 20, and 30 storage days. Results showed *t,t* CLA soybean oil had minimal effect on fatty acid composition, relative to previous *c,t* CLA incorporation reports. However, CLA-rich yolk viscosity was greater than controls, and was maintained during storage, as was VMS. Yolk weight and index were not affected by *t,t* CLA-rich soybean oil. The *t,t* CLA-rich soybean oil allowed CLA egg enrichment without the adverse quality effects of other CLA sources.

INTRODUCTION

Poultry feeding trials that reported conjugated linoleic acid (CLA) enriched eggs and subsequent egg quality changes have all used *cis, trans* (*c,t*) CLA isomer mixtures (Chamruspollert and Sell, 1999; Kim et al., 2007). CLA eggs had reduced egg weights and yolk indices (Suksombat et al., 2006, Kim et al., 2007). In addition, saturated fat levels increased, while monounsaturated fat was lowered (Chamruspollert and Sell, 1999; Kim et al., 2007). However, adverse egg quality was reduced or prevented when CLA was co-supplemented with other oils, such soybean oil (Aydin et al., 2001, Kim et al., 2007).

While there are few reports on *trans, trans* (*t,t*) CLA due to its limited availability, the superior bioactivity of this isomer has been recently recognized (Shah et al., 2014). A pilot scale photoisomerization process of linoleic acid in soybean oil was developed that produced up to 20% total CLA with 75% of total CLA in the *t,t* isomer form (Jain et al., 2008, Shah et al., 2012). A subsequent obese Zucker rat study showed that *t,t* CLA-rich soy oil reduced fatty liver and serum cholesterol (Gilbert et al., 2011). This *t,t* CLA-rich soybean oil was also fed to chickens to produce *t,t* CLA-rich eggs (Shinn et al., 2014). CLA-rich eggs with *t,t* isomers may have quality and textural changes that have not been reported with *c,t* CLA feeds.

No studies have determined changes in vitelline membrane strength (VMS) or the effect of CLA enrichment on egg yolk viscosity. Therefore, our aim was to investigate the effects of *t,t* CLA enrichment on egg quality during a typical shelf-life of 30 days refrigerated storage. The objectives were to determine the effect of *t,t* CLA-rich soy oil in feed on yolk fatty acid profile, yolk viscosity, and yolk quality during refrigerated storage. The quality parameters investigated included yolk weight, yolk index, moisture content, pH, and vitelline membrane strength.

PROCEDURES

Conjugated Linoleic Acid-Rich Soybean Oil Production and Feed Administration. An 18% CLA-rich soybean oil was produced by photoisomerization of refined, bleached and deodorized (RBD) soybean oil using the method of Jain et al. (2008). The CLA-rich soybean oil was combined with RBD soybean oil to produce treatment oils containing 15%, 10%, 5%, 2.5% and 0% CLA. The fatty acid composition of these two soybean oils are presented in Table 1. Treatment diets were produced by combining 10% (wt.) soybean oil or CLA-rich soybean oil with a pelleted commercial finisher diet (Cobb-Vantress, Siloam Springs, Ark.) using a Hobart stand mixer.

Sixty hens were randomly assigned to single bird cages in blocks of 5 birds each. Each soybean oil-enriched diet was randomly assigned to 2 blocks of 5 birds each. The remaining 10 hens continued on standard commercial feed without added soybean oil as a standard control group. After 12 days of treatment feed administration, eggs were collected daily, counted, and labeled with cage number and date for 20 days. Eggs collected were stored in a walk-in cooler at 4 °C and were refrigerated for 0, 20 or 30 days prior to analysis. Quadruplicate eggs from each treatment and storage duration were used in all subsequent analyses.

Fatty Acid Analysis. Total yolk lipids were extracted using a rapid hexane/isopropanol method (Shinn and Proctor, 2012). Fatty acid methyl esters (FAMEs) were prepared from all extractions using a rapid, micro FAMEs preparation method (Lall et al., 2009). Duplicate fatty acid profiles were obtained for each sample by GC-FID with the following settings: oven temp = 250 °C; sensitivity = 12, He gas = 30 mL/min, H2 = 31 mL/min, air = 296 mL/min, and over program time = 111 min.

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Viscosity Analysis. Yolk viscosity was determined using an AR-2000 Rheometer. A 40-mm diameter sand-blasted geometry was applied to the 2-mL yolk sample surface at a constant shear rate of 100 s^{-1} for the temperature range of 4-60 °C.

Egg Quality Analysis. Whole egg weights were measured, followed by yolk weights. Yolk index (YI), defined as the ratio of yolk height to diameter, was measured using a caliper. Yolk pH was determined with a pH meter, and yolk moisture content was determined gravimetrically by drying yolks in an oven at 100 °C for 20 h (AOAC, 1995).

Vitelline Membrane Strength was determined as the peak force (g) required to puncture through the yolk vitelline membrane using a TA-XT2i Texture analyzer equipped with a 5-kg load cell and a 1-mm probe (Caudill et al., 2010).

Statistical Analysis. Yolk viscosity data fits the Power Law in the temperature range of 4–60 °C, and can be modeled by a non-linear exponential 3-parameter model that describes the asymptote, viscosity at initial temperature, and decay rate (Eq. 1, Ibarz and Sintes, 1989). Parameter estimates were compared by analysis of means at an alpha level of 0.05.

$$\text{Viscosity} = A + B*e^{(C * \text{Temp})}$$

Eq. 1

Where A = asymptote, B = scale, and C = decay rate. Fatty acid and egg quality parameters were analyzed according to a split-plot design, with dietary CLA concentration as the whole plot and duration of egg storage as the sub-plots, to determine main effects of dietary CLA and duration of storage, and their interactions. Tukey's test was used to compare treatment and main effect means, as appropriate.

RESULTS AND DISCUSSION

Fatty Acid Analysis. Fatty acid profiles are presented in Table 2. The *t,t* CLA was the most abundant isomer in all CLA-rich yolks, followed by *t*-10, *c*-12 CLA. Egg yolk total saturated fat increased significantly as yolk CLA level increased ($P < 0.001$). However, previous CLA egg studies using *c,t* isomer mixtures observed a 34% increase in saturated fatty acid (SFA) levels with only 0.5% CLA in the diet (Aydin et al., 2001), but CLA-rich soybean oil raised SFA levels by only 28% with 1.5% CLA in the diet, relative to soy control yolks. Likewise, while previous studies reported a 32% drop in monounsaturated fatty acid (MUFA) concentrations (Aydin et al., 2001), this study determined only 25% decrease in MUFA concentration in CLA-rich yolks. Linoleic and linolenic acid concentrations were similar in all eggs produced from soy oil-rich diets, and were significantly greater than the standard control yolks ($P < 0.001$). In addition *t,t* CLA did not decrease long-chain polyunsaturated fatty acids (PUFA) as much as other studies. While arachidonic acid decreased from 3.7% to 2.7% of total fatty acids (FA) when hens were fed 2.5% *c,t* CLA (Ahn et al.,1999*), t,t* CLA-rich soybean oil only lowered arachidonic acid from 1.7% to 1.5%, relative to standard control yolks. Similarly, *c,t* CLA decreased DHA levels from 1.4% to 0.2% of total FA, but DHA in *t,t* CLA-rich yolks were not significantly different from control yolks (Szymczyk and Pisulewski, 2003).

Viscosity Analysis. Table 3 shows egg yolk viscosity after 0, 20, or 30 days refrigeration. Conjugated linoleic acid-rich yolks containing 2.7 mmole CLA had significantly greater viscosity throughout the storage duration, relative to control and soy control yolks.

Egg Quality Analysis. Egg quality parameters are presented in Table 4. Total egg weights resulting from 2.0 mmoles CLA incorporation were significantly smaller than all other yolk types at day 0 ($P = 0.006$). After 20 and 30 days refrigeration, total egg weights significantly decreased with increasing CLA concentration.

Likewise, 2.0 mmole CLA yolk weights were significantly lower on day 0, but no significant differences could be determined in yolk weights after 20 or 30 days of storage. Conjugated linoleic acid-rich soybean oil seemed to prevent yolk weight reduction that has been previously reported from *c,t* CLA supplementation (Kim et al., 2007).

Conjugated linoleic acid-rich yolks have been previously reported to affect yolk index in comparison with control yolks. However, this study determined that changes in yolk index were storage-time dependent and not dependent on CLA content.

Although control, soy control, and 0.5 mmole CLA eggs had significantly stronger vitelline membranes, 2.7 mmole CLA yolks showed a VMS increase at day 20, while other yolk VMS decreased. CLA-rich yolks with 2.7 mmole CLA did have significantly lower membrane strengths at day 0, but increased through day 20. After 30 days, 0.5 and 0.9 mmole CLA yolks were significantly stronger than soy control eggs.

Both pH and moisture content increased with increasing yolk CLA concentrations and storage duration, which is similar to previous reports (Aydin et al., 2001).

PRACTICAL APPLICATIONS

The adverse effects of CLA egg yolk incorporations, such as increased saturated fat, lower yolk weights, and yolk indices seemed to be lessened using CLA-rich soybean oil. In addition, CLA-rich yolks maintained greater viscosities during refrigerated storage. Furthermore, CLA-rich yolks upheld VMS longer during refrigeration. These enhanced qualities may benefit egg shelf-life and provide advantages in prepared egg-based dressings and sauces. Egg yolk viscosity and VMS in CLA eggs is worthy of further study as they may affect egg quality and have food processing applications.

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Table 1. Fatty acid composition of refined, bleached, deodorized (RBD) soy oil before photoisomerization, and resulting conjugated linoleic acid-rich soy oil (CLARSO) after 12-h photoisomerization.

Fatty acid	RBD Soy oil (g FA/ 100 g oil)	CLARSO (g FA/ 100 g oil)
Palmitic acid C16:0	12.2 ± 0.05	12.2 ± 0.02
Palmitoleic acid C16:1	0.09 ± 0.001	0.09 ± 0.001
Stearic acid C18:0	4.12 ± 0.04	4.24 ± 0.02
Oleic acid C18:1	25.0 ± 0.05	25.9 ± 0.06
Linoleic acid C18:2	55.0 ± 0.07	36.5 ± 0.05
Linolenic acid C18:3	3.54 ± 0.02	3.59 ± 0.02
cis-9, *trans*-11 CLA	ND †	1.64 ± 0.01
Trans-9,*cis*-11 & *cis-10,trans-12* CLA	ND	2.14 ± 0.02
trans-10, *cis*-12 CLA	ND	1.27 ± 0.01
trans, *trans* CLA	ND	13.1 ± 0.02
Total CLA	ND	18.15 ± 0.03

†Not detected.

Table 2. Egg yolk total conjugated linoleic acid (CLA) concentration and fatty acid concentrations from hens fed either a standard control diet, or a diet enriched with 10% soybean oil [N = 120]. Soybean oils had 0% (soy control), 2.5%, 5%, 10% or 15% CLA concentrations. Concentrations are expressed as mmole of fatty acid per 100 g yolk. Connecting letters within the same row indicate significant differences in fatty acid concentration.

Yolk polyunsaturated fatty acids	**Control yolk**	**Soy control yolk**	**0.5 mmole CLA**	**0.9 mmole CLA**	**2.0 mmole CLA**	**2.7 mmole CLA**
trans, trans CLA	0 ± 0e	0 ± 0e	0.21 ± 0.01d	0.43 ± 0.02c	1.11 ± 0.06b	1.43 ± 0.18a
cis-9, *trans*-11 CLA	0 ± 0e	0 ± 0e	0.14 ± 0.01a	0.15 ± 0.01a	0.13 ± 0.01a	0.15 ± 0.02a
trans-9, *cis*-11 & *cis*-10, *trans*-12 CLA	0 ± 0e	0 ± 0e	0.08 ± 0.001d	0.17 ± 0.01c	0.31 ± 0.01b	0.41 ± 0.04a
trans-10, *cis-12* CLA	0 ± 0e	0 ± 0e	0.07 ± 0.01d	0.14 ± 0.01c	0.36 ± 0.02b	0.55 ± 0.06a
cis-11, *trans*-13 CLA	0 ± 0e	0 ± 0e	0.01 ± 0.001d	0.03 ± 0.002c	0.07 ± 0.006b	0.11 ± 0.01a
Linoleic acid	16.97 ± 0.67b	28.03 ± 0.9a	27.46 + 0.53a	27.77 + 0.77a	27.51 + 0.66a	26.2 + 0.67a
Linolenic acid	0.31 ± 0.03c	0.87 ± 0.05a	0.81 + 0.04ab	0.78 + 0.05ab	0.77 + 0.03ab	0.69 + 0.06b
Arachidonic acid	0.17 ± 0.01a	0.13 ± 0.04a	0 + 0a	0 + 0a	0 + 0a	0.13 + 0.13a
Eicospentaneoic acid	1.75 ± 0.14ab	1.91 ± 0.05a	1.75 + 0.04ab	1.66 + 0.04ab	1.67 + 0.03ab	1.43 + 0.13b
Docosahexaneoic acid	0.47 ± 0.01de	0.95 ± 0.04a	0.8 + 0.02b	0.69 + 0.01bc	0.6 + 0.01cd	0.45 + 0.05e
Total PUFA	19.68 ± 0.77b	31.9 ± 0.95a	31.34 + 0.55a	31.82 + 0.82a	32.54 + 0.71a	31.56 + 0.7a
Yolk saturated fatty acids	**Control yolk**	**Soy control yolk**	**0.5 mmole CLA**	**0.9 mmole CLA**	**2.0 mmole CLA**	**2.7 mmole CLA**
Myristic acid	0.41 ± 0.01a	0.3 ± 0.01c	0.33 ± 0.01bc	0.39 ± 0.02ab	0.46 ± 0.03a	0.47 ± 0.02a
Palmitic acid	29.08 ± 0.38c	26.16 ± 0.33d	28.47 ± 0.23c	29.65 ± 0.36bc	30.67 ± 0.4ab	31.93 ± 0.65a
Stearic acid	11.55 ± 0.27c	12.52 ± 0.3c	14.97 ± 0.36b	16.19 ± 0.38ab	17.92 ± 0.38a	17.77 ± 0.74a
Eicosanoic acid	0.19 ± 0.18a	0.02 ± 0.01a	0.01 ± 0a	0.01 ± 0a	0.02 ± 0a	0.08 ± 0.05a
Total saturated fatty acids	41.22 ± 0.4c	38.99 ± 0.45d	43.77 ± 0.37bc	46.24 ± 0.51b	49.07 ± 0.42a	50.25 ± 1.3a
Yolk monounsaturated fatty acids	**Control yolk**	**Soy control yolk**	**0.5 mmole CLA**	**0.9 mmole CLA**	**2.0 mmole CLA**	**2.7 mmole CLA**
Palmitoleic acid	3.02 + 0.1a	1.48 + 0.03b	1.32 + 0.08bc	1.14 + 0.05cd	1.05 + 0.05cd	1.04 + 0.05d
Oleic acid	48.71 + 0.72a	40.01 + 0.63b	35.99 + 0.48c	33.35 + 0.66c	29.99 + 0.63d	30.12 + 1.26d
Total monounsaturated fatty acids	51.73 + 0.66a	41.49 + 0.64b	37.31 + 0.53c	34.48 + 0.65c	31.04 + 0.65d	31.16 + 1.29d

Table 3. Egg yolk viscosity variable estimates described by the exponential decay model, which includes R^2 value for each viscosity curve, initial viscosity at 4 °C, asymptote (lowest part of curve) and average decay rate.

	Control yolk †	Soy control	0.5 mmole CLA	0.9 mmole CLA	2.0 mmole CLA	2.7 mmole CLA
Day 0 Egg yolks. *Model R^2 = 0.85*						
Asymptote (Pa·s)	0.09 ± 0.05b §	0.24 ± 0.03a	0.27 ± 0.03a	0.2 ± 0.02a	0.21 ± 0.02a	0.28 ± 0.02a
Initial Viscosity at 4 °C (Pa·s)	1.82 ± 0.04d	2.04 ± 0.04d	2.22 ± 0.05c	1.77 ± 0.06d	2.41 ± 0.05b	3.74 ± 0.07a
Decay rate	-0.04 ± 0.00a	-0.05 ± 0.003a	-0.06 ± 0.003b	-0.07 ± 0.005b	-0.07 ± 0.003b	-0.08 ± 0.002c
Egg yolks stored for 20 days. ‡ *Model R^2 = 0.82*						
Asymptote (Pa·s)	0.12 ± 0.02c	0.10 ± 0.02c	0.20 ± 0.02b	0.08 ± 0.02c	0.20 ± 0.02b	0.33 ± 0.02a
Initial Viscosity at 4 °C (Pa·s)	0.72 ± 0.03c	0.80 ± 0.03c	1.45 ± 0.04c	1.17 ± 0.03b	2.52 ± 0.04a	2.86 ± 0.04a
Decay rate	-0.06 ± 0.007a	-0.05 ± 0.006a	-0.06 ± 0.004a	-0.05 ± 0.004a	-0.06 ± 0.002a	-0.07 ± 0.002a
Egg yolks stored for 30 days*. Model R^2 = 0.80*						
Asymptote (Pa·s)	0.08 ± 0.02a	0.5 ± 0.02a	0.04 ± 0.02a	0.09 ± 0.01a	0.07 ± 0.01a	0.07 ± 0.01a
Initial Viscosity at 4 °C (Pa·s)	0.99 ± 0.03b	0.95 ± 0.02b	0.62 ± 0.04c	1.0 ± 0.02b	1.29 ± 0.02a	1.29 ± 0.02a
Decay rate	-0.05 ± 0.003a	-0.05 ± 0.003a	-0.05 ± 0.004a	-0.07 ± 0.003b	-0.06 ± 0.002b	-0.06 ± 0.002b
Effects Test	**Prob > F**					
Yolk Type	<0.0001					
Storage	<0.0001					
Yolk Type*Storage	<0.0001					

† Yolks were stored at 4 °C prior to analysis.
‡ Variable estimates were compared by analysis of means at 0.05 alpha-level for each storage duration.
§ Connecting letters within the same row indicate significant differences from the model mean.

Table 4. Conjugated linoleic acid (CLA)-rich, soybean oil rich, and standard control egg yolk quality parameters were measured in quadruplicate on each storage duration.

	Whole Egg Weight				**Vitelline Membrane Strength**		
Yolk Type	*0 Days in Storage*	*20 Days in Storage*	*30 Days in Storage*	Yolk Type	*0 Days in Storage*	*20 Days in Storage*	*30 Days in Storage*
Control	64.8 ± 2.31a †	66.7 ± 2.1a	68.8 ± 0.6a	*Control*	5.28 ± 0.1a	3.96 ± 0.8ab	3.88 ± 0.1ab
Soy Control	62.7 ± 0.8a	62.3 ± 0.5b	62.3 ± 0.7b	*Soy Control*	5.34 ± 0.2a	2.68 ± 0.9b	2.08 ± 0.6b
0.5 mmole CLA	62.1 ± 3.68a	62.1 ± 1.9b	60.3 ± 0.6b	*0.5 mmole CLA*	5.18 ± 0.1a	3.40 ± 0.9ab	4.36 ± 0.7a
0.9 mmole CLA	61.4 ± 1.23a	59.3 ± 0.9b	58.6 ± 0.7b	*0.9 mmole CLA*	4.44 ± 0.1b	3.76 ± 0.6ab	4.74 ± 0.8a
2.0 mmole CLA	56.9 ± 1.27b	60.0 ± 1.1b	60.0 ± 1.5b	*2.0 mmole CLA*	4.20 ± 0.1b	3.28 ± 1ab	3.92 ± 1.0ab
2.7 mmole CLA	59.0 ± 0.83a	55.8 ± 0.4c	55.8 ± 0.6c	*2.7 mmole CLA*	4.46 ± 0.2b	4.9 ± 0.2a	3.48 ± 0.9ab
Effects Test	**Prob > F**			Effects Test	**Prob > F**		
Yolk Type	0.0094†			Yolk Type	0.58		
Storage	0.98			Storage	0.008		
Yolk Type*Storage	0.36			Yolk Type*Storage	0.037		
	Yolk Weight				**Yolk pH**		
Yolk Type	*0 Days in Storage*	*20 Days in Storage*	*30 Days in Storage*	Yolk Type	*0 Days in Storage*	*20 Days in Storage*	*30 Days in Storage*
Control	18.7 ± 0.6ab	20.2 ± 1.8a	18.8 ± 0.17a	*Control*	*6.21 ± 0.1a*	*5.96 ± 0.12ab*	*6.08 ± 0.01b*
Soy Control	19.8 ± 0.4a	19.9 ± 0.8a	18.5 ± 0.74a	*Soy Control*	6.23 ± 0.1a	5.91 ± 0.15ab	6.31 ± 0.03b
0.5 mmole CLA	18.2 ± 1.1ab	18.9 ± 0.3a	18.1 ± 1.06a	*0.5 mmole CLA*	6.21 ± 0.2a	5.88 ± 0.07ab	6.05 ± 0.01b
0.9 mmole CLA	17.9 ± 0.4ab	18.7 ± 0.6a	18.3 ± 0.52a	*0.9 mmole CLA*	6.22 ± 0.1a	5.62 ± 0.02b	7.17 ± 0.35a
2.0 mmole CLA	16.0 ± 0.2b	19.0 ± 0.6a	17.9 ± 0.25a	*2.0 mmole CLA*	6.20 ± 0.05a	6.32 ± 0.1a	7.29 ± 0.09a
2.7 mmole CLA	17.2 ± 0.6ab	18.0 ± 0.7a	18.9 ± 0.49a	*2.7 mmole CLA*	6.20 ± 0.1a	6.43 ± 0.18a	7.5 ± 0.18a
Effects Test	**Prob > F**			Effects Test			
Yolk Type	0.0061			Yolk Type	1		
Storage	0.038			Storage	<0.0001		
Yolk Type*Storage	0.27			Yolk Type*Storage	<0.0001		
	Whole Egg Weight				**Vitelline Membrane Strength**		
	Yolk index				**Moisture Content**		
Yolk Type	*0 Days in Storage*	*20 Days in Storage*	*30 Days in Storage*	Yolk Type	*0 Days in Storage*	*20 Days in Storage*	*30 Days in Storage*
Control	*0.4 ± 0.01a*	*0.35 ± 0.03ab*	*0.44 ± 0.01a*	*Control*	*48.1 ± 0.5a*	*47.4 ± 0.54b*	*46.4 ± 0.38c*
Soy Control	0.4 ± 0.01a	0.36 ± 0.05ab	0.44 ± 0a	*Soy Control*	46.9 ± 0a	47.7 ± 0.62b	48.7 ± 0.38bc
0.5 mmole CLA	0.4 ± 0a	0.35 ± 0.03ab	0.45 ± 0.02ab	*0.5 mmole CLA*	47.5 ± 1.48a	48.4 ± 1.71ab	48.6 ± 0.06bc
0.9 mmole CLA	0.39 ± 0.01a	0.38 ± 0.01a	0.42 ± 0.01ab	*0.9 mmole CLA*	47.0 ± 1.56a	48.0 ± 1.06ab	50.6 ± 0.73ab
2.0 mmole CLA	0.4 ± 0.03a	0.37 ± 0.02ab	0.37 ± 0.01b	*2.0 mmole CLA*	47.5 ± 0.62a	50.0 ± 0.08ab	51.8 ± 0.86a
2.7 mmole CLA	0.38 ± 0.01a	0.34 ± 0.02b	0.42 ± 0.01ab	*2.7 mmole CLA*	47.2 ± 0.62a	51.4 ± 1.83a	53.2 ± 0.08a
Effects Test	**Prob > F**			Effects Test	**Prob > F**		
Yolk Type	0.48			Yolk Type	0.98		
Storage	< 0.0001			Storage	<0.0001		
Yolk Type*Storage	0.17			Yolk Type*Storage	0.008		

†Connecting letters within the same column identify values with no significant difference at the 0.05 α-level.

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