2-1-2017

Arkansas Soybean Research Studies 2015

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Arkansas

Soybean Research Studies 2015

Jeremy Ross, Editor

DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

ARKANSAS AGRICULTURAL EXPERIMENT STATION

February 2017 Research Series 637

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

Cover photo: Young soybean plants in a test plot in Lonoke, Arkansas; credit: Mary Hightower, University of Arkansas System Division of Agriculture, Fayetteville, Ark.

Layout by Susan Scott; Technical editing and cover design by Gail Halleck.

Arkansas Agricultural Experiment Station, University of Arkansas System Division of Agriculture, Fayetteville. Mark J. Cochran, Vice President for Agriculture; Clarence E. Watson, AAES Director and Associate Vice-President for Agriculture–Research. WWW/InddCC2015.

ISSN: 2381-4926 CODEN: AKAMA6

PREFACE

The 2015 Arkansas Soybean Research Studies Series includes 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 results; therefore, these results should not be used as a basis for long-term recommendations.

Several research reports in this publication will appear in other University of Arkansas System Division of Agriculture's Arkansas Agricultural Experiment Station publications. This duplication is the results of the overlap in research coverage between disciplines and our effort to inform Arkansas soybean producers of 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.

All authors are either current or former faculty, staff, or students of the University of Arkansas System Division of Agriculture, or scientists with the United States Department of Agriculture, Agriculture Research Service.

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.

ACKNOWLEDGEMENTS

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

Most of the research results in this publication were made possible through funding provided by the soybean producers of Arkansas and administered by the Arkansas Soybean Promotion Board. We express sincere appreciation to the soybean producers and the members of the Arkansas Soybean Promotion Board for their vital financial support of these programs.

INTRODUCTION

Arkansas is the leading soybean-producing state in the mid-southern United States. Arkansas ranked 10th in soybean production in 2015 when compared to the other soybean-producing states in the U.S. The state represents 4.0% of the total U.S. soybean production and 3.7% of the total acres planted to soybean in 2015. The 2015 state soybean average was 49 bushels per acres, 0.5 bushel per acres less than the state record soybean yield set in 2014 (Table 1). The top five soybean-producing counties in 2015 were Mississippi, Desha, Poinsett, Phillips, and Arkansas Counties. These five counties accounted for 35% of soybean production in Arkansas in 2015.

While the final outcome was excellent, many challenges presented themselves throughout the 2015 growing season. Above average rainfall in some parts of the state during May and June prevented producers from planting soybean fields, and above average temperatures during August and September prevented many soybean fields from reaching their maximum yield potential. Even though disease pressure was light during 2015, many fields in the state were treated for several insect pest including stinkbugs, corn ear worms, and other caterpillar species. The most concerning discovery during the 2015 season was the positive identification of protoporphyrinogen oxidase (PPO)-resistant Palmer amaranth in several row crop counties. Many of these Palmer amaranth populations now have multiple herbicide resistance, and soybean production in these fields is becoming very difficult due to the loss of many herbicides.

Table 1. Arkansas soybean acreage, yield, and production, by County, 2014-2015.[a]

	All Planted		Harvested		Yield		Production	
	2014	2015	2014	2015	2014	2015	2014	2015
County	*Acres*		*Acres*		*Bushels*		*Bushels*	
Arkansas	168,200	160,200	168,100	160,100	55.1	53.9	9,254,000	8,626,400
Ashley	56,500	57,200	55,700	56,600	56.2	56.1	3,129,500	3,174,400
Chicot	146,800	162,400	146,500	161,300	54.4	53.0	7,974,000	8,541,000
Clay	112,500	117,900	112,200	117,700	46.1	49.9	5,173,000	5,873,000
Craighead	118,900	139,600	118,200	139,400	52.0	52.0	6,148,000	7,242,000
Crittenden	187,000	184,200	186,400	181,800	46.8	43.7	8,722,000	7,942,000
Cross	153,400	136,600	152,300	136,400	48.2	48.2	7,348,000	6,570,000
Desha	161,300	165,900	161,000	165,400	61.7	61.1	9,932,000	10,100,000
Drew	38,200	36,800	38,200	36,800	58.5	57.0	2,234,500	2,096,600
Greene	63,500	66,300	63,100	66,100	41.2	45.2	2,601,000	2,985,000
Independence	30,300	28,900	29,900	28,600	41.0	40.8	1,225,000	1,166,000
Jackson	118,000	114,600	117,300	114,000	39.8	40.5	4,665,000	4,618,000
Jefferson	112,500	110,400	112,000	105,300	52.8	60.6	5,910,000	6,378,000
Lawrence	59,400	50,700	59,200	50,400	38.3	37.9	2,265,000	1,908,000
Lee	145,500	133,500	145,100	131,300	48.7	47.6	7,070,000	6,247,000
Lincoln	79,200	77,000	79,200	76,800	55.8	58.3	4,420,000	4,474,000
Lonoke	107,000	112,500	106,800	111,500	49.9	46.4	5,325,000	5,168,600
Mississippi	292,000	297,300	291,500	294,900	52.4	53.0	15,270,000	15,621,000
Monroe	101,500	101,100	97,400	100,600	46.4	46.4	4,522,000	4,663,000
Phillips	206,500	203,800	206,300	201,000	60.9	47.1	12,562,000	9,469,000
Poinsett	180,500	183,400	179,900	183,000	48.0	51.8	8,644,000	9,477,000
Prairie	104,100	103,900	103,100	103,600	56.4	47.9	5,810,000	4,967,000
Randolph	34,400	35,900	34,200	35,700	41.0	45.2	1,401,000	1,614,000
Saint Francis	133,500	125,500	127,700	125,300	37.9	43.4	4,841,000	5,444,000
White	29,000	32,400	28,500	32,200	36.9	39.8	1,053,000	1,280,000
Woodruff	114,300	121,700	107,800	121,400	35.2	40.7	3,796,000	4,937,000
Other Counties[b]	176,000	140,300	172,400	132,800	40.1	32.8	7,105,000	4,784,000
State Totals	3,230,000	3,200,000	3,200,000	3,170,000	49.5	49.0	158,400,000	155,330,000

[a] Data obtained USDA-NASS, 2016.

[b] Benton, Conway, Crawford, Franklin, Lafayette, Logan, Perry, Pope, and Yell Counties.

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2015 Soybean Research Verification Program

C.L. Grimes[1], M.C. Norton[2], W.J. Ross[3], and C.R. Stark, Jr[4].

ABSTRACT

The 2015 Soybean Research Verification Program (SRVP) was conducted on sixteen commercial soybean fields across the state. Counties participating in the program included; Arkansas, Chicot, Clay, Craighead, Cross, Desha, Drew (2 fields), Jefferson, Lawrence, Lee, Lincoln, Monroe, Phillips, Prairie, Randolph, White and Woodruff Counties for a total of 932 acres. Grain yield in the 2015 SRVP averaged 62 bu/ac ranging from 16 to 90 bu/ac. The 2015 SRVP average yield was 11 bu/ac greater than the estimated Arkansas state average of 51 bu/ac. The highest yielding field was in Chicot County with a grain yield of 90 bu/ac. The lowest yielding field was a non-irrigated field in Drew County that produced 16 bu/ac.

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, 5) incorporate data from SRVP into CES educational programs at the county and state level. Since 1983, the SRVP has been conducted on 568 commercial soybean fields in 33 soybean-producing counties in Arkansas. The program has typically averaged about 10 bu/ac 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 CES 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 CES 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 2015, the following counties participated in the program; Arkansas, Chicot, Clay, Craighead, Cross, Desha, Drew (2 fields), Jefferson, Lawrence, Lee, Lincoln, Monroe, Phillips, Prairie, Randolph, White and Woodruff counties. The eighteen soybean fields totaled 932 acres enrolled in the program. Nine Roundup Ready® varieties were planted (Armor 46R42, Asgrow 4232, Asgrow 4632, NK S47-K5, NK S52-Y2. Pioneer 47T36, Pioneer 54T94, Progeny 4900, UA 5414); three Liberty Link® varieties (Halo 4:95, Delta Grow 4990 LL, Delta Grow 1967 LL); and two conventional varieties (UA 5014, UA 5612) in the eighteen 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.

[1] County Extension Agent, Cooperative Extension Service, Jonesboro.
[2] Soybean Research Verification Coordinator, Cooperative Extension Service, Monticello.
[3] Associate Professor, Department of Crop, Soil and Environmental Sciences, Lonoke Extension Center, Lonoke.
[4] Professor, Agricultural Economics, University of Arkansas, Monticello.

RESULTS AND DISCUSSION

Yield. The average SRVP yield was 62 bu/ac with a range of 16 to 90 bu/ac. The SRVP average yield was 11 bu/ac more than the estimated state yield of 51 bu/ac. 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 90 bu/ac and was seeded with Asgrow 4632 in Chicot County.

Planting and Emergence. Planting began with Lincoln County on 2 April and ending with Woodruff County planted 24 June. Due to rains in northeast Arkansas, the majority of the verification fields were planted in June (9), while 5 were planted in April and 4 in May. An average of 56 lbs/ac 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 SRVP were fertilized according to University of Arkansas System Division of Agriculture's Soil Test Laboratory results. Refer to Table 2 for detailed fertility information.

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

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

Insect Control. Fields were scouted on a weekly basis and CES recommendations were utilized for insect control programs. Refer to Table 4 fungicide and 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 program. Fifteen of the 18 fields in the 2014 SRVP were furrow-irrigated and 2 were center pivot. One field enrolled in the program was dry land.

PRACTICAL APPLICATIONS

Data collected from the 2015 SRVP reflect the general trend of increasing soybean yields and above average returns in the 2015 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.

ACKNOWLEDGEMENTS

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 along with the district administration for their support.

Table 1. Agronomic information for the 2015 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 4632	50	Rice	FSI	60	128K	5/5	5/13	10/1	72
Chicot	Asgrow 4632	60	Soybean	ESI	58	138K	4/4	4/13	8/27	90
Clay	Armor 46R42	25	Corn	FSI	60	140K	6/5	6/9	10/16	63
Craighead	Armor 46R42	46	Soybean	FSI	58	115K	6/11	6/16	10/15	59
Cross	Progeny 4900	108	Rice	FSI	60	90K	6/15	6/25	10/15	35
Desha	Pioneer 47T36	25	Corn	ESI	42	105K	4/22	5/1	9/23	83
Drew – 1	UA 5612	22	Soybean	FSNI	60	135K	5/4	5/13	10/5	16
Drew – 2	Pioneer 54T94R	40	Cotton	FSI	50	129K	5/23	5/30	10/8	61
Jefferson	Delta Grow 4990 LL	64	Soybean	FSI	55	124K	5/5	5/13	10/10	62
Lawrence	Delta Grow 4967 LL	60	Soybean	FSI	60	145K	6/18	6/23	11/12	51
Lee	Asgrow 4232	20	Cotton	ESI	59	129K	4/4	4/13	8/27	58
Lincoln	NK S47-K5	75	Cotton	ESI	59	115K	4/2	4/11	8/26	87
Monroe	UA 5014C	40	Rice	FSI	58	127K	6/8	6/15	10/20	63
Phillips	Asgrow 4632	34	Soybean	ESI	58	132K	4/8	4/16	9/23	60
Prairie	UA 5414	30	Rice	FSI	60	97K	6/16	6/21	10/15	77
Randolph	NK S52Y2	105	Soybean	FSI	54	120K	6/03	6/9	11/23	55
White	Halo 4:95 LL	38	Corn	FSI	42	105K	6/6	6/11	10/07	66
Woodruff	Pioneer 47T36	90	Wheat	DCI	54	120K	6/24	6/29	10/21	61
Average		52			56	122K	5/17	5/24	10/6	62

State Avg. 51 bu/ac.

Table 2. Soil tests results, applied fertilizer and soil classification for the 2015 Soybean Research Verification Fields

		Applied Fertilize N-P-K (lb/ac)			
County	**pH**	**P**	**K**	**Pre-plant**	**Soil Classification**
Arkansas	6.6	11	72	0-80-120	Dewitt silt loam
Chicot	6.8	34	92	0-30-90	Sharkey clay
Clay	6.5	104	172	0-0-120	Falaya silt loam
Craighead	0	0	0	0-0-0	Hillemann & Tichnor silt loam
Cross	6.4	121	300	0-0-60	Henry silt loam
Desha	6.5	56	128	0-0-60	McGehee, Rilla silt loam
Drew - 1	6.0	54	130	0-0-60	Grenada, Henry silt loam
Drew - 2	6.3	20	116	0-60-60	Rilla silt loam
Jefferson	6.1	36	92	0-23-90	McGehee silt loam, Perry clay
Lawrence	6.2	17	104	0-40-60	Foley-Calhoun silt loam
Lee	6.4	60	204	0-0-0	Dubbs loam, Dundee silt loam
Lincoln	6.8	52	122	0-0-60	Herbert silt loam
Monroe	6.3	34	96	0-36-72	Foley-Calhoun-Bonn complex
Phillips	6.0	21	179	0-30-60	Henry silt loam, Lagrange sandy loam
Prairie	6.3	21	179	0-30-60	Stuttgart silt loam
Randolph	6.0	85	181	0-0-90	Bosket fine sandy loam
White	7.3	87	219	0-0-60	Silt loam
Woodruff	6.2	54	174	0-0-0	Wiville & Dubbs silt loam

Table 3. Herbicide rates and timings for 2015 Soybean Research Verification Program fields by county.

	Herbicide	
County	**Burndown/Pre-emergence**	**Post-emergence**
Arkansas	2.8 oz/ac Enlight	24 oz/ac Flexstar plus 22 oz/ac Roundup PowerMax
Chicot	Burndown: 26 oz/ac Roundup PowerMax plus 32 oz/ac 2,4-D Pre-emerge: 26 oz/ac Roundup PowerMax plus 2 oz/ac Valor	26o z/ac RoundupPowerMax
Clay	2 oz/ac Zidua plus 1oz/ac Valor	1st: 28 oz/ac Roundup PowerMax plus 0.33 oz/ac Classic 2nd: 28 oz/ac Roundup PowerMax
Craighead	------------------------	1st: 32 oz/ac Roundup PowerMax 2nd: 32 oz/ac Roundup PowerMax plus 16 oz/ac Flexstar
Cross	5 oz/ac Verdict	1st: 32 oz/ac Roundup PowerMax plus 0.33 oz/ac Classic 2nd: 40 oz/ac Glyphosate plus 24 oz/ac Ultra Blazer
Desha	Burndown: 22 oz/ac Roundup PowerMax plus 24 oz/ac 2,4-D Pre-emerge: 22 oz/ac Roundup PowerMax plus 20 oz/ac Metolachlor	22 oz/ac Roundup PowerMax plus 32 oz/ac Prefix
Drew - 1	Burndown: 32 oz/ac Glyphosate Pre-emerge: 32 oz/ac Glyphosate plus 2 oz/ac Envive plus 16 oz/ac Metolachlor	32 oz/ac Prefix
Drew - 2	22 oz/ac Roundup PowerMax plus16 oz/ac 2,4-D	1st: 22 oz/ac Roundup PowerMax plus10 oz/ac Prefix 2nd: 22 oz/ac Roundup PowerMax plus 10 oz/ac Prefix
Jefferson	2 oz/ac Zidua	1st: 32 oz/ac Liberty plus 16 oz/ac Dual Magnum 2nd: 32 oz/ac Liberty plus 24 oz/ac Flexstar
Lawrence	------------------------	1st: 32 oz/ac Liberty 2nd: 32 oz/ac Liberty
Lee	40 oz/ac Gramoxone plus 3.5 oz/ac Envive	24 oz/ac Roundup PowerMax plus 21 oz/ac Metolachlor
Lincoln	Burndown: 24 oz/ac Roundup PowerMax plus 1 oz/ac Sharpen plus1% MSO Pre-emerge: 20 oz/ac Metolachlor	1st: 22 oz/ac Roundup PowerMax plus 2 oz/ac Zidua 2nd: 22 oz/ac Roundup PowerMax plus 32 oz/ac Prefix
Monroe	------------------------	24 oz/ac Storm plus 16 oz/ac Dual Magnum
Phillips	32 oz/ac Boundary	1st: 32oz/ac Glyphosate plus 21 oz/ac Metolachlor 2nd: 32oz/ac Glyphosate plus 24 oz/ac Flexstar
Prairie	------------------------	1st: 32 oz/ac Roundup PowerMax plus 16 oz/ac Me-Too-Lachlor 2nd: 32 oz/ac Roundup PowerMax
Randolph	56 oz/ac Flexstar GT plus 2 oz/ac Valor	40 oz/ac Glyphosate plus 16 oz/ac Ultra Blazer
White	16 oz/ac Me-Too-Lachlor	1st: 26 oz/ac Liberty 2nd: 29 oz/ac Liberty
Woodruff	20 oz/ac Gramoxone plus 2 oz/ac Valor	1st: 16 oz/ac Ultra Blazer plus 16 oz/ac Me-Too-Lachlor 2nd: 32 oz/ac Roundup PowerMax plus 32 oz/ac Prefix

Table 4. Fungicide and insecticides applications in 2015 Soybean Research Verification fields by county.

County	Aerial Web Blight	Frogeye	Bollworm/Defoliators	Stink Bug
Arkansas	----------	----------	---------	6.4 oz/ac Brigade
Chicot	----------	----------	----------	4.27 oz/ac Brigade plus 0.5 lbs/ac Acephate
Clay	----------	8 oz/ac Quadris Top	1.9 oz/ac Lambda-Cy	----------
Craighead	----------	4 oz/ac Priaxor	2 oz/ac Belt	----------
Cross	----------	----------	9 oz/ac Beseige	----------
Desha	----------	----------	----------	----------
Drew - 1	----------	----------	---------	----------
Drew - 2	----------	9.5 oz/ac Quadris Top	2 oz/ac Belt	----------
Jefferson	----------	----------	10 oz/ac Besiege	----------
Lawrence	----------	----------	2 oz/ac Belt	----------
Lee	----------	----------	----------	3.66 oz/ac Lambda-Cy
Lincoln	----------	----------	----------	----------
Monroe	---------	----------	----------	----------
Phillips	----------	----------	----------	4.74 oz/ac Brigade
Prairie	----------	9 oz/ac Quadris Top	2 oz/ac Belt	----------
Randolph	----------	10 oz/ac Quadris Top	----------	----------
White	----------	10 oz/ac Quadris Top	----------	----------
Woodruff	----------	8 oz/ac Quadris Top	2 oz/ac Belt	----------

Relationships Among Canopy Temperature, Wilting Ratings, Maturity, and Yield in Soybean

L.C. Purcell[1] and C.A. King[1]

ABSTRACT

Soybean genotypes differ in how quickly they wilt during the progression of a drought, but measurements of wilting are based upon a subjective, visual rating scale. During the onset of drought, transpiration decreases, and canopy temperature increases. Hence, canopy temperature measurements may make an ideal, objective measure of the first symptoms of drought stress. Our objective was to measure canopy temperature from an aerial platform and compare relative temperature values to wilting ratings. A set of 41 diverse, soybean genotypes were grown in an irrigated experiment at the University of Arkansas System Division of Agriculture's Arkansas Agricultural Research and Extension Center, Fayetteville, Arkansas. Just prior to irrigation events on 29 July and 11 August 2015, infrared (IR) images were taken of the experiment from a height of approximately 150 feet. Immediately after the aerial images were taken, canopy wilting was rated on a scale from 0 (no wilting) to 100 (completely wilted and dying). Customized software was used to extract canopy temperature information of each plot from multiple images on each date, and these values were averaged and normalized. Relative canopy temperatures between the two dates were positively correlated (r = 0.65). Relative canopy temperature on 29 July was also positively associated (r = 0.35) with wilting ratings from 11 August. At both measurement dates, maturity group (MG) was negatively associated with canopy temperature, meaning that canopy temperature increased at later growth stages. For both the first and second measurement dates, yield decreased linearly as relative temperature increased, but this relationship was strongly affected by differences in maturity among genotypes.

INTRODUCTION

Although approximately 80% of the soybean crop in Arkansas is irrigated (USDA-NASS, 2016), much of the crop still suffers from drought due to inadequate well capacity and labor capacities and other factors. Some unimproved soybean genotypes from the USDA germplasm collection wilt considerably later during the progression of drought than currently grown cultivars (King et al., 2009). The delayed wilting trait is believed to be a particularly valuable trait for increasing soybean drought tolerance (Sinclair et al., 2010).

To move this trait from poorly adapted genotypes to high-yielding cultivars requires a mechanism by which breeding lines can be readily characterized for the trait. Currently, genotypes are scored visually on a scale from 0 (no wilting) to 100 (severe wilting and dying), but this method is subjective and can only be used for about 3 hours per day on days when drought is occurring and the sun is unobstructed (King et al., 2009).

Transpiration decreases early during the progression of drought, resulting in increased canopy temperature. Previous research, however, was unable to detect differences among genotypes in canopy temperature measurements when made from the ground's surface (Ries et al., 2012). Our objective was to determine relative canopy temperature from an aerial platform on a diverse set of soybean genotypes during early stages of drought and to establish the relationship of relative canopy temperature with wilting rating and yield.

PROCEDURES

Forty-one genotypes were planted at University of Arkansas System Division of Agriculture's Arkansas Agricultural Research and Extension Center, Fayetteville, Arkansas on 2 June 2015 on a Captina silt loam. These genotypes are the parental lines used in the Soybean Nested Association Mapping (SoyNAM) project (http://www.soybase.org/SoyNAM/population.php?parent=4J105-3-4) and represent diverse genotypes from the USDA collection with maturity groups (MGs) ranging from 2 to 5. The goal of the SoyNAM project is to improve the yield of soybean by determining the location of genes that determine yield and other agronomic traits. To do this, 40 diverse soybean genotypes were each crossed with one parental genotype, IA3023 (Table 1). From each cross, 140 recombinant inbred lines (RILs) were developed, and each line was genotyped with 4312 molecular markers. The present research is evaluating the 41 parental genotypes for canopy temperature under drought conditions. Once genotypes are identified that are extremes for canopy temperature, the next step will be to map the trait in the corresponding recombinant inbred population.

Each plot consisted of four rows, spaced 18 inches apart, and 20 feet in length and seeded at a population of 140,000 per acre. There were four replications arranged in a randomized complete block design. After emergence, a sprinkler irrigation system was installed, and irrigation was applied when the estimated soil-moisture deficit reached 1.5 inches (Purcell et al., 2007).

[1]Professor and Project/Program Director, respectively, Department of Crop, Soil, and Environmental Science, Fayetteville.

On 29 July and 11 August, just prior to an irrigation event, aerial infrared (IR) measurements were made over the experiment. The camera used was a FLIR Tau 2 640 IR camera (FLIR Systems, Goleta, Ga.) with a resolution of 640 × 512 pixels. The IR camera provides a unitless value for each pixel in the image that corresponds to a relative temperature value. The relative temperatures have values between 0 and 255 that cover approximately 22 °F, resulting in temperature detection differences of 0.1 °F. Although this system does not allow the determination of the exact temperature of any one plot, the system does allow accurate comparisons of temperature differences among plots. The camera was lifted above the experiment approximately 150-ft using a 6-ft diameter, tethered balloon on calm days or a helikite on windy days (SkySentry, LLC. Falcon, Colo.) filled with approximately 100 cu. ft of helium.

Images captured from the video of the camera output were first processed in GIMP (www.gimp.org) to remove lens distortion and to rotate the image so that the field edge was horizontal. The relative temperature value within each plot was determined using customized software (Purcell et al., 2016) that extracted the average value of pixels from each plot and exported the values to a spreadsheet. For each plot, relative temperature values were expressed as the difference between a specific plot and the average value of plots from an image. From five to eight relative temperature values for each plot were determined and then averaged for data analysis.

The same days that relative canopy temperatures were measured, canopy wilting was rated on a scale from 0 (no wilting) to 100 (severe wilting and dying) (King et al., 2009). At maturity, the center portion of the two center rows were harvested, and yields were expressed at 13% moisture. Pearson correlation coefficients were determined from genotypic means for specific measurement dates using PROC CORR SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.).

RESULTS AND DISCUSSION

Yield among the SoyNAM parental lines ranged from 33 to 67 bu/ac (data not shown). Genotypes included in the SoyNAM project include a wide range of MGs from 2 through 5 and both improved and ancestral genotypes. A large portion of differences in yield, however, can be explained by maturity. Yield was positively associated with the day of year at which seedfill began ($r = 0.62$, $P \leq 0.01$, Table 2), indicating that yield generally increased with later maturity.

The relative canopy temperature range was from -27 to 40 for 29 July and from -13 to 12 for 11 August. This corresponds to an absolute temperature difference of approximately 6.7 °F among genotypes on 29 July and a difference of about 2.5 °F on 11 August. Although the ranges of relative temperature were quite different for these two dates, there was a positive correlation ($r = 0.65$, $P \leq 0.01$) between relative canopy temperature for 29 July and 11 August. Despite having a considerably greater range in relative canopy temperature values for 29 July than for 11 August, the range in wilting ratings for these two dates was similar (12 and 14, respectively). This may reflect a greater ability of IR thermography to detect drought stress than the subjective wilting ratings.

PRACTICAL APPLICATIONS

This research demonstrates for the first time that relative canopy temperature is positively associated with wilting ratings in soybean and that relative canopy temperature tends to increase at later stages of development. These results lay the foundation for being able to use IR thermography as a screening tool for drought tolerance in breeding programs.

ACKNOWLEDGEMENTS

The authors thank the Arkansas Soybean Promotion Board and the United Soybean Board for funding this research. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Genotypes in the Soybean Nested Association Mapping (SoyNAM) project.

Genotype	Maturity group	Genotype source
4J105-3-4	3	Purdue Univ.
5M20-2-5-2	3	Purdue Univ.
CL0J095-4-6	3	Purdue Univ.
CL0J173-6-8	3	Purdue Univ.
HS6-3976	3	Ohio State Univ.
LD00-3309	4	Univ. of Illinois
LD01-5907	3	Univ. of Illinois
LD02-4485	2	Univ. of Illinois
LD02-9050	4	Univ. of Illinois
LG00-3372	3	USDA-ARS, Univ. of Illinois
LG03-2979	3	USDA-ARS, Univ. of Illinois
LG03-3191	4	USDA-ARS, Univ. of Illinois
LG04-4717	3	USDA-ARS, Univ. of Illinois
LG04-6000	4	USDA-ARS, Univ. of Illinois
LG05-4292	4	USDA-ARS, Univ. of Illinois
LG05-4317	4	USDA-ARS, Univ. of Illinois
LG05-4464	3	USDA-ARS, Univ. of Illinois
LG05-4832	3	USDA-ARS, Univ. of Illinois
LG90-2550	3	USDA-ARS, Univ. of Illinois
LG92-1255	2	USDA-ARS, Univ. of Illinois
LG94-1128	2	USDA-ARS, Univ. of Illinois
LG94-1906	2	USDA-ARS, Univ. of Illinois
LG97-7012	3	USDA-ARS, Univ. of Illinois
LG98-1605	3	USDA-ARS, Univ. of Illinois
Magellan	4	Univ. of Missouri
Maverick	3	Univ. of Missouri
NE3001	3	Univ. of Nebraska
PI 398881	3	South Korea
PI 404188A	2	China
PI 427136	3	South Korea
PI 437169B	2	Russian Federation
PI 507681B	2	Uzbekistan
PI 518751	2	Serbia
PI 561370	3	China
PI 574486	2	China
Prohio	3	USDA-ARS, Ohio State Univ.
S06-13640	4	Univ. of Missouri
Skylla	2	Michigan State Univ.
TN05-3027	5	Univ. of Tennesee
U03-100612	2	Univ. of Nebraska
IA3023	3	Iowa State Univ.

Table 2. Pearson correlation coefficients for yield, canopy wilting ratings on 29 July and 11 Aug., relative canopy temperature measurements on 29 July and 11 August, and day of year for beginning seedfill.

	Yield	Wilting 29 July	Wilting 11 Aug	Rel. Can. Temp. 29 July	Rel. Can. Temp. 11 Aug	Days to Beg. Seedfill
Yield	1	0.24	-0.32*	-0.78**	-0.47**	0.62**
Wilting (29 July)		1	0.55**	-0.06	0.06	0.12
Wilting (11 Aug)			1	0.35*	0.20	-0.55**
Relative Canopy Temp. (29 July)				1	0.61**	-0.47**
Relative Canopy Temp. (11 Aug)					1	-0.07
Days to Beginning Seedfill						1

Significance is indicated at the 5% (*) and 1% (**) levels.
Rel. Can. Temp. = Relative canopy temperature.
Days to Beg. Seedfill = Days to beginning seedfill.

Custom Software for Analyzing Aerial Digital Images

L.C. Purcell[1], C.J. Purcell[2], C.A. King[1], and M.K. Davies[1]

ABSTRACT

Aerial images of research experiments on soybean and other crops have the potential to provide information on differences in how genotypes respond to nutrition, drought stress, and disease. A critical component that is lacking for using this information is interpretation of the data and the ability to quantify data on individual plots quickly and easily. This research reports the development of customized software (Badhorse, v. 1.0) that divides aerial images of field experiments into grids corresponding to experimental plots. The software has selections that allow bordered regions of the plots to be excluded from measurements, and the software has options for analyzing images from color infrared (IR), grayscale IR, dark green color index (DGCI), and canopy coverage. Data from an entire field can be analyzed at once, and the output is saved in a comma-separated values (CSV) format that can be opened in a spreadsheet. Aerial color images from irrigated and dryland soybean experiments in 2015 were taken throughout seedfill and used to determine DGCI, which is closely associated with nitrogen concentration. Analysis of DGCI data using Badhorse had near perfect agreement with analysis of DGCI values determined from measuring individual plots but required only a fraction of the time.

INTRODUCTION

The introduction of reliable, inexpensive unmanned aerial systems (UASs) into U.S. agriculture is anticipated to fundamentally change the way that farmers and agricultural scientists collect information about their crops. With correct sensors in place, information regarding crop nutrition, crop stress, disease, and soil moisture can be remotely collected.

Using remote-sensing, scientists have the potential of collecting data on large numbers of plots at the same time from aerial platforms and using that information in improving management and selection protocols in breeding programs. One impediment for utilizing this information includes a lack of appropriate tools to quantify remote-sensing data for individual research plots. The objective of this research was to develop software that could quickly and easily quantify remotely sensed measurements from images of research plots taken from an aerial platform.

PROCEDURES

Color images of soybean plots at the University of Arkansas System Division of Agriculture's Arkansas Agricultural Experiment Station in Fayetteville, Arkansas were taken from a height of approximately 150 feet several times during the 2015 season from both irrigated and non-irrigated experiments. The camera was positioned over the experiments using a 6-ft diameter tethered balloon (on calm days) or a helikite on windy days, (SkySentry, LLC. Falcon, Colo.); the balloon and helikite were both filled with helium. Images were made using a Canon S-100 digital camera, which was programmed to take pictures every 2 sec. at bracketed f-stops above and below the automatically selected F stop value. During measurements, a 4 ft by 8 ft board was placed at the field edge on which colored circles with 40-inch radii were painted corresponding to dark green color index values (DGCI) of 0.5722 (green) and 0.0733 (yellow) (Fig. 1a). The DGCI is a measure of the intensity of greenness of plants ranging from 0 to 1 and corresponds closely with nitrogen (N) concentration (Rorie et al., 2011). The colored circles served as standards and allowed for the correction of DGCI values that might change due to lighting conditions (Rorie et al., 2011).

Data were collected from individual plots measuring 5 ft by 20 ft from the color images using two different procedures: (1) a manual procedure in which individual plots were digitally 'cut' from the larger aerial image and analyzed using GIMP software (www.gimp.org) and (2) an automated procedure using customized software written in Java (www.java.com) in which the user defines the boundaries of plots and all the plots are analyzed at once. Prior to image analysis using either procedure, individual images were first rotated in GIMP so that the field boundary was horizontal and then distortion was removed in GIMP using the 'lens distortion' and 'perspective' features.

For analysis of DGCI values from individual plots, the histogram function of GIMP was used to obtain average red, green, and blue (RGB) values of pixels within the portion of an image corresponding to a plot. Values of RGB were converted to hue, saturation, and brightness (HSB) values in GIMP using the 'Colors' option under the 'Dockable Di-

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alogs' menu. The uncorrected DGCI values were calculated using the HSB values as described by Rorie et al. (2011). To correct the DGCI values, the DGCI values of the colored standards were determined, and then these values were used to correct values of individual plots using a two-point calibration procedure (Rorie et al., 2011).

Customized software (Badhorse, v. 1.0) was developed in Java (www.java.com) to automate the measurement of DGCI from individual plots. The images were initially rotated to the desired orientation for analysis and then corrected for lens distortion and perspective in GIMP as described previously. Badhorse then allows the user to select a grid pattern corresponding to plot length and width dimensions (Fig. 1a). Once the plot dimensions are chosen, the user can choose the amount of border area to be removed between plots and from plot ends (Fig. 1b). From a drop-down menu, the user selects the type of analysis to perform. Current options not discussed in this report include infrared (IR) grayscale, IR color, and canopy coverage and as reported, herein, DGCI. The user is prompted to select the portion of the image corresponding to the yellow and green standards (Fig. 1c), and then the user chooses the portion of the aerial image for which data should be analyzed and saved (Fig. 1d). The corrected DGCI values are saved in a comma-separated value (CSV) file that can be opened in a spreadsheet.

Java was chosen as the target platform for two primary reasons: cross-platform support and modularity of design. Java programs run on any computer that has installed a java run-time environment; hence, Badhorse can be used on Windows, Apple, and Linux systems. Lastly, Java programs are modular, which allows for easy extensibility. In practical terms, this makes it easy to add support for additional types of analysis and to modify the program to meet changing needs.

To determine if values of DGCI from analysis of entire images using Badhorse agreed with values determined on individual plots using GIMP, images from several dates were compared over a range of conditions by both methods. The relationships between values determined using Badhorse and using GIMP were evaluated by simple linear regression.

RESULTS AND DISCUSSION

Values of DGCI determined using Badhorse agreed very well with the values determined with GIMP (Fig. 2). Regression analysis between values from Badhorse and GIMP had a slope not significantly different from 1 and an intercept not significantly different from 0; the r^2 value of the relationship was 0.97. The automated method using Badhorse was both reliable and intuitive.

In addition, analysis with Badhorse saved considerable time compared with the method of analyzing individual plots in GIMP. To determine DGCI in GIMP takes an experienced user around 3 minutes per plot whereas Badhorse can determine DGCI of an entire field (e.g., data collected on 80 plots in Fig. 1d) in about 5 minutes. Badhorse has also been used successfully for analyzing aerial images for grayscale IR, color IR, and canopy coverage. Badhorse is covered by a Creative Commons license (https://creativecommons.org/) and can be downloaded at: https://github.com/carlinpurcell/badHorse

PRACTICAL APPLICATIONS

Customized software was developed that greatly speeds and simplifies the analysis of data from aerial images of experimental plots. The ability to analyze remotely sensed data of aerial images from experimental plots makes possible and practical new tools for crop management and breeding.

ACKNOWLEDGEMENTS

The authors thank the Arkansas Soybean Promotion Board and the United Soybean Board for funding this research. Support was also provided by the University of Arkansas System Division of Agriculture.

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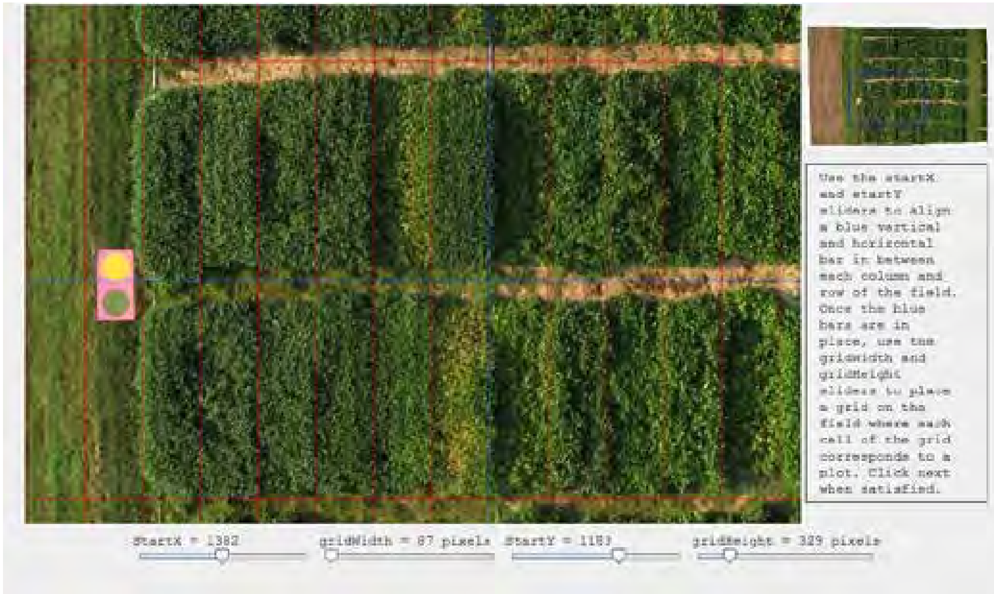
A


Use the startX and startY sliders to align a blue vertical and horizontal bar in between each column and row of the field. Once the blue bars are in place, use the gridWidth and gridHeight sliders to place a grid on the field where each cell of the grid corresponds to a plot. Click next when satisfied.
startX = 1382
gridWidth = 87 pixels
startY = 1183
gridHeight = 329 pixels

B


Use the dx and dy sliders to change the width and height of each area to be sampled (i.e., to select the inner rows of each plot). Once satisfied with the selected sample areas, click next.
dx is 13 pixels
dy is 78 pixels

C

D

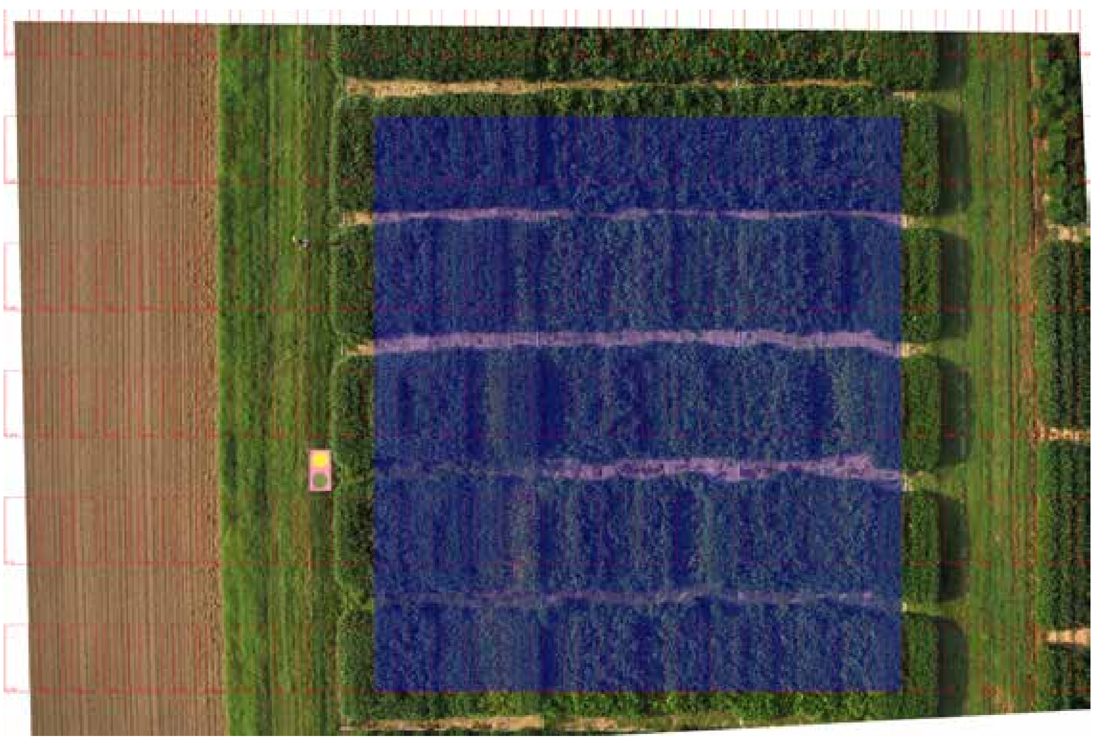


Fig. 1. Screen captures from the customized software package, Badhorse, of aerial color images taken during seedfill. The yellow and green circles on the pink board serve as color standards and are used in standardizing color analysis among different images. The upper right portion of Figs. 1a-to-c allows the user to select the portion of the field to view and to zoom in to areas of interest. Gridlines are positioned in the field to correspond to plot lengths and widths (a). Bordered sections of plots are chosen for analysis (b). The color standards are chosen by zooming in, which allows for a two-point calibration for all color analysis in the experimental plots (c). The portion of the field for which data will be analyzed and sent to a spreadsheet is selected (indicated in blue, d).

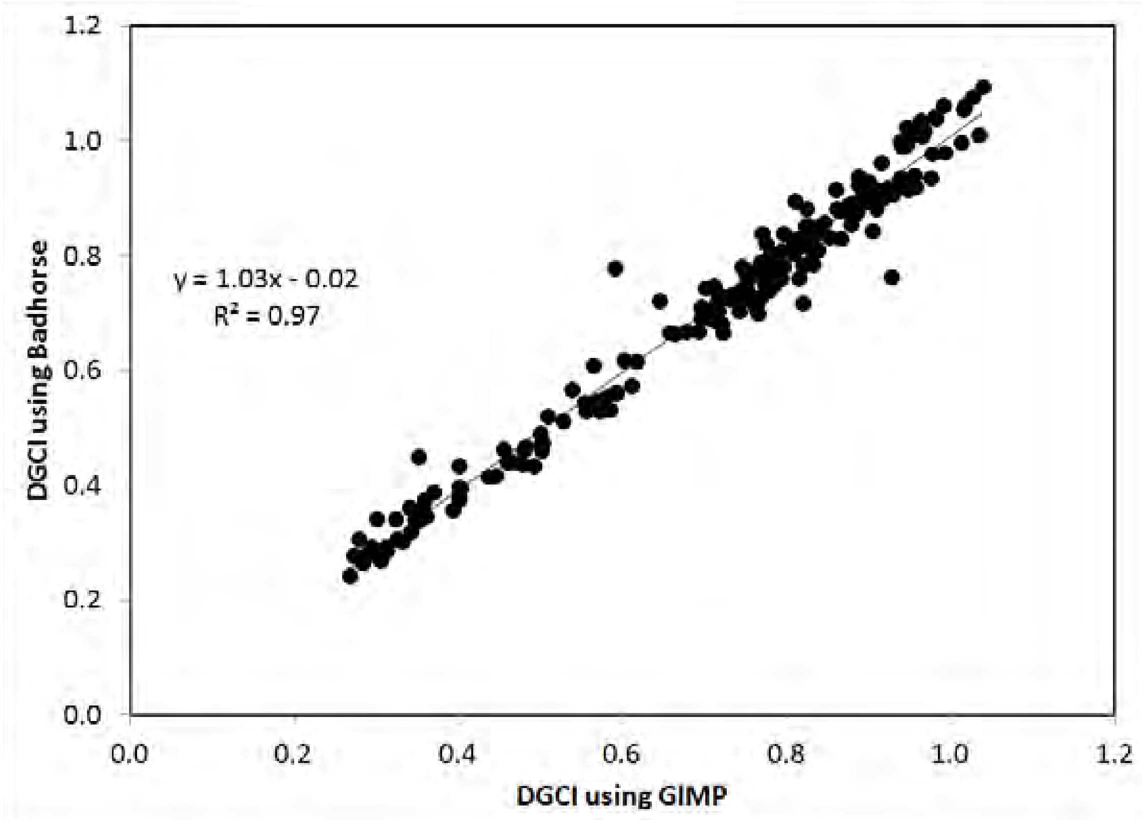


Fig. 2. Dark green color index (DGCI) values of soybean plots determined using the software Badhorse versus DGCI values determined from the same plots individually using the software GIMP. Values are from several images taken throughout the seedfill period.

Assessment of Soybean Varieties in Arkansas for Sensitivity to Chloride Injury

S. Green[1] *and M. Conatser*[2]

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 in 2015 for reaction to elevated chloride salts. A 50 mM chloride-salt solution treatment was used to induce a genotypic uptake response in soybean plants. Leaf tissue from treated plants was collected and analyzed for chloride concentration. 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 concentration. Cultivars having high levels of leaf tissue chloride concentration are known as includers, while those having low leaf tissue chloride concentration are known as excluders, and cultivars having a segregating population of individual plants with high and low chloride concentration are known as mixed. The 2015 assessment of soybean cultivars revealed that of the 275 soybean lines evaluated, only 22% of maturity group 4 soybean and 48% of maturity group 5 soybean showed excluder response. Many of the soybean producers in Arkansas grow maturity group 4 soybean and are limited in their options when chloride sensitivity is an important factor in their decision.

INTRODUCTION

Arkansas has some of the most fertile and productive soils in the world, originating from the Mississippi River alluvial flood plain. 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 (Rupe et al., 2000). This problem is usually due to salt accumulations following repeated applications of well water with elevated salt concentration 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 are then either translocated to the foliage (includer cultivars) or stored in the roots (excluder cultivars) (Abel, 1969). 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

During the 2015 growing season, 275 soybean cultivars were obtained from the University of Arkansas System Division of Agriculture's Soybean Variety Testing Program for evaluation of chloride sensitivity. This program used a greenhouse hydroponic protocol for screening soybean cultivars for reaction to elevated chloride salts (Rupe et al., 2000). In the greenhouse, seed from each cultivar was germinated in potting soil media. Once the soybean plants emerged and had reached VC stage, they 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 (from a combination of NaCl and $CaCl_2$) 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 laboratory oven (Isotemp, Thermo Fisher Scientific, Inc., Waltham, Mass.) at 104 °F (40 °C) for 24 hours. After drying, samples were ground using a Wiley mill (Thomas Scientific, Swedesboro, N.J.) with a #20 sieve.

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One hundred mg 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 mL 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).

RESULTS AND DISCUSSION

Based on the soybean leaf tissue chloride concentration of each sample, a genotypic response was evident 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 had been termed excluder cultivars, and those that translocate the chloride ions to other tissues in the plant have been termed includer cultivars (Abel, 1969). Therefore, a determination of chloride excluder was made for soybean cultivars in which every individual plant contained a low concentration of leaf tissue chloride. A chloride includer determination resulted when every plant within a cultivar contained a high concentration of leaf tissue chloride. A mixed determination was made if a soybean cultivar contained a segregated population in which some individual plants contained a low concentration of leaf tissue chloride, while others contained a high concentration.

Two hundred seventy-five soybean cultivars from the Variety Testing Program were evaluated in 2015. This population of testing material consisted of maturity group four (MG4) and maturity group five (MG5) soybean cultivars. Twenty-two percent of MG4 cultivars showed an excluder genotype response, while MG5 cultivars had 48% excluder reaction to elevated chloride salts (Fig. 1). The greater number of MG5 excluders over MG4 soybean excluder cultivars is most likely due to the contribution 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 are made available to allow Arkansas soybean producers and breeders to select soybean genotypes and varieties suitable for growing at locations affected by high chloride concentrations occurring naturally within the soil or added by poor quality irrigation water.

ACKNOWLEDGEMENTS

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

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Johnson, H. Jr. 1980. Hydroponics: A guide to soil less culture. Leaf let 2949. Berkeley: Division of Agriculture and natural Resources. Univ. of California.

Rupe, J.C., J.D. Widick, W.E. Sabbe, R.T. Robbins, and C.B. Becton. 2000. Effect of chloride and soybean cultivar on yield and the development of sudden death syndrome, soybean cyst nematode, and southern blight. Plant Dis. 84:669-674.

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

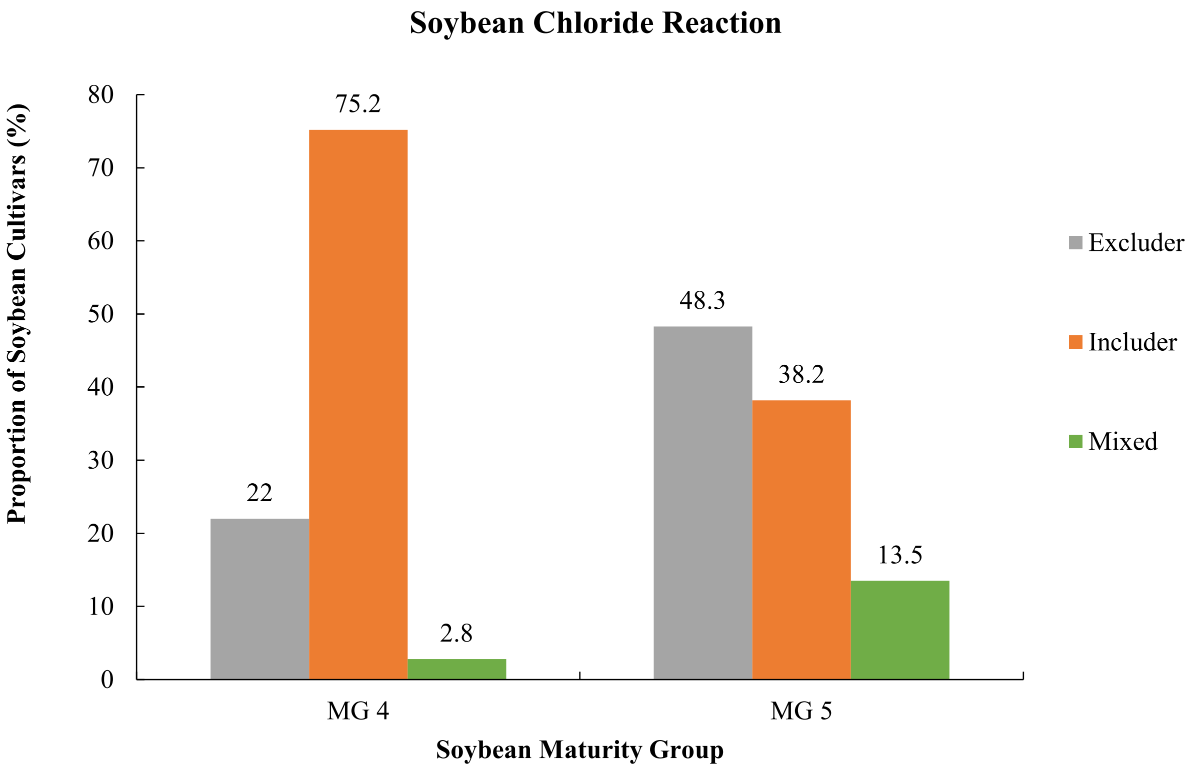

Fig. 1. Soybean chloride reaction for soybean lines evaluated in the 2015 University of Arkansas System Division of Agriculture's Variety Testing Program. Bars represent proportion of soybean cultivars exhibiting the particular chloride reaction within each maturity group.

Developing Profitable Irrigated Rotational Cropping Systems

J. Kelley[1]

ABSTRACT

A long-term field trial evaluating yield and resulting economic outcomes of eight rotational cropping systems that include soybean, wheat, corn, and grain sorghum was initiated at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Branch Research Station near Marianna, Arkansas in April of 2013. Wheat yields from wheat harvested in June 2014 did not differ when planted following corn, grain sorghum, or early-season soybean the previous year and averaged 72 bu/ac. In 2015, wheat yields following corn were slightly lower than when following other crops, but all rotations had similar yields. Corn yield was not impacted by previous crop in 2014 or 2015 with average yields of 248 and 220 bu/ac. Significant yield differences were seen for early-season soybean yields depending on the previous crop. In 2014, early-season soybean planted in April yielded only 43 bu/ac when following soybean, but yielded 64 bu/ac when following corn or grain sorghum. In 2015 early-season soybean yields did not differ among rotations. In 2014, double-crop soybean following double-crop soybean had yields of 30 bu/ac but double-crop soybean that followed corn or grain sorghum produced 39 or 40 bu/ac. In 2015, a similar trend was seen with double-crop soybean following double-crop soybean yielding less than those following corn or grain sorghum. Differences in soybean yields were likely in part caused by high soybean cyst nematode levels. Economic analysis of profitability of each cropping system 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 was 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 continues to shift 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 long-term field trial evaluating yield and resulting economic outcomes of eight rotational cropping systems that Arkansas producers may use was initiated at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Branch Research Station near Marianna, Arkansas in April of 2013.

The eight rotational cropping systems evaluated include:

Corn-Soybean-Corn-Soybean. Corn planted in March/April, then early-season group IV soybean the following year.

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.

Soybean-Wheat-Double-Crop Soybean-Wheat. Early-season group IV soybean, wheat planted after soybean harvest, double-crop soybean after wheat harvest.

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.

Continuous Corn. Corn planted in March/April every year.

Continuous Soybean. Early planted group IV soybean planted in April every year.

Grain Sorghum-Soybean-Grain Sorghum-Soybean. Full-season grain sorghum, followed by early planted group IV soybean planted the following year.

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.

The soil in the experiment area 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 was 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-in. row spacing. Wheat plots planted each fall were also planted on 38-in. wide raised beds and planted with a grain drill with 6-in. row spacing. Summer

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crops were irrigated via furrow irrigation according to the University of Arkansas System Division of Agriculture Cooperative Extension Service's (CES) irrigation scheduler program. Normal production practices such as planting dates, seeding rates, weed control, insect control, and fertilizer recommendations for each crop followed current CES recommendations. Harvest yield data were 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.

RESULTS AND DISCUSSION

The results discussed below are from 2014 and 2015 and represent the first and second year of results (Tables 1 and 2) from this project. Wheat yields in June 2014 ranged from 69-75 bu/ac and previous crop did not have an impact on yield. Similar results were seen in 2015 when wheat following corn was slightly lower yielding than when following soybean. Wheat harvest in 2014 was delayed by the lateness of the crop and rainfall at harvest, which delayed double-crop soybean planting until 7 July, reducing the overall yield potential; however, significant differences in yield were seen based on previous crop. In 2014, double-crop soybean averaged 39 or 40 bu/ac when following corn or grain sorghum and only 30 bu/ac when following early-season soybean the previous year. In 2015, a similar trend was seen with double-crop soybean generally yielding less when following double-crop soybean the previous year.

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/ac for when following early-season soybean. In 2015, no differences in yield were seen among any rotations. Differences in yields of early-season soybean between years is not clear.

Corn yield did not vary based on previous crop in 2014 or 2015, with average yields of 248 and 220 bu/ac. Lack of influence of previous crop on corn yield was surprising as some crop rotations show a yield penalty when corn follows corn. However, more years of data are needed to verify this. Full-season grain sorghum is grown in rotation and each year will always be following a soybean crop. Average grain sorghum yields in 2014 and 2015 were 143 and 123 bu/ac. Double-crop grain sorghum was greatly impacted by sugarcane aphid in 2014 and was not harvested. In 2015, double-crop grain sorghum planted in early June yielded 88 bu/ac. Sugarcane aphids were controlled; however, several insecticide applications were needed for control.

Economic analysis is ongoing and is not included in this report at this time.

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 for Arkansas and mid-South crop producers.

ACKNOWLEDGEMENTS

Funding for this project was provided by the Arkansas Soybean, Corn and 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

NSD = no significant difference.

Table 2. Wheat, corn, grain sorghum, early-season soybean, double-crop soybean and double- crop grain sorghum yields from 2015 based on previous crop grown in 2014.

Previous Crop in 2014	Wheat	Corn	Grain Sorghum	Early-Season Soybean	Double-Crop Soybean	Double-Crop Sorghum
	--------------------------------bu/ac --------------------------------					
Early-Season Soybean	72	221	119	49	---	88
Corn	68	224	---	49	43	---
Grain Sorghum	73	---	---	51	42	---
Double-Crop Soybean	69	214	126	---	38	---
Double-Crop Sorghum	---	---	---	50	---	---
LSD (0.05)	4	NSD	NSD	NSD	NSD	---

NSD = no significant difference.

Association of Salt Uptake in Roots and Chloride Inclusion with a Gene Insertion in Sensitive Cultivars

J. Newsome[1], A.G. Laney[1], L.D. Nelson[1], M. Conatser[2], S. Green[2], P. Chen[3] and K.L. Korth[1]

ABSTRACT

Increases in soil salt concentrations and the resulting chloride toxicity in soybean, [*Glycine max* (L.) Merr.], continue as problems faced by Arkansas growers. Using measures of plant physiology, we have demonstrated that the key events leading to salt tolerance in soybean occur in the roots. Based on knowledge of the major gene responsible for salt tolerance in soybean, we developed a simple assay to screen tissue for the presence of the functional gene. This molecular marker will be useful to compare breeding lines and identify those that carry this important gene.

INTRODUCTION

Saline soils are common worldwide and limit the yield potential of many agricultural crops. Salt-affected soils are found on every continent and are caused by a high concentration of soluble ions, with sodium (Na^+) and chloride ($Cl^–$) being the most soluble and damaging to plants (Munns and Tester, 2008). Some locations and soil textures in Arkansas, particularly where groundwater irrigation is used, are especially prone to buildup of $Cl^–$ levels. Soil salinity is most commonly assessed by soil electrical conductance (EC), which increases with soluble ion content. The Food and Agriculture Organization's (FAO) soil database suggests that between 6% and 8% of all land meets the threshold of salinity, > 4 deci-Siemens/m (FAO, 2008) and irrigated fields are especially susceptible to salt accumulation. As salinization of soils grows due to intense cultivation and deposition of salts over time, the need to develop crops with tolerance to salt becomes more pronounced.

Variation in salt tolerance exists among soybean, with genotypes being distinguished by ability, or lack thereof, to exclude $Cl^–$ ions from foliar tissues. The ability to exclude harmful salt from photosynthetic leaves allows tolerant soybean to maintain higher chlorophyll and stomatal conductance under saline conditions (Dr. Korth's Lab, unpublished). Though differences in ion uptake among genotypes are well documented, the key mechanisms employed by tolerant cultivars to cope with salt stress are still largely unknown (Luo et al., 2005; Valencia et al., 2008). Grafting experiments provide a method by which the rootstock and scion tissues can be assessed for their role in response to a variety of growth conditions. We take advantage of this relatively inexpensive method to assess the role of soybean rootstock in the uptake of Na^+ and $Cl^–$ into foliar tissues.

Genetic mapping of segregating populations derived by crossing sensitive and tolerant lines has revealed a major quantitative trait locus (QTL) conferring salt tolerance located on *linkage group N (chromosome 3)* (Valencia et al., 2008). This major QTL, accounting for greater than 50% of observed variance in $Cl^–$ uptake, originated in the S-100 cultivar and is thought to be the main source of tolerance in the southern U.S. soybean germplasm pool (Valencia et al., 2008; Lee et al., 2004). Recently, Guan et al. identified a gene encoding a putative cation/H^+ antiporter conferring salt tolerance, GmSALT3 (capital letters in the gene name designate the functional form of the gene), within the previously reported S-100 QTL region (Guan et al., 2014). Insertion of a 3.78 kb DNA fragment probably disrupts function of the GmSALT3 gene and correlates with salt sensitivity in the lines tested. The sensitive allele with the gene insertion was designated Gmsalt3 (lowercase letters in the gene name designate the non-functional form of the gene). Gene expression of GmSALT3 was localized to the vascular tissues within roots of tolerant lines, making this putative cation transporter a strong candidate as the causal gene of the salinity tolerance associated with the S-100 QTL.

PROCEDURES

Reciprocal grafts were performed between salt-sensitive cv 'Clark' and salt-tolerant cv 'Manokin' soybean seedlings using the "straw-band" technique (Bezdicek et al., 1972). Grafted plants and ungrafted controls of each cultivar were treated for 14 days by daily flooding with 100 mM NaCl or deionized H_2O. Leaf tissue from the first trifoliate of each of three plants of each cultivar from both treatments was collected and dried in a 31 °C incubator for 72 hours to ensure complete desiccation of the leaf tissues. One-hundred milligrams of pulverized dried tissue from each sample was shipped at room temperature to Arkansas State University for chloride analysis by a Haake Buchler Digital Chloridometer (Haake Buchler Instruments, Inc., Saddlebrook, N.J.).

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Ten milligrams of dried tissue from the same samples were pulverized in 500 ul of H_2O and the leaf solution was analyzed for Na content via a hand-held Horiba Na^+ meter.

To assess the GmSALT3 genotype of the soybean cultivars Clark, Manokin, 'Glenn', 'Osage', 'Lee', and 'Williams-82', genomic DNA was isolated from two plants of each line by CTAB extraction (Wilson, 1987). These lines were selected because they are or were commonly grown U.S. varieties and have all been previously categorized as Cl^- includes or excluders. One primer set was designed to amplify DNA within the 5' conserved region of exon 3 of this locus (Fig. 1, orange arrows). A second set of primers was designed to amplify within the retrotransposon insertion reported by Guan et al (Fig. 1, red arrows). Each sample was tested by polymerase chain reaction (PCR) with both primer sets using standard conditions. Amplicons were visualized using GelGreen™ (Biotuim; Hayward, Calif.) on a 2% agarose TAE gel and run at 80 volts until adequate separation of bands was achieved.

RESULTS AND DISCUSSION

Six soybean cultivars, including three salt-sensitive lines (Clark, Glenn, Williams-82) and three salt-tolerant lines (Manokin, Osage, Lee), were genotyped at the GmSALT3 locus. Genomic DNA was tested by PCR for the presence of the conserved region of exon 3 of GmSALT3 and for the presence of the retrotransposon insertion (Guan et al., 2014). Figure 1B shows the results of the PCR in which all lines tested were found to possess the conserved region of exon 3, corresponding to the 322 base pair product. Only salt-sensitive lines gave rise to the 565 base pair product corresponding to the insertion.

Mineral analysis was carried out on dried tissues from three plants of each genotype from both treatments. Both Na^+ and Cl^- content in plants possessing salt-sensitive Clark rootstock were significantly higher under salt treatment compared to H_2O-treated controls of the same cultivar, whereas plants possessing Manokin rootstock showed no significant differences in Na^+ or Cl^- content between treatments (Fig. 2). These results show that salt-tolerant soybean rootstock plays a major positive role in preventing the uptake of Na^+ and Cl^- ions into foliar tissues and as a result confers tolerance to saline conditions. Plants with excluder rootstock were also found to have significantly lower levels of visible leaf scorch (data not shown).

PRACTICAL APPLICATIONS

Results of the grafting experiments demonstrate the critical role that root tissues play in ion exclusion during salt stress in soybean. Future work should focus on root function, where we can assess key differences in physiology of sensitive and tolerant soybean lines. With a better understanding of the mechanisms underlying the salt tolerance response within soybean roots, additional methods of screening for salt tolerance can be developed, allowing for easier selection of these traits by breeders.

Confirmation of the presence of corresponding alleles for salt sensitivity and tolerance in southern U.S. cultivars provide a promising target for the development of molecular markers that are strongly associated with salt tolerance. Furthermore, this locus could serve as a target for change in high-yielding salt-sensitive lines for the development of elite, salt-tolerant lines in fewer breeding cycles.

ACKNOWLEDGEMENTS

We are grateful for generous support from the Arkansas Soybean Promotion Board and the University of Arkansas System Division of Agriculture.

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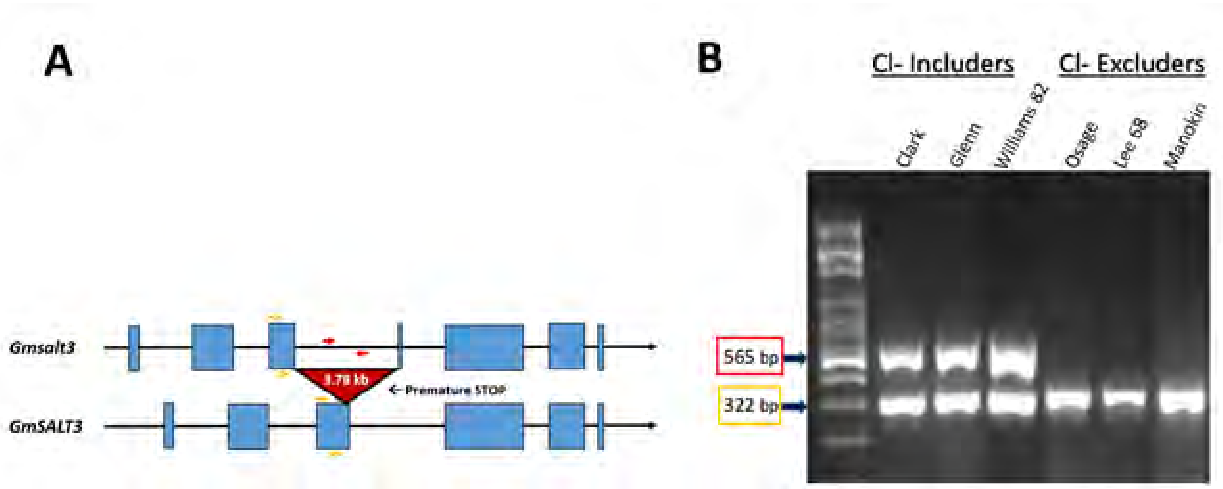

Fig. 1. A retrotransposon insertion in the coding sequence of GmSALT 3 corresponds to chloride inclusion and salt sensitivity in soybean. (A) Schematic of genomic sequence for salt-sensitive allele Gmsalt3 and salt tolerant allele GmSALT3 with location of binding sites for primers used (B) Gel electrophoresis visualization of DNA products from six soybean lines using primer sets 1 and 2.

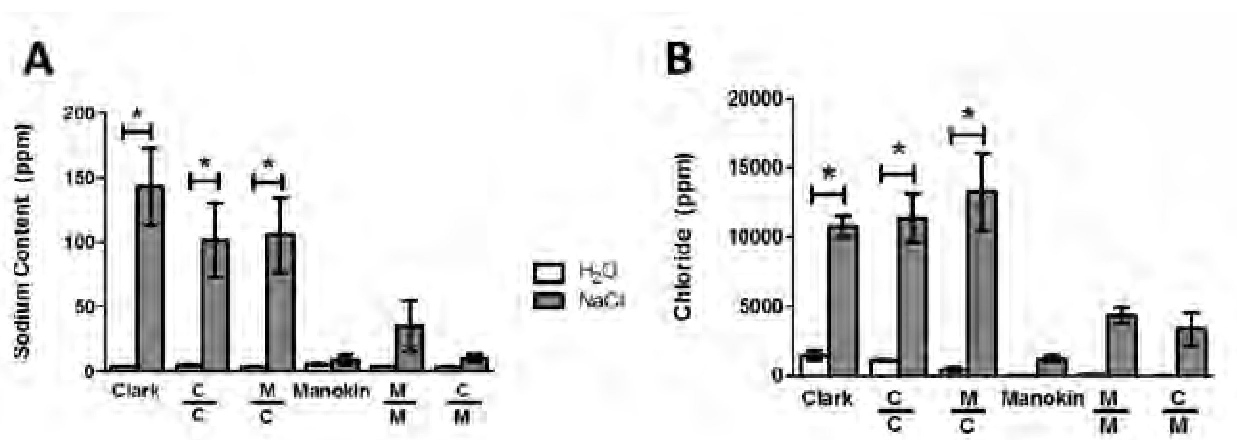

Fig. 2. Salt-tolerant rootstock from the cv. Manokin is associated with Na^+ and Cl^- exclusion under saline conditions. Mineral level were measured in ungrafted Clark (C) or Manokin (M) plants or in grafted plants following treatments as described in Methods section. Lettering on x-axis indicates scion cultivar (top) and rootstock cultivar (bottom). (A) Sodium content of soybean leaves in parts per million. (B) Chloride content of soybean leaves in parts per million. Asterisks indicate significance (*P* < 0.05) according to Student's *t*-test; n = 3.

Liberty Link®, Roundup Ready® Comparison Study

W.J. Ross[1], C.D. Bokker[1], and N. Pearrow[2]

ABSTRACT

A study to compare soybean grain yield of many of the currently available Maturity Group 4 and 5 Liberty Link® soybean varieties to proven high yielding Roundup Ready® soybean varieties has been conducted since 2011. This study was developed to serve as a supplement to the Arkansas Soybean Performance Test, and to identify if there was any "yield-lag" with Liberty Link soybean varieties compared to commonly grown Roundup Ready soybean varieties. Data from this study is similar to the data obtained from previous years, in that many of the currently available Liberty Link soybean varieties yield as well as, if not better than, the Roundup Ready soybean varieties tested.

INTRODUCTION

Because of the increasing number of glyphosate-resistant weeds, alternate herbicide-resistant crops and herbicides with different modes of action are needed to protect crop yield. One such herbicide-resistant crop and herbicide is the Liberty Link® (LL) soybean herbicide system. Liberty Link soybean from Bayer CropScience was first introduced in 2009 and was bred to be resistant to glufosinate herbicide (Liberty®), which is a non-selective, contact, broad-spectrum post-emergence (POST) herbicide for weed control. The LL herbicide system is the most comparable system to the Roundup Ready® (RR) herbicide system, in regard to weed spectrum and is a viable alternative for the control of glyphosate-resistant weeds such as Palmer amaranth.

When LL soybean varieties were introduced in 2009, there were concerns that the LL varieties had a "yield lag" or depressed grain yield when compared to the currently available Roundup Ready soybean varieties. A trial was initially conducted in 2011 to compare the grain yields for commercially available LL and RR soybean varieties. Prior to 2014, LL and RR soybean varieties were evaluated in separate variety tests in the Arkansas Soybean Performance Tests, and yield comparisons of the different technologies were not statistically possible. For this reason, a research trial was initiated to be a supplemental test of the Arkansas Soybean Performance Tests to evaluate the grain yield of these two herbicide-resistant technologies in a side-by-side comparison.

PROCEDURES

Trials were established at the University of Arkansas System Division of Agriculture's Newport Extension Center (NEC), Newport, Ark., and at the Pine Tree Research Station (PTRS), Colt, Ark. in 2015. Soybean varieties were grouped according to maturity group (MG), with separate trials for MG 4 and MG 5 soybean varieties. Management with respect to irrigation, fertility, and late-season pest control closely followed recommendations from the University of Arkansas System Division of Agriculture, Cooperative Extension Service for soybean production. In each trial, soybean were irrigated as needed using over-head or flood irrigation at the NEC and PTRS, respectively.

Prior to planting, seed companies were asked to provide the most current LL soybean varieties available in their portfolio. Glyphosate-resistant soybean varieties were selected based on yield performance in the 2014 Arkansas Soybean Performance Tests (Bond et al., 2014). The MG 4 trial had 29 LL and 5 RR soybean varieties (Table 1), and the MG 5 trial consisted of 24 LL and 4 RR soybean varieties (Table 2). Plots consisted of 4 rows spaced 15 in. apart by 35 ft long. Trials were planted using a Precision Kincaid Vacuum Plot Planter at both NRS and PTRS on 5 June 2016 and 17 June 2016, respectively. Trials at both locations received preplant herbicide applications, and POST herbicide applications of glyphosate or glufosinate according to herbicide technology. At maturity, plots were harvested, and the moisture content and weight of the grain were determined. Grain yield was adjusted to 13% moisture and reported as relative yield of the highest yielding variety within each trial.

Within each test, entries were arranged as a randomized complete block design with four replications. Data was 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 an alpha level of 0.05.

RESULTS AND DISCUSSION

As with any variety trial, there was a wide range of grain yields for the soybean varieties tested. Relative grain yields for all varieties tested ranged from 66.7%-100% and 73.4%-

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100% for the MG 4 trials at NRS and PTRS, respectively (Table 1). The highest yielding soybean variety in the MG 4 test at NEC was Asgrow AG4632. The statistical analysis showed no differences in relative grain yield for three additional RR varieties, Progeny 4900RY, Delta Grow DG4670, and Pioneer P49T97R, and for three LL varieties, Credenz CZ 4818LL, Pioneer P48T67L, and Stine 49LL02. For the MG 4 test at PTRS, the LL variety Credenz HBK 4950LL had the highest relative yield, with only one RR variety and six LL varieties showing no statistical difference in relative yield.

Similar results were observed in the MG 5 tests at NEC and PTRS. At both locations, the RR variety Pioneer P50T40R obtained the highest relative yield (Table 2). The range of relative yield at NEC (75.2%-100%) and PTRS (74.8%-100%) for the MG 5 tests was narrower than that seen in the MG 4 test at both locations. For the NEC MG 5 test, four LL and three RR varieties had relative yield not statically different than Pioneer P50T40R. No difference in relative yield was seen for 17 LL varieties and two RR varieties at the MG 5 test at PTRS when compared to Pioneer P50T40R.

Results from this study indicate that several Liberty Link soybean varieties have yields comparable to Roundup Ready soybean varieties, and no “yield-lag” was seen in the Liberty Link system. Results from this study should be used with other variety testing data to make Liberty Link soybean variety planting decisions. Soybean variety selection should not be based solely on variety performance, but in conjunction with disease and nematode ratings, performance on specific soil texture, irrigation needs, chloride sensitivity, and other herbicide tolerances. Soybean producers are encouraged to seed newly released soybean varieties on a small acreage to evaluate performance under their specific management practices, soils, and environment. Producers are also encouraged to seed their soybean acreage to several varieties to reduce the risk of disease epidemics and environmental effects. Soybean varieties that have been tested under Arkansas growing conditions are more likely to reduce potential risks associated with crop failure.

PRACTICAL APPLICATIONS

Data from this trial will assist soybean producers in selecting Liberty Link soybean varieties that are comparable to high yielding Roundup Ready soybean varieties under similar conditions.

ACKNOWLEDGEMENTS

The authors would like to thank Armor Seed, Bayer CropScience, Delta Grow Seed Company, Crop Production Services, DuPont Pioneer, Monsanto, Progeny Ag Products, Stine Seed, Stratton Seed Company, Terral Seed and the Arkansas Soybean Promotion Board for their funding of this research. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Relative yield of selected Maturity Group IV LibertyLink® and Roundup Ready® soybean varieties tested at the Newport Extension Center (NEC) and the Pine Tree Research Station (PTRS), 2015.

Variety	Maturity Group	Herbicide Technology	NEC	PTRS
			Relative Yield (%)	
Armor 495	4.9	LL	85.3	85.0
Credenz HBK 4950LL	4.9	LL	89.3	100.0†
Credenz CZ 4818LL	4.8	LL	66.7	83.9
Credenz HBK 4953LL	4.9	LL	92.0†	94.0†
Crdeenz CZ 4540LL	4.5	LL	76.0	74.4
Credenz CZ 4748LL	4.7	LL	82.5	90.3
Credenz CZ 4105LL	4.1	LL	68.3	80.1
Credenz HBK 4643LL	4.6	LL	71.7	84.7
Delta Grow DG4990LL	4.9	LL	80.5	83.8
Delta Grow DG4967LL	4.9	LL	78.0	95.5†
Delta Grow DG4767LL	4.7	LL	79.3	78.3
Delta Grow DG4867LL	4.8	LL	89.7	87.4
Delta Grow DG4981LL	4.9	LL	67.0	84.0
Dyna Gro S44LS76	4.4	LL	88.5	98.8†
Dyna Gro S49LL34	4.9	LL	84.0	92.5
Dyna Gro S49LS65	4.9	LL	88.7	92.0
GoSoy 4912LL	4.9	LL	87.3	95.1†
GoSoy 4714LL	4.7	LL	86.3	87.5
Pioneer P48T67L	4.8	LL	92.0†	81.3
Progeny P4819LL	4.8	LL	86.0	84.9
Progeny P4814LL	4.8	LL	76.0	86.0
Progeny P4560LL	4.5	LL	82.0	79.3
Progeny P4930LL	4.9	LL	87.7	89.9
Terral REV 49L29	4.9	LL	86.0	93.7†
SBPS 4781LL	4.7	LL	88.0	90.0
SBPS 4562LL	4.5	LL	80.0	81.2
Stine 46LD02	4.6	LL	71.5	82.4
Stine 49LL02	4.9	LL	93.3†	96.3†
Asgrow AG4632	4.6	RR2Y	100.0†	86.8
Progeny 4900RY	4.9	RR2Y	92.3†	73.4
Delta Grow DG4670	4.6	RR2Y	98.7†	80.1
Terral REV 47R34	4.7	RR	88.3	94.9†
Pioneer P49T97R	4.9	RR	94.3†	85.3
		LSD (0.05)	9.56	7.16

†Relative yields of these varieties are not significantly different from the variety with the highest relative yield.

Table 2. Relative yield of selected Maturity Group V LibertyLink® and Roundup Ready® soybean varieties tested at the Newport Extension Center (NEC) and the Pine Tree Research Station (PTRS), 2015.

Variety	Maturity Group	Herbicide Technology	NEC	PTRS
			Relative Yield (%)	
Armor 53-L55		LL	85.7	93.8†
Armor 501		LL	91.6†	90.0
Credenz CZ 5242LL		LL	90.1†	98.0†
Credenz CZ 5225LL		LL	80.9	91.5†
Credenz CZ 5147LL		LL	80.6	86.3
Credenz CZ 5445LL		LL	84.3	98.7†
Credenz CZ 5150LL		LL	94.3†	96.8†
Delta Grow 5067LL		LL	87.6	99.5†
Delta Grow 5461LL		LL	86.2	81.8
Dyna Gro S52LL66		LL	88.4	98.8†
Dyna Gro S55LS75		LL	72.7	88.5
GoSoy 5213LL		LL	82.1	91.5†
GoSoy 5515LL		LL	75.2	84.5
Pioneer P53T62L		LL	95.1†	99.3†
Progeny P5160LL		LL	86.4	94.0†
Progeny P5414LL		LL	83.0	91.0†
Terral REV 51L25		LL	78.5	91.3†
Terral REV 55L95		LL	77.4	74.8
Stine 50LF32		LL	86.5	93.7†
Stine 50LE20		LL	85.6	90.5†
Stine 54LE23		LL	81.9	96.3†
Stine 54LD00		LL	82.7	94.0†
Stine 50LD02		LL	89.0†	88.0
Stine 51LE20		LL	83.3	96.5†
Pioneer P50T40R		RR	100.0†	100.0†
Syngenta NK S52-Y2		RR2Y	94.4†	85.8
Asgrow AG5335		RR2Y	96.5†	99.5†
Progeny P5333RY		RR2Y	96.0†	95.8†
		LSD (0.05)	11.1	9.7

†Relative yields of these varieties are not significantly different from the variety with the highest relative yield.

Comparison of Organic and Conventional Soybean Production in Arkansas

C.D. Bokker[1] *and W.J. Ross*[1]

ABSTRACT

With the increasing demand for organic soy products and increased premiums of organic soybeans for producers, this study was developed to compare the common soybean systems in the mid-South. Organic soybean production relies heavily on early mechanical weed control, later planting dates, and quick canopy closure to aid in the growth of the plants and to ensure a greater pest free environment. Organic production is not a common practice seen on large scale production farms in the mid-South, where producers rely on pesticide usage for weed, insect and disease control. This study compares glufosinate, glyphosate, conventional and organic production systems. Within this study, comparisons of common fertility and weed control related to each production system will also be noted to give an idea of estimated cost difference between the production systems.

INTRODUCTION

Organic production has become increasingly popular in the last few years as the public demand for organic foods increases (McBride et al., 2015). Very little organic soybean production research has been conducted in the mid-South U.S., where the weed, insect and disease pressures are unlike other row crop areas in the United States. The University of Arkansas System Division of Agriculture initiated research to determine if organic soybean production is cost prohibitive in the state, in comparison to the other soybean production practices currently used by soybean producers. The biggest challenge soybean producers face in the mid-South is weed control. During the 2015 growing season, preliminary research was started comparing weed control methods used in organic production (e.g., mechanical aid and physical labor) to the typical chemical weed control systems used in soybean production.

PROCEDURES

A field experiment was conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark. in 2015. This experiment took place in a production field of soybeans grown under furrow-irrigated conditions. No residual herbicides were applied prior to planting; however, glyphosate was applied as a burn down in early spring prior to choosing the location for this test. The study was planted on 17 June 2015 under normal planting conditions. Five treatments in the study included glufosinate, glyphosate, conventional, organic, and an untreated check. All plots were planted with a seeding rate of 170,000 seeds/acre. Early season weed control was utilized in the organic plots at 9 and 14 days after planting by rotary hoeing through the plots. Standard herbicide applications were made in the glufosinate, glyphosate, and conventional plots.

RESULTS AND DISCUSSION

Weed control is one of the biggest challenges in organic row crop production. At 9 days after planting (DAP), a 20 ft rotary tiller was used across the organic plots for weed suppression. Stand improvements were seen at the 9 DAP timing as the dry, cracking soil was scratched to allow plants to continue to emerge (Table 1). At the 14 DAP timing, an average stand reduction of 35.5% was seen (Fig.1). Stand counts after the final rotary tillage in the organic system were lower in comparison to the conventional, untreated, and glufosinate by 55,000, 25,000 and 2,000 plants/ac, respectively. The organic stand was 10,000 plants/ac greater than the glyphosate treatment.

For the remainder of the season, hand weeding was used to control mainly grass weeds in the organic plots. A total of 17 man hours were spent weeding during July and August. Excellent weed control was observed in the conventional, glyphosate, and glufosinate treatments with standard used rates for each herbicide system.

Soybean grain yields for each treatment are shown in Fig. 2. Lower soybean grain yields were seen in the organic treatment when compared to the three herbicide systems due to the heavy grass pressure. In addition, reduced grain yields in the organic treatments could be a result of reduced plant growth caused by early-season weed pressure. Soybean grain yields of the three herbicide systems could be due to varietal differences.

PRACTICAL APPLICATIONS

Data from this trial will be used to begin development of organic soybean production practices for use in Arkansas. Additional research will be conducted in the following years to increase organic soybean production recommendations.

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ACKNOWLEDGEMENTS

The authors would like to thank the Arkansas Soybean Promotion Board for their funding of this research. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Percent stand change in the organic treatment after rotary tillage 9 days after planting (DAP).

Treatment	% change
Organic 1	6.6
Organic 2	6.5
Average	6.5

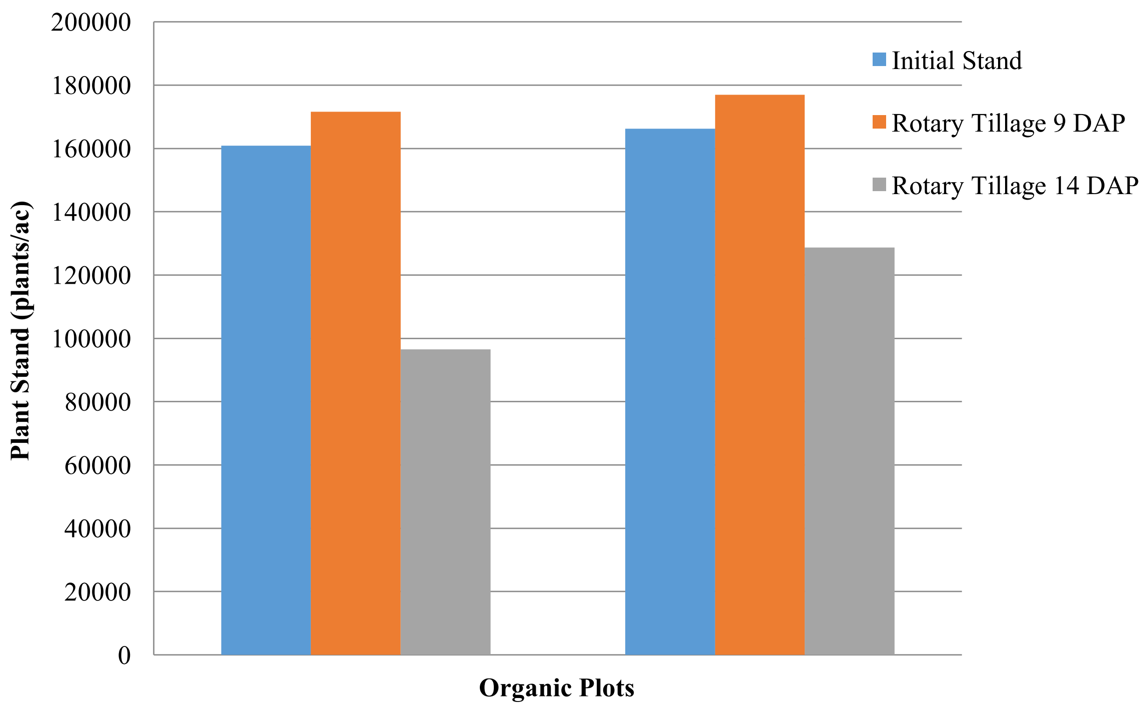

Fig. 1. Initial plant stands and subsequent plant stands after rotary tillage event in organic treatments at Pine Tree Research Station near Colt, Ark.

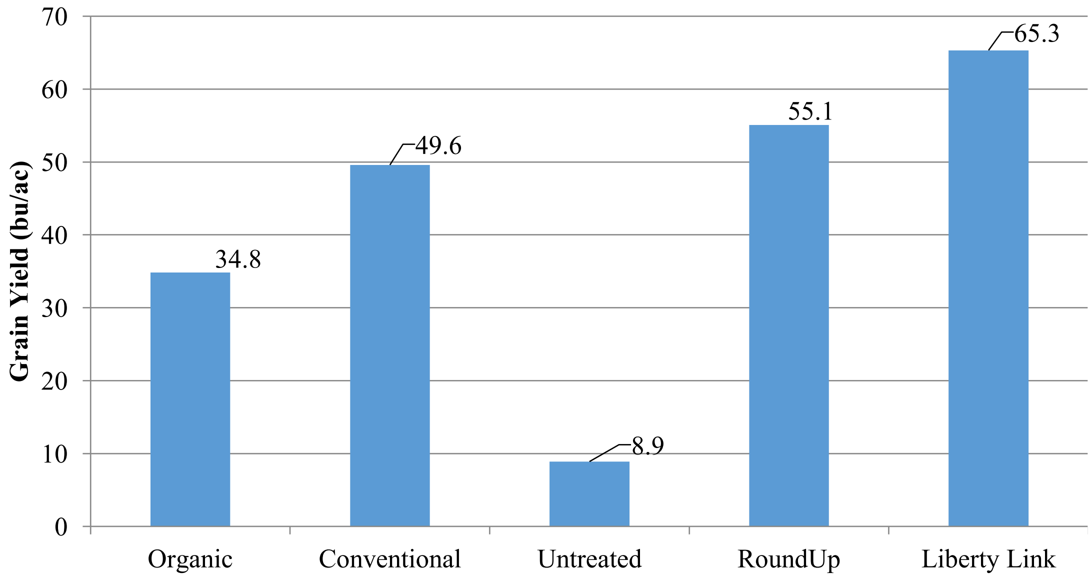

Fig. 2. Soybean grain yield from five different herbicide programs at Pine Tree Research Station near Colt, Ark.

Soybean Seed Treatment by Seeding Rate Study

W.J. Ross[1] *and C.D. Bokker*[1]

ABSTRACT

With the increase in soybean [*Glycine max* (L.) Merr.] seed cost and higher commodity prices, the use of soybean fungicide and insecticide seed treatments have increased over the past several years. However, with production margins becoming narrower, producers are faced with decisions on where to cut production costs. One area were soybean producers are saving some production cost is by reducing soybean seeding rates. In 2015, a study was conducted to compare the soybean grain yield response to three different seed treatments and six different seeding rates. Initial findings indicate that all three seed treatments increased soybean grain yields at the lower seeding rates compared to the untreated check, but as seeding rates increased, no yield differences were seen with the seed treatments compared to the untreated check.

INTRODUCTION

The use of fungicide and insecticide soybean [*Glycine max* (L.) Merr.] seed treatments has increased over the last decade (Esker and Conley, 2012). This increase is due in part to the soybean producers shifting towards earlier plantings. Typically, these earlier plantings are into cooler and wetter soil, which slows seedling emergence and gives the seed greater exposure to early-season root rotting pathogens and soil insects. Seed-applied fungicides and insecticides have given producers a way to manage a broad spectrum of early and mid-season pathogen and insect species (Gore et al., 2014).

In past years, soybean producers have used a wide range of soybean seeding rates for stand establishment. Current recommended soybean seeding rates for Arkansas range from 100,000–185,000 seed/ac depending on planting conditions, soil texture, and planting date (W.J. Ross, unpublished data, 2016). The objective of this study was to determine the impact of insecticide and fungicide seed treatments with variable seeding rates on soybean grain yield.

PROCEDURES

Trials were established at the University of Arkansas System Division of Agriculture's Newport Extension Center (NEC), Newport, Ark., and at the Pine Tree Research Stations (PTRS), near Colt, Ark. in 2015. The soybean variety Pioneer P47T36 was used for each trial which was a 4.7 maturity group Roundup Ready® soybean variety. Management with respect to irrigation, fertility, and late-season pest control closely followed recommendations from the University of Arkansas System Division of Agriculture Cooperative Extension Service for soybean production. In each trial, soybean were irrigated as needed using over-head or flood irrigation at the NEC and PTRS, respectively.

Prior to planting, soybean seed were treated with the individual seed treatments. Seed treatments included an untreated check, ApronMaxx® RTA at 5 fl oz/cwt, CruiserMaxx® at 3 fl oz/cwt, and Nipsit® INSIDE at 1.28 fl oz/cwt. Seeding rates for each seed treatment were 50,000, 75,000, 100,000, 125,000, 150,000, and 200,000 seed/ac. Plots consisted of 4 rows spaced 15 in. by 35 ft long. Trials were planted using a Precision Kincaid Vacuum Plot Planter at both the NEC and PTRS on 6 May 2015, and 7 May 2015, respectively. At maturity, plots were harvested, and the moisture content and weight of the grain were determined. Grain yield was adjusted to 13% moisture and reported as bu/ac for each trial.

Within each test, treatments were arranged as a randomized complete block design with four replications. Data was 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 an alpha level of 0.05.

RESULTS AND DISCUSSION

Soybean yield varied across locations, therefore statistical analysis were conducted by location. At the NEC location, soybean grain yield tended to reach maximum yield for the untreated check (UTC), ApronMaxx, and Nipsit INSIDE treatments at 125,000 seed/ac (Fig. 1). Soybean grain yields were significantly higher than the UTC treatment at the 50,000 seeding rate for all three seed treatments, and for the 75,000 seeding rate both the ApronMaxx and CruiserMaxx treatments. For all three seed treatments, the 100,000 seeding rates treatment yielded lower than the UTC. This could be explained by the variability between replications within this study. Very little yield differences were seen at the seeding rates above the 125,000 seed/ac treatment for the UTC, ApronMaxx and CrusierMaxx seed treatments. Grain yields for the Nipsit INSIDE seed treatment at seeding rates at or above the 75,000 seed/ac treatment were not significantly different or lower than the UTC.

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Results from the PTRS location were somewhat different compared to the NEC results. The trend in soybean grain yields continued to increase as soybean seeding rates increased for all three seed treatments and the UTC (Fig. 2). The only treatments yielding greater than the UTC were the CrusierMaxx seed treatment at 125,000 and 150,000 seed/ac, and the Nipsit INSIDE seed treatment at 100,000 seed/ac.

Results from this study indicate a possible yield advantage for seed treatments at lower seeding rates compared to untreated seed. Differences in results between locations could be due to environmental conditions, insect pressure, or other factors. Additional data will be needed before definitive conclusions can be obtained from this study.

PRACTICAL APPLICATIONS

With the current volatility in the commodities market and the increase in production cost, soybean producers are looking for any means to cut production cost. Many are reducing inputs such as fertility and seeding rates. With this and future data, soybean production recommendations for seeding rates and the use of insecticide and fungicide seed treatments can be developed.

ACKNOWLEDGEMENTS

The authors would like to thank the Arkansas Soybean Promotion Board for their funding of this research. Support was also provided by the University of Arkansas System Division of Agriculture.

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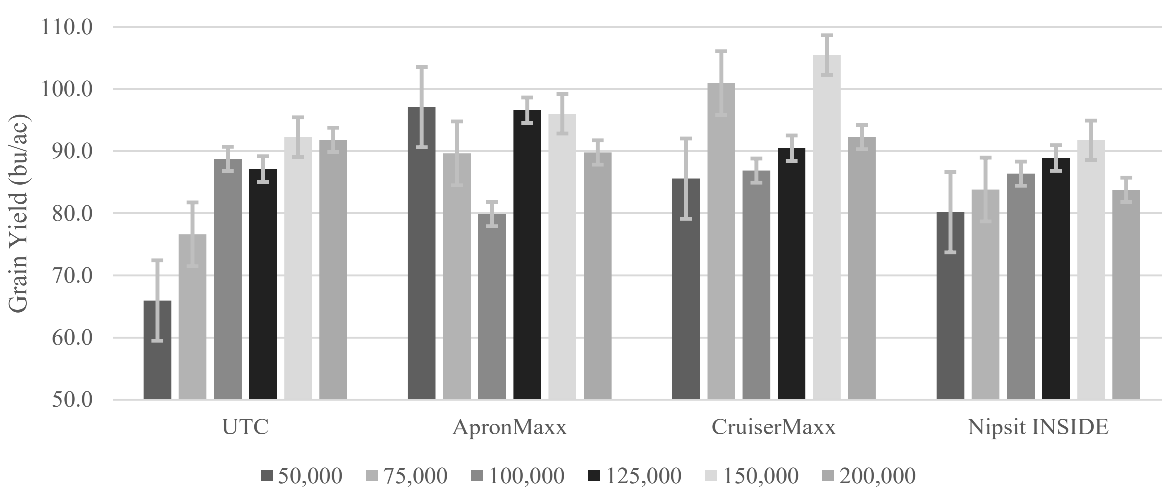

Fig. 1. Effect of seed treatment and seeding rate on soybean grain yield at the Newport Extension Center (NEC) location. Where error bars overlap, mean grain yield is not significantly different ($\alpha = 0.05$).

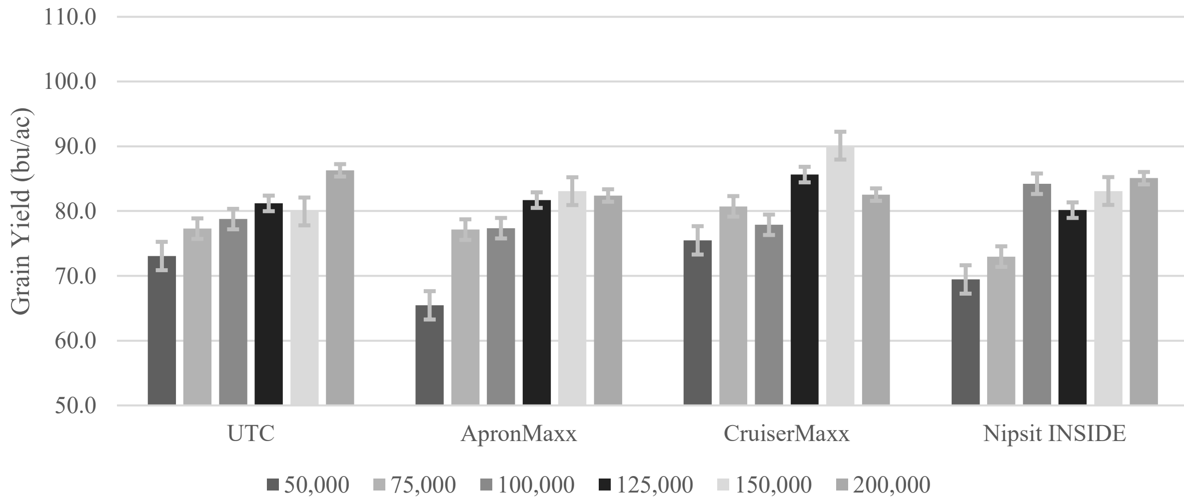

Fig. 2. Effects of seed treatment and seeding rate on soybean grain yield at the Pine Tree Research Station (PTRS) location. Where error bars overlap, mean grain yield is not significantly different (α = 0.05).

BREEDING

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. Conventional cultivars developed in this soybean breeding program are well adapted to be grown in Arkansas and other southern states. We design new cross combinations every year to develop new and improved soybean cultivars; the main focus being high yield, good disease package, and wide adaptability. New cross combinations and breeding populations are advanced in Fayetteville and 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 2015, four lines were released as cultivars: one conventional (UA 5115C), one Roundup Ready (UA 5715GT), one large-seeded roasted soybean type with black seeds (UA Mulberry), and one high sucrose/low stachyose (UA 5515HS) lines.

INTRODUCTION

High yield, pest resistance, stress tolerance, and good adaptation are the main traits we aim to combine in developing new soybean lines. Using high-yielding new lines with disease package and 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) in addition to salt tolerance. 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, UA 5213C, and UA 5014C have been used in commercial production and cultivar development in other breeding programs. Osage and UA 5612 have been used as yield checks in the USDA uniform tests.

PROCEDURES

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

Annually, 200-250 different crosses are made for several projects using high yielding lines developed from the University of Arkansas System Division of Agriculture breeding program and 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 subsequently evaluated in advanced replicated trials in 3-5 Arkansas locations. The best lines are selected and evaluated in the USDA Southern Uniform Test and the Arkansas Soybean Variety Performance Test. Promising lines are increased for foundation seed in preparation for cultivar release. All advanced lines are tested for

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disease 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. Sudden death syndrome, 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 new successful release of UA 5014C (Chen et al., 2016), new high yielding conventional line UA 5615C was released with a non-exclusive license to private industry. It is a high yielding MG 5 variety with determinate growth habit and gray pubescence color. In 2013 (16 locations) and 2014 (17 locations), USDA Uniform MG 5 tests, UA 5615C ranked 2nd and 1st, respectively, out-yielding private and public check cultivars. Following the first Roundup Ready cultivar, UA 5414RR, we released new Roundup Ready MG 5 cultivar, UA 5715GT, with determinate growth habit and gray pubescence color. Additionally, we released high sucrose and low stachyose/phytate variety, UA 5515HS, with gray pubescence color and determinate growth habit. Foundation seed were produced for previously and newly released cultivars. In 2015, foundation seed were produced for Osage (1070 units), UA 5612 (1101 units), UA 5213C (1037 units), UA 5014C (1032 units), and UA 5615C (47 units). In addition, 3950 and 905 units were produced for Roundup Ready cultivars UA 5414RR and UA 5715GT. Moreover, foundation seed were produced for large-seeded (R08-4004; 629 units and UA Kirksey; 42 units), high protein (UA 5815HP; 222 units), and high sucrose/low stachyose (UA 5515HS; 461 units) lines in 2015. Small scale pre-foundation and breeder seed for other promising high-yielding lines were also produced in Stuttgart, Ark. for future release.

Another high-yielding conventional variety in the process of release is R10-430 that is proposed to be released as UA 5115C. It has determinate growth habit and gray pubescence color with relative maturity of 5.1. R10-430 has been tested in 2012 (18 locations) and 2013 (15 locations) USDA Uniform Trials for MG 5 and both years it is ranked 1st with high yield compared to commercial and public check cultivars. 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 2015 USDA Uniform test MG 4, 5, or 6 and those lines yielded 93% to 106% of the check mean yield. In MG 4-S (southern states) test, R12-226 yielded 101% check mean (Ellis, AG 4632RR2Y, AG 4835, AG4933RR2, and AG 3934RR2; 60.4 bu/ac). In the MG V test, two lines, R12-2142 and R11-262, yielded 104% and 102% of the check mean (Osage, Ellis, JTN-5203, UA 5612, AG 5332RR2Y, AG5534RR2, and AG5335; 56.7 bu/ac), respectively. In MG 6 test, two lines, R11-171 and R11-2517, yielded 106% and 102% of the check mean (AG 6534, NCC07-8138, NC-ROY, and NCC06-1090; 57.5 bu/ac), respectively.

A total of 18 lines were evaluated in the 2015 USDA Uniform Preliminary Test MG 4-S, 5, or 6. Those 18 lines yielded 88% to110% of the check yield (63.7, 58.3, and 50.1 bu/ac for MG 4-S, 5, and 6, respectively). In MG 5, R10-1261 yielded 99% of the check mean (Osage, Ellis, JTN-5203, UA 5612, AG 5332RR2Y, AG 5534RR2, AG 5335; 58.3 bu/ac) and three lines in MG 6 test, R12-514, R11-2559, and R12-1012, yielded 110%, 105%, and 104% of the check mean (AG 6534, NCC07-8138, NC-ROY, NCC06-1090; 50.1 bu/ac), respectively. These promising lines with high yield will be evaluated in the 2016 USDA Uniform Test.

In addition, 11 advanced high-yielding lines were evaluated in 2015 Arkansas Soybean Variety Tests and 16 specialty lines (4 high oil, 6 high protein, 3 modified fatty acid, and 3 high sucrose and low stachyose/phytate) were evaluated in the 2015 Southern Regional Quality Traits Test for potential release in the future.

Also evaluated in 2015 were 265 advanced and 690 preliminary conventional lines, 60 advanced and 285 preliminary RR lines, 75 advanced and 540 preliminary Roundup Ready 2 Yield lines, 85 advanced and 120 preliminary genetic diversity lines, 60 advanced and 105 preliminary drought tolerant lines, 30 advanced and 180 preliminary disease resistant lines (Table 1). In addition, specialty lines were tested in 2015: 35 advanced and 120 preliminary high protein, 25 advanced and 135 preliminary high oil, 145 advanced and 660 preliminary modified fatty acid (high oleic and/or low linolenic, low sat), 30 advanced and 255 preliminary high sugar/low phytate (Table 2). A total of 1885 plant populations were also advanced for breeding purposes. In addition, 9773 progeny rows were evaluated in 2015 and 1698 of which were selected for 2016 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 soybean industry. The University of Arkansas System Division of Agriculture Soybean Breeding and Genetics program provides high-yielding cultivars with low seed cost to growers and seeds for the conventional and RR cultivars 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, UA 5615C, UA 5414RR, and UA 5715GT 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.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support of the Arkansas Soybean Promotion Board. We also thank the University of Arkansas Experiment Station personnel for the help and support with our field work. We also thank Arkansas Variety Testing Program for testing our lines prior to release. Support was provided by the University of Arkansas System Division of Agriculture.

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Table 1. Overview of University of Arkansas System Division of Agriculture's Soybean Soybean Breeding and Genetics Program tests in 2015.

Test	No. of entries
Released varieties	5
USDA Uniform/Preliminary Tests	33
AR Variety Testing Program	11
Arkansas advanced lines	400
Arkansas preliminary lines	1,515
Progeny rows	9,773
Breeding populations (F_1 – F_4)	1,885
New crosses	404

Table 2. Overview of food-grade and specialty trait tests of the University of Arkansas System Division of Agriculture's Soybean Breeding and Genetics program in 2015.

Specialty type	No. of advanced lines	No. of preliminary lines
Tofu/milk	75	240
Edamame	60	120
Natto	150	150
High Protein	35	120
High Oil	25	135
High Oleic/low linolenic/low saturated fatty acid	145	660
Sugar	30	255
Flood	45	45
Drought	60	105
Diversity	85	120

Soybean Germplasm Enhancement Using Genetic Diversity

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ABSTRACT

The University of Arkansas System Division of Agriculture Soybean Breeding Program constantly introduces new germplasm to develop and release varieties and lines with special traits, high yield and wide adaptation to Arkansas and other southern states. The varieties generated can be used by Arkansas farmers to produce value-added soybean crop. In the seed composition project, a non-exclusive license was granted to a local company for the use of the high protein variety 'UA 5814HP'. In 2016, 5000 acres of UA 5814HP are being commercially grown. Another high protein line, R11-7999, with 44% protein, 20% oil, and grain yield 104% of the check yield across 23 environments over 3 years, is under preparation for its release. In addition, 'UA 5515HS' with unique seed composition (8.1% sucrose, 0.4% stachyose, and low phytate as indicated by the value of 1406 μg/g inorganic phosphorus, and grain yield 85% of the check yield) was released targeting animal feed market. In response to the demand on developing non-trans fat soybean lines to meet edible vegetable oil market criteria, three high oleic and low linolenic lines have been developed: UARK-282, UARK-292, and UARK-602 with grain yields 91-97% of the check yield, 84.3-86.4% oleic, and 2.8-3.4% linolenic. In addition, two high-yielding diversity and two drought tolerant lines are in the process of release. Moreover, we released 'UA Mulberry' with a black-seed coat for the roasted soynut and edamame market. We are also working on breeding for pest and disease resistance using sources with disease and pest resistance and those lines are being evaluated for yield.

INTRODUCTION

The introduction of new germplasm is vital for a breeding program to survive in the long term. A breeding program is destined to fail if there is no interchange of germplasm with other domestic and foreign breeding programs. It is well documented that narrow genetic base was used in soybean breeding for cultivar development and only 26 ancestors accounted for 90% of the total ancestry of cultivars used from 1947 to 1988 (Gizlice et al., 1994). Fortunately, soybean breeders in the U.S. have created a very active germplasm exchange system. Even with the current restrictions for the trade of germplasm such as patents and other legal limits, it is important to keep access to the germplasm available to public.

The University of Arkansas System Division of Agriculture's Soybean Breeding Program maintains an active exchange of germplasm with other U.S. and foreign breeding programs to keep the genetic diversity of its parental stock in order to guarantee the success in the long term for the breeding of different traits. This report highlights the main breeding progress in the use of germplasm for traits of interest such as drought, modified seed composition, seed quality traits, pest and disease resistance, stress tolerance, and yield improvement.

PROCEDURES

Every year a new breeding cycle is started for the traits of interest. This includes making approximately 100-120 new cross combinations, advancing of breeding populations from F_2 to F_4 generations using the modified single-pod descent method (Fehr, 1987) consisting of picking two or three pods from approximately 1200 plants in each generation. In F_4 generation, individual plants are selected and 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, or stress tolerance).

RESULTS AND DISCUSSION

Genetic Diversity for Yield Improvement. When high yield is the breeding target, it is important to introduce new parents with diverse pedigree that can introduce novel "yield genes" into the existing gene pool, but these new parents must have high-yielding potential to enhance the probability to generate higher yielding recombinants from a given cross. Thus, it is important to generate first high-yielding

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lines with "exotic" germplasm in the pedigree before using them in an applied breeding program. The Soybean Breeding and Genetics Program is in the process of releasing two high-yielding diversity lines with 25% exotic germplasm in the pedigree (R10-5086 with 25% PI 290126 B in the pedigree and R11-6870 with 25% PI 594208 in the pedigree) and these lines have grain yield 99% and 96% of the high yielding check Osage (65.6 bu/ac) (Table 1). These two new pipeline products have a relative maturity of 5.6 and will be available to public and private breeders to use in the breeding programs for yield enhancement. The use of R10-5086 and R11-6870 in public and private breeding programs will potentially introduce new "yield" genes into the gene pool and will help to maintain the genetic gain for yield in the long term. For the same purpose, we have developed breeding populations containing exotic germplasm from various sources provided by breeders from different states (Missouri, Tennessee, North Carolina, Virginia, and Illinois) for yield enhancement purposes.

Pest Resistance. In 2015, new lines have been advanced and evaluated for pest and disease tolerance. New germplasm have been used in the Soybean Breeding Program with resistance to soybean cyst nematode (SCN), sudden death syndrome (SDS), phomopsis seed decay (PSD), frogeye leaf spot (FLS), asian soybean rust (ASR), stink bugs (SB), and salt stress. In 2015, 25 advanced and 176 preliminary lines derived from parents with SDS, SCN, ASR, FLS, PSD, and SB-resistance were evaluated for yield. Among those advanced and preliminary lines tested, ten lines with SDS-resistant parents in the pedigree, one with SCN and one with SB-resistance parents showed high yield (92% to 103% grain yields of the check yield; AG4632, AG4934, AG5335, AG5533 and P4930LL, with mean yield of 57.4 bu/ac). High-yielding lines from this study will be tested for pest and disease resistance. Additionally, 31 new lines for SCN, 50 for SDS, 45 for PSD, 12 for soybean rust, nine for FLS, and eight for salt tolerance were selected from progeny rows and they will be evaluated in the 2016 preliminary disease tests.

Seed Quality Traits. We have successfully used germplasm to develop value-added varieties with special seed composition traits. In 2014, we released the high protein variety 'UA 5814HP' derived from the cross of two high protein lines: R95-1705 from Arkansas and S00-9980-22 from Missouri. Another high protein line, R11-7999, with 44% protein, 20% oil, and 104% grain yield of the check yield across 23 environments over 3 years is in the process of release.

In addition, 'UA 5515HS' with unique seed composition (8.1% sucrose, 0.4% stachyose, and low phytate as indicated by the value of 1406 μg/g inorganic phosphorus, and 85% grain yield of the check yield) was released in early 2016. UA 5515HS is a MG 5 variety and is intended for human and livestock dietary purposes with a potential production premium. UA 5515HS is currently being used for animal feeding trials.

Moreover, using a backcrossing breeding method and applying a marker assisted selection procedure, high oleic fatty acid from the original sources (PI 603452 and PI 283327) and low linolenic fatty acid from two Iowa lines (IA 2065 and IA 3017) were combined in adapted high-yielding backgrounds such as Osage, UA 5612, and three promising high oleic lines were developed: UARK-282, UARK-292, and UARK-602 with 91% to 97% grain yields of the check yield, 84.3% to 86.4% oleic, and 2.8% to 3.4% linolenic fatty acid. In preparation for future release, we are re-evaluating their yield potential and increasing breeder seed of these three lines. Using the same backcrossing procedure, high oleic and low linolenic fatty acid traits are being incorporated in adapted Arkansas cultivars/lines such as R09-430, UA 5615C, and UA 5715GT.

Food-Grade Soybean. In early 2016, roasted soynut and edamame type soybean variety, 'UA Mulberry', was released. UA Mulberry was derived from the cross of two large-seeded lines, R01-3597F from Arkansas and V96-7198 from Virginia. UA Mulberry is a conventional, MG 5.8 vegetable soybean variety with large seed size and black seed coat, which is suitable for soynut production when mature, and for edamame production when green.

Drought Tolerance. The two best drought tolerant lines, R10-2436 (R01-52F × R02-6268F) and R10-2710 (R01-52F × N97-9658), are in the process of being released as germplasm. Both lines, R10-2436 and R10-2710, are high-yielding under irrigation with grain yields 74.7 and 71.4 bu/ac, respectively (Table 2), compared to MG 4 (AG 4907, AG4933; 70.8 bu/ac on average) and MG 5 (5002T, AG5332, AG 5606, AG5534; 73.6 bu/ac on average) checks. R10-2436 and R10-2710 exhibited 26% and 28% yield reduction, respectively, under drought compared to 45% and 44% average yield reduction in MG 4 and MG 5 commercial checks.

PRACTICAL APPLICATIONS

The University of Arkansas System Division of Agriculture Soybean Breeding Program has been successful using the available germplasm in the development of high-yielding soybean varieties with better adaptation to stress conditions and improved seed-quality traits such as high protein, high oil, high oleic, low linolenic, and high sugar for specialty markets. These lines will be released as new varieties for use by the Arkansas farmers to produce value-added soybean crop. These new lines will also be used in our and other breeding programs in the U.S.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support of the Arkansas Soybean Promotion Board. We also thank the University of Arkansas Experiment Station personnel for the help and support. Support also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Grain yield (bu/ac) of two advanced diversity lines with 25% of exotic germplasm in the pedigree, evaluated in the USB-Diversity MG5 Test in several southern locations in the U.S.

Name	Pedigree	2013	2014	2015	LSMean[a]	% CK Mean
R10-5086 [b]	Osage × R99-1613F	65.4	63.7	65.7	64.9	102
R11-6870 [c]	5002T × R01-3474F	.	64.0	62.3	63.0	99
Osage		63.2	65.8	67.8	65.6	
5002/Ellis		59.3	65.4	65.7	63.5	
95Y70		65.3	63.8	.	64.7	
AG5332		.	62.5	64.3	63.2	
AG 5606/AG5534		63.3	62.5	63.1	63.0	
5601T		60.1	62.4	.	61.4	
Check Mean (LSMean) [c]		62.3	63.7	65.1	63.6	
N. Locs		5	6	4		

[a] Adjusted mean, according to the Least Square Means (LSMeans) option of SAS.
[b] Contains 25% of PI 290126B from R99-1613F.
[c] Contains 25% of PI 594208 from R01-3474F.

Table 2. Grain yield (bu/ac) of advanced drought lines under irrigation and dryland conditions in Stuttgart, Ark. across two years.

Name	Pedigree	Yield-Irrigated	Yield-Dry	%Yield Reduction
R10-2436	R01-52F × R02-6268F	74.7	55.5	26
R10-2710	R01-52F × N97-9658	73.8	53.4	28
Checks (MG4) [a]		72.4	39.9	45
Checks (MG5) [b]		75.4	42.6	44

[a]MG4 Checks: average of AG 4907, AG4933, and P4930LL.
[b] MG5 Checks: Average of 5002T, AG 5606, AG5332, and AG 5534.

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

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ABSTRACT

It is the focus of the University of Arkansas System Division of Agriculture's Soybean Breeding and Genetics program to develop high-yielding varieties and provide pure breeder seed for commercialization. The goal of the program is to provide to southern soybean producers products with improved yield, quality, drought, flooding and disease resistance, as well as salt tolerance. Lines with desired traits are selected, advanced, and maintained for purity for future release to seed dealers and farmers. This report summarizes the effort during the 2015 growing season.

INTRODUCTION

In response to increasing requests from soybean farmers 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 duteous in the effort of releasing high-yielding, conventional cultivars. Increased demand for conventional varieties has solidified the need for public breeding programs since private companies have focused primarily on genetically modified (GM) varieties. Since the patent for the original Roundup Ready technology expired in 2015, we have ramped up our work on developing glyphosate-tolerant varieties. Glyphosate-tolerant varieties provide a lower seed cost alternative to farmers, who can then save the seed for planting the following year. We also incorporate specialty traits in our breeding program by developing high-yielding varieties with added high protein, high oil, high sugar, or modified fatty acids. These proprietary traits provide the farmers an opportunity for a supplemental profit on their crop.

PROCEDURES

Breeder seed and plant row purifications are grown out and we take meticulous care in rogueing for off-types or mixtures. Fourteen varieties were in foundation and pre-foundation production in 2015: 50 ac of UA 5612, 50 ac of UA 5014C, 25 ac of R09-430, 25 ac each of R07-2000 and R07-2001, and 20 ac of R07-6614RR were grown at the Pine Tree Research Station near Colt, Ark. In addition, 90 ac of UA 5414RR, 30 ac of Osage, 19 ac of UA 5213C, one acre each of R10-230 and R10-28, three ac of UA Kirksey and 10 ac each of R07-6614RR and UA 5814HP were grown in Stuttgart, Ark. at the Rice Research and Extension Center (Table 1).

In 2015, 300 single plants of Osage, UA 5213C, UA 5414RR, R07-2001 and UA Kirksey were pulled, threshed 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 2016 growing season.

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 its trait such as protein, oil, sugar, or fatty acid content. They were also submitted for disease testing: root-knot nematode, reniform nematode, soybean cyst nematode, stem canker, sudden death syndrome, and frogeye leaf spot, as well as for salt tolerance. Additionally, all these lines were tested for their sensitivity to metribuzin. All of these lines have been evaluated in soybean variety testing programs in multiple states and in USDA trials.

RESULTS AND DISCUSSION

In 2015, the Arkansas Soybean Foundation Seed program received orders of 5061 units of conventional soybean in total: 1061 units of Osage, 1081 units of UA 5612, 739 units of UA 5213C, and 974 units of UA 5014C. These cultivars have competitive yield with MG late 4 and early to mid-MG 5 commercial cultivars available in the south. In addition, we produced 587 units of UA 5814HP and 619 units of R08-4004 per agreements with non-exclusive licensing for private industry.

The original Roundup Ready patent expired in 2015 and farmers can now save seeds of Roundup Ready soybean varieties for planting. In 2014, we released our first glyphosate-tolerant variety, UA 5414RR. This variety is MG

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5.4 with determinate growth habit. A total of 90 ac of UA 5414RR were grown in Stuttgart, Ark. and 2425 units were made available to farmers to purchase in 2015. It was rogued for off-types at blooming and at harvest and two acres were purified to be used as foundation seed for 2016 production.

In addition, we have five conventional varieties and one glyphosate-tolerant variety that were considered for release in 2015. UA Mulberry and R07-10397 lines show great promise in the soy-nut and edamame markets. R07-2000 is a high-sucrose, low-stachyose, and low-phytate variety. Its intended use is for the soymeal market as a dietary supplement for human and livestock consumption, it will also have a potential production premium. R09-430 is a high-yielding maturity group 5.1 variety. R09-430 has been tested in state variety testing programs in Kansas, Arkansas, Missouri, Tennessee and Mississippi and also in USDA trials. It has performed very well in all regional tests and has ranked in the top of the USDA test for several years. It has 42.3% protein and 22.5% oil on a dry-weight basis. It is a high-yielding cultivar with great promise to Arkansas farmers. UA 5615C, is a high-yielding MG 5 that will be licensed as a non-exclusive license to private industry. UA 5715GT, is a glyphosate-tolerant, late MG 5 variety. It is being released because it is a high-yielding variety and well adapted to Arkansas and other soybean production areas in southern U.S. UA 5715GT has an advantage of 2.0 bu/ac over our previous RR variety, UA 5414RR, released in 2014.

In 2015, we licensed R09-3789 as UA 5814HP, which is a high protein conventional variety. UA 5814HP was released because of its high seed protein content (45.7%) with little or no yield drag. UA 5814HP has a yield potential similar to the conventional and Roundup Ready check cultivars. The high yield and high protein will make UA 5814HP a valuable variety for the animal feed market.

PRACTICAL APPLICATIONS

Production of breeder and foundation seed of different varieties (conventional, glyphosate-tolerant, and modified-seed composition) developed in the University of Arkansas System Division of Agriculture Soybean Breeding and Genetics program provides high seed quality (purity and % germination) to local soybean producers, enhancing the competitiveness of Arkansas soybean in both the national and international markets.

ACKNOWLEDGEMENTS

The authors would like to gratefully acknowledge the cooperation and support of the Arkansas soybean producers and the support of the Arkansas Soybean Promotion Board for their interest and funding. We would also like to thank the staff at Foundation Seed in Stuttgart, Ark. and the Pine Tree Research Station in Colt, Ark.: Chuck Wilson, Debra Ahrent-Wisdom, Ronnie Sherman, Shawn Clark, and Jody Hedge and the staff at the Arkansas Crop Variety Improvement Program: Don Dombek, Rheta Howard, and John Carlin for their role in licensing our products. We also want to give many thanks and kudos our students, post-docs, visiting scholars, downstate technicians, and hourlies for all their hard work in purification of our varieties. Support was also provided by the University of Arkansas System Division of Agriculture.

Table 1. 2015 Foundation, pre-foundation seed production overview.

Name	Previous Name Prior to Release in 2015	Type	2015 Planted (ac)	Plant Row Purification	Certified 2014	2015 Seed Orders (units)	2015 Available (units)	2015 Breeder Seed (units)
Osage		Conv.	30	2015	yes	560	1070	50
UA 5612		Conv.	50	2015	yes	710	1101	50
UA 5213C		Conv.	19	2015	yes	530	1037	60
UA 5014C		Conv.	50	2015	yes	0	1032	50
UA 5414RR		RR1	90	2015	yes	3145	2425	50
UA 5715GT	R09-6114RR	RR1	30	2014	yes	0	0	50
2015 Pre Foundation Seed Production								
UA 5515HS	R07-2000	High Sugar	25	2015	yes	pending licensing	Estimated 400	0
R07-2001		High Sugar	25	2014	yes			0
UA 5615C	R10-230	Conv.	1	2014	yes	pending licensing	Estimated 50	0
R10-28		Conv.	1	2014	yes	pending licensing	Estimated 50	0
R09-430		Conv.	25	2014	yes	pending licensing	Estimated 600	50
2015 License Agreement Seed Production								
UA 5814HP	R09-3789	High Protein	10	2015	yes	500	587	50
R08-4004		Tofu/Soymilk	10	2014	yes	600	619	0

Conv. = Conventional.

Development of Flood-Tolerant Soybean Varieties and Breeding Lines

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ABSTRACT

Flooding is a common environmental stress that affects plant growth reducing seed yield. Flood stress can occur at any point during the crop growing season and the extent of the damage depends on the plant's growth stage. The University of Arkansas System Division of Agriculture's Soybean Breeding Program is committed 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, identification of flood Quantitative Trait Loci (QTLs) for marker-assisted selection (MAS), advancement of flood-tolerant genetic populations, and study of physiological effects of flooding on soybean. This report highlights the flood-tolerant soybean breeding effort made at the Soybean Breeding Program in 2015.

INTRODUCTION

Flooding is the second most important abiotic stress after drought, affecting 16% of worldwide production (Boyer, 1982). It is caused by prolonged periods of rain, excessive irrigation, rainfall after irrigation, and impermeable soils. Soybean grown under flooding conditions experience rhizosphere hypoxia (oxygen levels below optimal) and anoxia (complete lack of oxygen), both of which prevent optimum growth. Flood reduces plant canopy height, dry matter accumulation, and seed yield. 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 50% to 56% during the reproductive stage (Oosterhuis et al., 1990). Daily yield reductions have been calculated at 1.6% at V4 and 3.6% at R2 stage (Scott et al., 1989). Plants flooded at the R5 stage showed a yield reduction of 20% to 39% in contrast to non-flooded checks (Rhine et al., 2010). Similarly, Sullivan et al. (2001) reported a 20% yield loss when soybean plots were flooded for three days at V2 and V3 growth stages. 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 flood without significantly reducing yield. Screening and identification of sources of flood tolerance have become ongoing goals of the University of Arkansas System Division of Agriculture's Soybean Breeding Program.

PROCEDURES

The yield potential of 39 advanced soybean lines was evaluated in two advanced tests (15FLF-1 and 15FLF-2) in three Arkansas locations: University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark.; Lonn Mann Cotton Research Station, Marianna, Ark.; and Rohwer Research Station, near Rohwer, Ark. with each variety replicated three times without flooding. Flood tolerance tests of these 39 lines were conducted at the Rice Research and Extension Center in Stuttgart, Ark. with each line replicated two or three times within each flood test. In addition, 37 lines with flood-tolerant pedigrees (RA-452 × Osage, RA-452 × R01-581F, RA 452 × 91210-350, 5002T × 91210-350, 5002T × N97-9658, N97-9658 × 91210-350, PI 471931 × PI 471938, R04-342 × 91210-350, Caviness × R08-2496, and R08-2416 × Jake) were evaluated in a preliminary flood test (15FLP) without flooding in two Arkansas locations (Stuttgart, Ark. and Marianna, Ark.) with one replication of each line. In a separate study, a total of 120 new lines derived from flood-tolerant pedigrees (Narow × Jake, R07-6669 × Jake, Caviness × R08-2496, R07-6669 × R09-2988, R07-6669 × R10-412 RY, R08-107 × Jake, R08-2416 × Jake, R08-1178 × Jake, R08-47 × Jake, R08-527 × Jake, R09-2567 × Jake, R09-430 × Jake, R06-1270 × Jake, PI 471931 × R08-2416, PI 471931 × R02-1325, and 5601T × Walters) 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 University of Arkansas System Division of Agriculture Soybean Breeding Program, other U.S. soybean breeding programs, and the USDA World Soybean Collection to combine flood tolerance, yield, and special seed quality traits.

Additional sets of screening tests with 3 replications each were conducted in the field at Stuttgart, Ark. with the purpose of identifying sources of flood tolerance for future crossing. Entries included 33 high-yielding conventional and glyphosate-tolerant lines and 56 drought-tolerant lines

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from the Soybean Breeding Program, and 208 commercial varieties from Arkansas Variety Testing Program. For all tests, 100 seeds of each variety/line were planted in a 10-ft row in June, 2015; once plants reached R1 growth stage (first flower at any node), flooding 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 our program, FDS is used to evaluate flood tolerance. This score is based on a 0 to 9 scale, 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 = 4.0 to 5.9, sensitive if average FDS = 6.0 to 7.9, and highly sensitive if average FDS ≥ 8.0.

In order to identify an effective flood-tolerance screening method, a separate set of tests were conducted for a second year in 2015. Forty varieties/lines from the Soybean Breeding Program with contrasting responses to flooding (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 immediately after removal of the flood water at 2-day intervals for four times. In addition, a SPAD 502 Chlorophyll Meter (Spectrum Technologies, Aurora, Ill.) was used to compare leaf chlorophyll content between flooding and no flooding treatments.

Two F7:8 mapping populations: WH-A (5002T × 91210-350) and WH-B (RA-452 × Osage) were screened for flood tolerance in 3 replication tests with the objective of identifying QTL associated with flood tolerance for marker assisted selection (MAS). Several additional collaborative tests with the University of Missouri and the University of Georgia were conducted to identify flood-tolerant varieties/lines and molecular markers associated with this trait.

RESULTS AND DISCUSSION

Among the lines tested in 15FLF-1, six lines (R11-262, R11-245, R10-230, R09-430, R11-6870, and R12-5328) had high yield (102%-113% seed yield of the check yield) and high flood tolerance (low foliar damage score = 2.7-3.8; high plant survival rate = 67.7%-86.1%) (Table 1). In the 15FLF-2 test, eight variety/lines (R10-4892, R04-342, R07-6669, Walters, R13-12695, R13-12535, R13-12638, and R13-12552) exhibited high flood tolerance (low foliar damage score = 3.0-3.8; high plant survival rate = 67.2%-82.7%) and yielded 85%-104% of the checks (AG4934, AG5335, AG5533; 57.0 bu/ac) (Table 2). Results from both advanced tests showed that the line R11-262 was the best performing line (113% grain yield of the check yield) with high flood tolerance (foliar damage score = 3.3; plant survival rate = 77.7%), while the line R11-6870 showed the highest flood tolerance (foliar damage score = 2.7; plant survival rate = 86.1%) with high yield (105% grain yield of the check yield).

In the preliminary flood test, ten lines (R14-21518, R14-14051, R14-14038, R14-14008, R14-14092, R14-13987, R14-14082, R14-21526, R14-14050, and R14-14014) yielded 101%-121% of the check (AG4632, AG4934, AG5335, AG5533, AG5732, 95Y70, P4930LL, and Osage; 46.0 bu/ac) (Table 3). High-yielding lines in this test will be selected for yield and flood tolerance evaluation in 2016. A total of 120 progeny rows were visually selected based on plant uniformity and overall field performance at maturity. A total of 2 F_4, 2 F_2, and 11 F_1 breeding populations were advanced. In addition, 18 new crosses for flood project were made.

In the screening of 33 high-yielding conventional and glyphosate-tolerant lines for identification of flood-tolerant sources for future crossing, seven lines (R11-2354, R11-2299, R12-514, R11-262, R11-2419, R10-5086, and R12-6529RR) showed high tolerance to flood (foliar damage score = 3.2-3.8; plant survival rate = 77.0%-85.6%) (Table 4). In addition, in the screening of 56 lines developed for drought tolerance, eight lines (R13-12229, R13-12092, R13-12210, R13-11810, R12-2392, R10-2622, R13-11979, and R13-12395) exhibited high flood tolerance (foliar damage score = 2.7-3.8; plant survival rate = 65.4%-89.7%) (Table 4). In the screening of commercial cultivars, 21 cultivars (Mycogen 5N404R2, Mycogen 5N433R2, AvDx-D714, AvDx-D814, Delta Grow DG 4790 RR2, Delta Grow DG 4940 RR, Go Soy 4714GTS, Go Soy 483C, Progeny P 4757RY, Progeny P 4930LL, Progeny P 5414LL, Progeny P 5555RY, Progeny P 5610RY, Progeny P 5752RY, Armor 48-C5, Pioneer P49T09BR, Pioneer P50T15BR, Hutcheson, S11-20124, R10-197RY, and R10-230) showed high tolerance to flood stress (Table 4).

Data from the tolerance screening method and mechanism test grown for a second year in Stuttgart, Ark supported the initial results indicating that the optimum flood treatment for genotype screening in the field is either 6 to 9 days of flooding at the R1 stage, or 9 to 12 days at the V5, because most differences among genotypes are visible for FDS and PSR at these growth stages (Table 5). In the 3-day flood test at V5 and R1 stages (D3V5 and D3R1), all varieties/lines evaluated appeared to be highly tolerant to flood stress with low FDS (1.5 and 1.8 for V5 and R1, respectively) and high PSR (92.8% and 88.6% for V5 and R1, respectively). These results suggest that most soybean varieties/lines are able to survive a 3-day flooding event, thus this treatment is not useful to distinguish tolerant soybean genotypes from sensitive ones (Table 5; Figs. 1 and 2). In the 6-day flooding test, 75% of the varieties/lines were tolerant at V5, but only 48% were tolerant at R1. In general, 6-day flooding at V5 had an average of 3.3 FDS and 70.1% PSR as compared to 4.1 FDS and 58.1% PSR at R1 stage (Table 5; Figs. 1 and 2). In the 9-day flooding test at V5 stage (D9V5), 33% of the varieties/lines were tolerant, however, only 15% of the varieties/lines showed tolerant to flood at R1 stage (D9R1) (Table 5; 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 5; Figs. 1 and 2). Results of 2014 and 2015 flood duration tests (Table 6) indicate: 1) the longer flood duration at either V5 or R1, the more damage in terms of foliar score and plant survival rate; 2) foliar flood damage scores are negatively correlated with plant survival rate; 3) plants are more sensitive to flood at R1 than V5 stage; 4) most soybean plants will not be able to survive after 12 days of flooding in the field; and 5) The optimum flood duration treatment for screening in the field is between 6 and 12 days at either V5 or R1 stages.

Furthermore, we investigated leaf chlorophyll content in R1 stage in 2014 and at V5 stage in 2015 with flood and non-flood treatments using a SPAD 502 Chlorophyll Meter. Results showed a significant average reduction of 30.8% in chlorophyll content after flood treatment at R1 stage in 2014 (Table 7) and 35.6% in chlorophyll content after flood treatment at V5 stage in 2015 (Table 8). This reduction explained the change in leaf color (from green to yellow) observed after flood treatment.

In order to identify soybean flood-tolerant QTLs and develop markers for MAS, two genetic mapping populations WH-A (5002T × 91210-350) and WH-B (RA-452 × Osage) were screened for flood tolerance in 3 replication tests in Stuttgart, Ark. in 2015. In the WH-A population, no line showed high tolerance to flood stress (foliar damage score $<$ 4.0), 10 lines showed moderate flood tolerance (foliar damage score = 4.0-5.9), 61 lines and parent 5002T were sensitive to flood stress (foliar damage score = 6.0-7.9), and four lines and parent 91210-350 were highly sensitive to flood stress (foliar damage score $\geq$8.0). Results showed that most lines (87%) were sensitive to flood and very few lines (13%) were moderately tolerant to flood (Fig. 3). In the WH-B population, 17 lines showed high flood tolerance (foliar damage score $<$ 4.0), 61 lines showed moderate flood tolerance (foliar damage score = 4.0-5.9), 30 lines were sensitive to flood stress (foliar damage score = 6.0-7.9) and one line was highly sensitive to flood stress (foliar damage score $\geq$8.0). The parent RA-452 showed high flood tolerance (foliar damage score = 3.4) and the parent Osage exhibited moderate tolerance to flood stress (foliar damage score = 5.6; Fig. 3). These results indicate that population WH-B is more flood tolerant than population WH-A, as most lines (71.6%) exhibit tolerance to flooding.

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.

ACKNOWLEDGMENTS

The authors appreciate the financial support of the soybean producers of Arkansas through funds administered by the Arkansas Soybean Promotion Board. We thank the personnel at the Rice Research and Extension Center in Stuttgart, Ark. and other University of Arkansas Experiment Stations for field support and assistance. We also thank the Arkansas Variety Testing Program for providing soybean commercial cultivars for our tests. We thank the Universities of Missouri and the University of Georgia for germplasm exchange. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. 2015 Arkansas advanced flood test-1 (15FLF-1) grown in 3 locations (Lon Mann Cotton Research Station, Pine Tree Research Station, and Rowher Research Station) with 3 replications.

Entry	Name	Pedigree	Yield[a]	% Cks[b]	FDS[c]	PSR[d] (%)
16	R09-1589	5002T × R01-4752	65.4	114	4.3	60.1
18	R11-262	5002T × R04-357	64.9	113	3.3	77.7
4	UA 5014C	Ozark × Anand	64.2	112	7.3	11.6
17	R11-245	5002T × R04-357	64.0	111	3.2	82.9
22	R10-5086	Osage × R99-1613F	62.8	109	4.3	68.3
1	Osage	Hartz 5545 × KS4895	62.6	109	4.5	54.2
30	R12-2653	R07-7232 × R01-581F	62.0	108	6.3	35.2
27	R10-2436	R01-52F × R02-6268F	61.7	107	6.2	43.4
6	R10-230	5002T × R04-357	61.2	106	3.5	84.2
2	UA 5612	R97-1650 × 98601	60.9	106	4.0	69.7
3	UA 5213C	R98-1523 × 98601	60.8	106	4.7	55.0
28	R11-2933	R01-52F × N01-11771	60.8	106	4.5	63.9
29	R10-2622	R01-888F × R05-5559	60.5	105	4.3	65.5
14	R11-89RY	Osage × RR2Y	60.4	105	4.2	57.4
7	R09-430	BA 743303 × R00-684	60.3	105	3.8	74.8
23	R11-6870	5002T × R01-3474F	60.2	105	2.7	86.1
20	R11-1617	R03-263 × UA 4805	60.1	105	6.0	47.2
25	**AG5533**	**N/A**	**60.0**	**104**	**6.2**	**30.7**
19	R11-1578	R03-263 × UA 4805	59.8	104	4.2	66.7
24	R11-7636	R05-4519 × R01-2731F	59.2	103	4.3	53.3
26	R12-5328	Caviness × R01-3474F	58.6	102	3.5	67.7
9	R07-6614RR	Lonoke × Hutcheson-RR	58.4	102	4.3	66.7
15	**AG5335**	**N/A**	**57.4**	**100**	**6.0**	**39.2**
11	UA 5814HP	R95-1705 × S00-9980-22	56.8	99	4.2	57.6
10	R10-197 RY	Ozark BC1F4	56.5	98	4.0	69.4
8	UA 5414RR	R96-3427 × 98601	55.9	97	4.5	54.4
21	R09-5026	S00-9925-10 × UA 4805	55.9	97	4.2	68.8
5	**AG4934**	**N/A**	**55.2**	**96**	**6.7**	**44.0**
13	R07-2000	Ozark × V99-5089	53.5	93	6.2	51.9
12	R08-4004	R95-1705 × MFL-552	45.4	79	6.0	45.0
		CHECK MEAN	**57.5**			
		CV	**7.0**			
		GRAND MEAN	**59.5**			
		LSD	**3.9**			

[a] Average yield of 3 locations.

[b] Percentage of three check yields (AG 5533, AG 5335, and AG 4934).

[c] FDS = Foliar damage score (flood-tolerant if average FDS < 4.0, moderately tolerant if average FDS = 4.0 to 5.9; sensitive if average FDS = 6.0 to 7.9, and highly sensitive if average FDS ≥ 8).

[d] PSR = Plant survival rate (flood-tolerant if average PSR > 70%, moderately tolerant if average PSR = 50% to 70%, sensitive if average PSR = 30% to 50%, and highly sensitive if average PSR < 30%).

Table 2. 2015 Arkansas advanced flood test-2 (15FLF-2) grown in 3 locations (Lon Mann Cotton Research Station, Pine Tree Research Station, and Rowher Research Station) with 3 replications.

Entry	Name	Pedigree	Yield[a]	% Cks[b]	FDS[c]	PSR[d] (%)
15	**AG5533**	**N/A**	**63.8**	**111.9**	**6.3**	**38.2**
3	R10-4892	5002T × R01-3474F	59.4	104.2	3.0	82.7
2	R04-342	R97-1650 × 98601	57.3	100.5	3.7	67.3
10	**AG5335**	**N/A**	**54.9**	**96.3**	**5.3**	**49.0**
1	R07-6669	Lonoke × R00-33	54.0	94.7	3.7	69.2
4	Walters	Forrest × Narow	53.2	93.3	3.2	67.2
5	**AG4934**	**N/A**	**52.4**	**91.9**	**5.6**	**45.5**
12	R13-12746	Caviness × R08-2496	51.1	89.6	4.3	64.3
13	R13-12754	Caviness × R08-2496	50.0	87.7	4.1	66.0
9	R13-12695	RA 452 × 91210-350	49.5	86.8	3.8	74.0
6	R13-12535	5002T × 91210-350	49.2	86.3	3.8	74.1
7	R13-12683	R08-2416 × Jake	49.1	86.1	4.9	50.9
14	R13-12638	R01-52F × 91210-350	48.7	85.4	3.6	77.1
11	R13-12552	5002T × 91210-350	48.4	84.9	3.4	78.7
8	R13-12690	RA 452 × 91210-350	43.6	76.5	6.0	47.8
		CHECK MEAN	**57.0**			
		CV	**8.2**			
		GRAND MEAN	**52.3**			
		LSD	**4.0**			

[a] Average yield of 3 locations.
[b] Percentage of three check yields (AG 5533, AG 5335, and AG 4934).
[c] FDS = Foliar damage score (flood-tolerant if average FDS < 4.0, moderately tolerant if average FDS = 4.0 to 5.9; sensitive if average FDS = 6.0 to 7.9, and highly sensitive if average FDS ≥8).
[d] PSR = Plant survival rate (flood-tolerant if average PSR >70%, moderately tolerant if average PSR = 50% to 70%, sensitive if average PSR = 30% to 50%, and highly sensitive if average PSR <30%).

Table 3. 2015 Arkansas preliminary flood test (15FLP) grown in 2 locations (Lon Mann Cotton Research Station and Rice Research Station) with 1 replication.

Entry	Name	Pedigree	Yield[a]	%Checks[b]
5	**AG4632**	**N/A**	**53.8**	**125**
39	R14-21518	RA-452 × Osage	52.2	121
35	**95Y70**	**N/A**	**51.5**	**120**
22	R14-14051	R08-2416 × Jake	49.9	116
40	**Osage**	**Hartz 5545 × KS4895**	**47.3**	**110**
21	R14-14038	R08-2416 × Jake	47.0	109
6	R14-14008	5002T × N97-9658	44.6	104
20	**AG5335**	**N/A**	**44.2**	**103**
43	R14-14092	Caviness × R08-2496	44.2	103
4	R14-13987	5002T × N97-9658	43.8	102
42	R14-14082	Caviness × R08-2496	43.7	102
10	**AG4934**	**N/A**	**43.6**	**101**
41	R14-21526	RA-452 × R01-581F	43.6	101
19	R14-14050	R08-2416 × Jake	43.5	101
8	R14-14014	N97-9658 × 91210-350	43.4	101
30	**AG5732**	**N/A**	**42.8**	**99**
15	**P4930LL**	**N/A**	**42.7**	**99**
45	R14-14111	Caviness × R08-2496	42.6	99
33	R14-21457	RA-452 × Osage	42.5	99
23	R14-14056	R08-2416 × Jake	42.3	98
25	**AG5533**	**N/A**	**42.2**	**98**
37	R14-21490	RA-452 × Osage	42.0	98
34	R14-21476	RA-452 × Osage	41.6	97
9	R14-21346	PI 471931 × PI 471938	41.3	96
1	R14-21258	5002T × 91210-350	41.3	96
16	R14-20472	R04-342 × 91210-350	40.4	94
32	R14-21436	RA-452 × Osage	40.3	94
24	R14-14062	RA 452 × 91210-350	40.2	93
38	R14-21493	RA-452 × Osage	40.2	93
2	R14-21278	5002T × 91210-350	40.2	93
31	R14-21411	RA-452 × Osage	40.2	93
27	R14-14072	RA 452 × 91210-350	38.8	90
18	R14-14044	R08-2416 × Jake	38.2	89
26	R14-14071	RA 452 × 91210-350	37.9	88
44	R14-14100	Caviness × R08-2496	37.5	87
28	R14-14077	RA 452 × 91210-350	36.9	86
17	R14-20483	R04-342 × 91210-350	36.8	86
12	R14-21356	PI 471931 × PI 471938	36.4	85
3	R14-21319	5002T × 91210-350	35.7	83
7	R14-14032	N97-9658 × 91210-350	35.2	82
36	R14-21482	RA-452 × Osage	34.8	81
29	R14-14078	RA 452 × 91210-350	32.5	75
13	R14-21383	PI 471931 × PI 471938	32.4	75
11	R14-21349	PI 471931 × PI 471938	30.7	71
14	R14-21388	PI 471931 × PI 471938	29.6	69
		CHECK MEAN	**46.0**	

[a] Average yield of 2 locations.

[b] Percentage of eight check yields (AG 4632, 95Y70, Osage, AG 5335, AG 4934, AG 5732, P4930LL, and AG 5533).

Table 4. 2015 Screening tests for flood tolerance in Arkansas.

			Number of varieties/lines		
Flood tolerance	**FDS[a]**	**PSR[b] (%)**	**CV[c] + RR1**	**Drought[d]**	**Commercial**
High	< 4.0	60.0 - 89.7	7	8	21
Moderate	4.0 - 5.9	30.5 - 69.7	14	22	75
Sensitive	6.0 - 7.9	10.8 - 42.6	13	24	91
Highly sensitive	≥ 8.0	0.0 - 10.3	0	2	21
Total			**34**	**56**	**208**

[a] FDS = foliar damage score.
[b] PSR = plant survival rate.
[c] Conventional lines.
[d] Drought-resistant lines.

Table 5. 2015 Flood duration test in Arkansas.

			Number of cultivars/lines		
Test[a]	**FDS[b]**	**PSR[c] (%)**	**Tolerant**	**Moderately tolerant**	**Sensitive**
D3V5	1.5	92.8	40	0	0
D3R1	1.8	88.6	40	0	0
D6V5	3.3	70.1	30	9	1
D6R1	4.1	58.1	19	17	4
D9V5	5.1	49.5	13	19	8
D9R1	6.5	36.5	6	10	24
D12V5	6.4	34.2	3	13	24
D12R1	7.2	24.6	0	8	32
D15V5	7.0	25.7	0	7	33
D15R1	7.9	15.9	0	5	35

[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] FRS = Foliar damage score (flood-tolerant if average FDS < 4.0, moderately tolerant if average FDS = 4.0 to 5.9; sensitive if average FDS = 6.0 to 7.9, and highly sensitive if average FDS ≥ 8).
[c] PSR = Plant survival rate (flood-tolerant if average PSR >70%, moderately tolerant if average PSR = 50% to 70%, sensitive if average PSR = 30% to 50%, and highly sensitive if average PSR < 30%).

Table 6. Summary of Arkansas flood duration tests grown in 2014 and 2015.

		FDS [a]		% PSR [b]		No. Varieties/Lines					
						Tolerant		Mod. Tolerant		Sensitive	
Day	Stage	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
3	V5	1.1	1.5	99.4	92.8	40	40	0	0	0	0
3	R1	1.7	1.8	86.5	88.6	40	40	0	0	0	0
6	V5	3.2	3.3	69.1	70.1	31	30	8	9	1	1
6	R1	4.6	4.1	53.9	58.1	15	19	17	17	8	4
9	V5	5.3	5.1	42.0	49.5	11	13	19	19	10	8
9	R1	7.5	6.5	15.9	36.5	0	6	1	10	39	24
12	V5	6.0	6.4	36.1	34.2	2	3	19	13	19	24
12	R1	8.7	7.2	4.0	24.6	0	0	0	8	40	32
15	V5	7.3	7.0	16.5	25.7	0	0	6	7	34	33
15	R1	8.4	7.9	8.0	15.9	0	0	0	5	40	35

[a] FDS = Foliar damage score (flood-tolerant if average FDS <4.0, moderately tolerant if average FDS = 4.0 to 5.9; sensitive if average FDS = 6.0 to 7.9, and highly sensitive if average FDS ≥8).
[b] PSR = Plant survival rate (flood-tolerant if average PSR >70%, moderately tolerant if average PSR = 50% to 70%, sensitive if average PSR = 30% to 50%, and highly sensitive if average PSR <30%).

Table 7. Leaf chlorophyll content before and after flood treatments in 2014 (R1 stage) flood duration tests.

Day	Stage	Before flood[a]	After flood[a]	% Reduction
3	R1	32.3	25.6	20.7
6	R1	32.1	23.5	26.8
9	R1	32.2	18.8	41.6
12	R1	31.9	21.3	33.2
15	R1	33	22.6	31.5
Average		**32.3**	**22.4**	**33.2**

[a] Indexed chlorophyll content reading.

Table 8. Leaf chlorophyll content before and after flood treatments in 2015 (V5 stage) flood duration test.

Test	Before flood[a]	After flood[a]	% Reduction
D3V5	33.2	23.5	29.2
D6V5	32.9	22.9	30.4
D9V5	33.1	21.4	35.3
D12V5	33.9	19.8	41.6
D15V5	32.3	19.1	40.9
Average	**33.1**	**21.3**	**35.6**

[a] Indexed chlorophyll content reading.

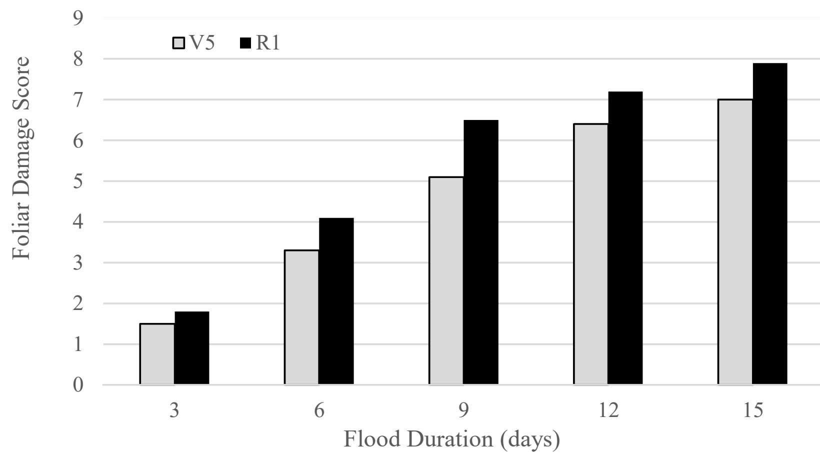

Fig. 1. Plant foliar damage under flooding for different durations.

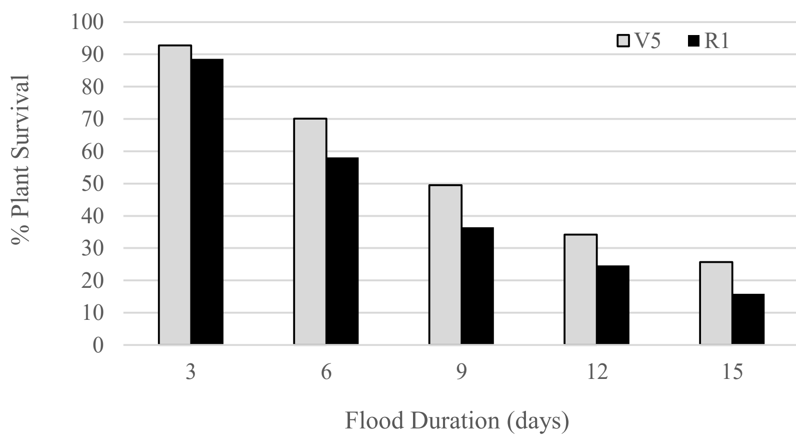

Fig. 2. Plant survival rate under flooding for different durations.

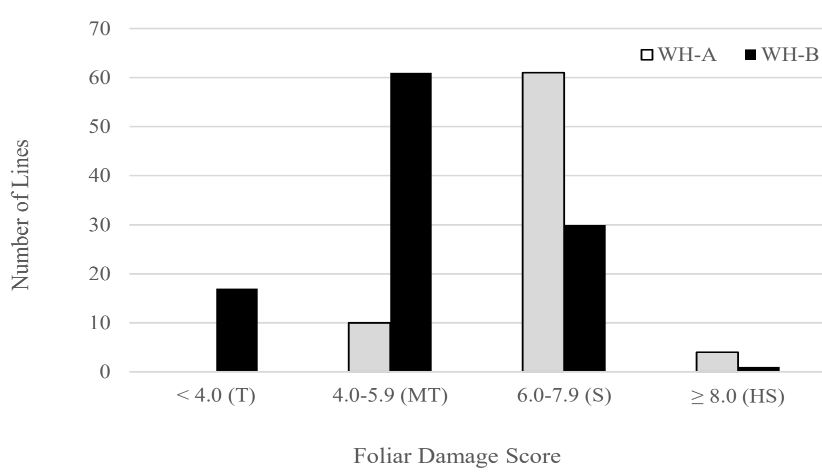

Fig. 3. Flood screening of two genetic mapping populations.

A New Transgenic Approach to Control Diseases of Soybean in Arkansas

B. Bluhm[1] and J. Stover[1]

ABSTRACT

Cercospora diseases of soybean are common in Arkansas, and could further increase in incidence and severity due to the emergence of resistance to strobilurin fungicides throughout the state. Genetic resistance has been difficult to identify and incorporate into commercial cultivars. In this project, we are creating transgenic resistance to foliar diseases of soybean caused by *Cercospora* species (frogeye leaf spot and Cercospora leaf spot). We are using an approach known as host induced gene silencing (HIGS), in which transgenic soybean plants are developed that silence genes in *Cercospora* pathogens during disease development. We identified numerous pathogen genes to be targeted transgenically, and developed a cost effective technique to create transgenic soybean lines. The creation and advancement of transgenic lines is ongoing; as lines become mature, they will be tested in greenhouse and field conditions. Creating transgenic resistance will provide an important new tool to manage *Cercospora* diseases of soybean in Arkansas, and will improve the profitability of soybean production.

INTRODUCTION

Frogeye leaf spot (caused by *Cercospora sojina*) and Cercospora leaf blight (caused by *Cercospora kikuchii*) are two of the most common and problematic foliar diseases of soybean in Arkansas. *Cercospora kikuchii* also causes purple seed stain of soybean, which negatively affects grain quality. In recent years, *Cercospora* pathogens caused more yield loss in Arkansas soybean than all other foliar diseases combined, and are a top-three disease problem in the state (Allen et al., 2016). In 2015, frogeye leaf spot and Cercospora leaf blight suppressed Arkansas soybean yield by 2.73 million bushels (Allen et al., 2016).

Management of frogeye leaf spot and Cercospora leaf blight is challenging. Both pathogens have recently evolved resistance to strobilurin fungicides (Price et al., 2013). Genetic resistance in soybean would be the most cost effective and sustainable management strategy. However, genetic resistance against frogeye leaf spot is complicated by the existence of many races of the pathogen (Mian et al., 2008), and genetic resistance has not yet been identified for Cercospora leaf blight.

Genetic resistance against plant diseases can be accelerated by transgenic approaches. A new approach for transgenic resistance known as host induced gene silencing (HIGS) has recently been developed to improve plant resistance against diseases. In short, the principle of HIGS is that a plant transgene produces a mimic of a pathogen's gene. When the pathogen attacks the transgenic plant, it encounters the gene mimic, which tricks the pathogen into turning off some of its own genes. As a result, the pathogen's growth is halted, which prevents disease from developing.

Although HIGS has shown great promise in some plants (Tinoco et al., 2010), it had not been utilized to control soybean diseases before this project. Thus, the goal of this work has been to develop transgenic disease resistance in soybean (utilizing HIGS) to target *Cercospora* diseases of soybean that are important in Arkansas agriculture.

PROCEDURES

In previous work funded by the Arkansas Soybean Promotion Board, we identified and validated numerous pathogen genes as targets for HIGS. The pathogen genes selected to target with the first set of transgenes are involved in pathogen growth, phytotoxin production, and pathogen signaling/communication. One example is *CZK3*, a *Cercospora* pathogenicity gene first described in the corn pathogen *Cercospora zeae-maydis* (Shim and Dunkle, 2003) and confirmed in the soybean *Cercospora* pathogens in the lab at the University of Arkansas System Division of Agriculture's Arkansas Agricultural Experiment Station (AAES) last year.

Transgenes were created by first creating a hairpin RNA targeting fungal genes of interest. Then, a novel plasmid created in Dr. Bluhm's lab (pBYR3) was used to shuttle transgenes into soybean. We developed a soybean transformation protocol based on Paz et al. (2006). Seed of transgenic plants will be increased in containment greenhouses (Rosen Center, University of Arkansas, Fayetteville campus) and evaluated for levels of transgene expression, transgene stability, expression in various tissues, and other measures of quality control.

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RESULTS AND DISCUSSION

In the previous two years of this project, efforts were focused on identifying and validating suitable pathogen genes to target via HIGS. Host induced gene silencing will only be effective if the pathogen gene being targeted is crucial for growth and/or disease development. To this end, we identified over 20 suitable pathogen gene targets. Transgenic plants are being generated that target *CZK3* and four other high-priority gene targets.

Transgenic plants are being propagated within the University of Arkansas Plant Transformation Facility (Fig. 1). Creating transgenic soybean plants requires the regeneration of plants from small amounts of undifferentiated plant tissue, which requires careful maintenance of young, transgenic material. Thus, the current stage in the process is the most labor intensive. As transgenic plants are generated, they are raised in the greenhouse to produce seed. Once seed is available from the first generation of transgenic plants, a couple of seasons are required for seed increase and transgene stabilization before lines can be tested in field conditions.

PRACTICAL APPLICATIONS

Transgenic resistance created in this project will be shared with the Arkansas Soybean Breeding Program so that new sources of resistance can be incorporated into soybean cultivars that are adapted for Arkansas production conditions. The transgenes will also be licensed for utilization by commercial soybean breeding programs. New sources of genetic resistance to soybean *Cercospora* diseases will increase the profitability of soybean production in Arkansas by decreasing yield losses and input costs associated with disease management.

ACKNOWLEDGEMENTS

The authors would like to thank the Arkansas Soybean Promotion Board for their funding of this research. Support was also provided by the University of Arkansas System Division of Agriculture. Additionally, this work is supported in part by the USDA National Institute of Food and Agriculture, Hatch project 1008895. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the U.S. Department of Agriculture.

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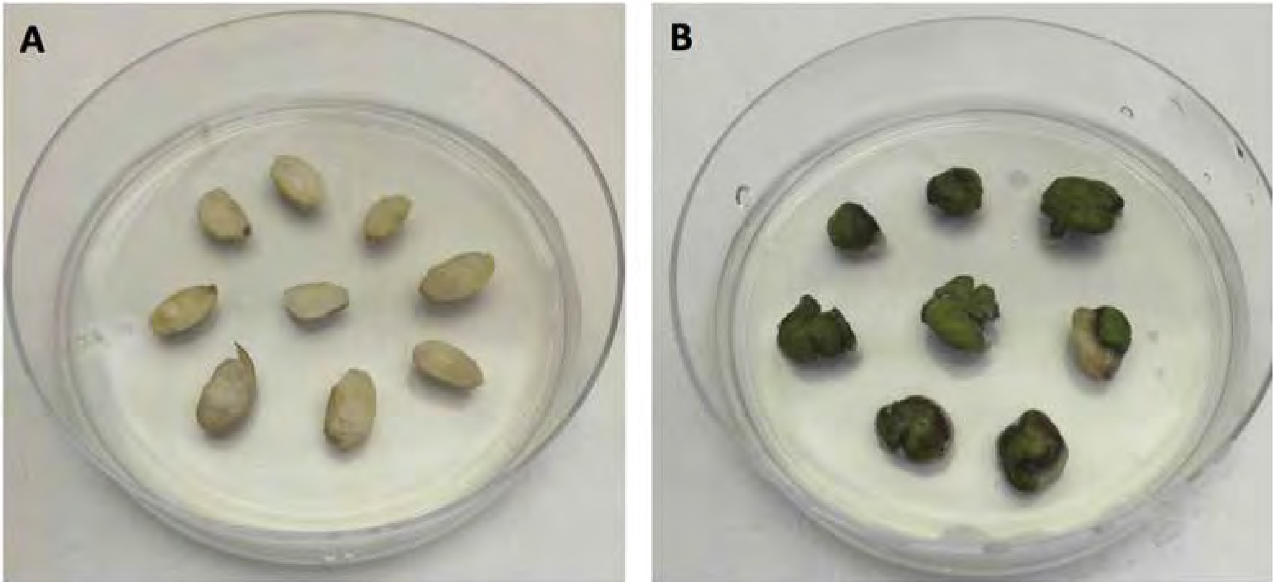

Fig. 1. Creation of transgenic soybean to improve disease resistance. (A) Soybean seed at the initial stage of transgene introduction. (B) Callus (undifferentiated) tissue forming 14 days after introduction of the transgene. After callus tissue matures, transgenic soybean plants are regenerated and raised in greenhouses to produce seed.

Early-Season Fungicide Applications to Reduce Colonization of *Rhizoctonia solani* and Limit the Risk of Aerial Blight in Soybean Fields under Rice-Soybean Rotation

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* and aerial blight was examined in two fields under soybean-rice rotation each year for three years. The value of early-season fungicide applications to limit colonization and aerial blight development in these fields was assessed by comparing positions in grower fields that received or did not receive a fungicide application prior to reproductive development. Early-season fungicide applications showed a high level of suppression of colonization by *R. solani* for all but one field over the three years. Aerial blight did not develop in any field during the study. 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 these results.

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. Intensive soybean-rice rotations in the mid-South increase the potential for *Rhizoctonia solani* to cause economic losses on soybean by ensuring a source of inoculum from the previous rice crop. Estimated yearly losses for aerial blight average \$12.6 million with the range over a 10 year period being \$2 to \$46 million, 1998-2007 (Wrather and Koenning, 2009). As with many other foliar and stem pathogens on soybean, aerial blight is managed with applications of fungicides once symptoms develop. However unlike these other diseases, aerial blight is a single-cycle disease so inoculum for disease development in a field is limited to inoculum produced in previous seasons. Disease initially occurs as foci from this overwintering inoculum with the pathogen growing up the plant and to adjacent plants. Fungicide applications often have limited efficacy because the soybean canopy limits the amount of fungicide coming in contact with the pathogen. This paper examines the efficacy of early-season fungicide applications to limit the colonization of soybean by *R. solani*, the first stage in disease development.

PROCEDURES

Research was conducted in two soybean fields in 2013, 2104, and 2015. Each field had a history of rice-soybean rotation and a known history of aerial blight or sheath blight. Fields were GPS-mapped to identify features, area, and levee placement before planting.

Approximately 200 GPS points were monitored in each field for colonization and disease development in 12 passes to represent each field, 100 points in 2013. To monitor colonization of *R. solani* early in the season, 10 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 (3 in., 8 cm) 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 from the soybean tissue were cultured and identified. After the initial sampling, the fungicide azoxystrobin (Quadris®) was applied to 6 of the 12 passes at the labeled rate for soybean. Plants were sampled using a similar procedure approximately two weeks after fungicide application to examine the efficacy of this early-season fungicide application on suppression of colonization. Aerial blight development was monitored in each field during reproductive growth stages.

RESULTS AND DISCUSSION

Colonization of soybean was common for *R. solani* and other *Rhizoctonia* species during the season. The only substantial colonization of soybean by AG1-IA was in 2013 in a field near Stuttgart. In this field, isolates from soybean at V-3 included *R. solani* AG1-IA and AG11 and *Rhizoctonia oryzae*. For the Stuttgart field, the early-season fungicide application showed a high level of suppression of *R. solani* AG1-IA compared to numbers of isolates recovered from the non-sprayed passes from the second sampling ($P = 0.0756$, Fig. 1). Disease did not progress in the Stuttgart field or a field near Hazen in 2013 as a result of a lack of rainfall and hot summer temperatures.

In 2014, colonization of soybean was examined across *Rhizoctonia* species. For a field near Dumas, the early-season fungicide application showed a high level of suppression

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of *Rhizoctonia* compared to the percentage of plants with *Rhizoctonia* from the non-sprayed passes for the second sampling (*P* = 0.0004, Fig. 2). Almost all isolates were not the aerial blight pathogen, AG1-IA, but were AG11 and disease did not progress. A field near Weiner did not get sprayed until R1 to R2. Colonization of plants was much greater at both sampling times, greater than 45%, and fungicides showed no ability to suppress colonization, but again, *R. solani* AG1-IA was not a common isolate (Fig. 2).

In 2015, colonization of soybean was examined as colonization by specific AGs of R. *solani*. A soybean field near Gould had colonization of soybean by AG7 and AG11. Colonization by AG7 and AG11 was significantly reduced by the fungicide, *P* = 0.0009 and *P* = 0.0331, respectively (Fig. 3). In the absence of a fungicide, the percentage of plants colonized by *R. solani* continued to increase. Similarly in a field near Waldenburg, an increase in colonization of plants by AG11 was observed over sample times for the non-sprayed passes (Fig. 3). The application of fungicides significantly reduced colonization after fungicide application compared to passes not receiving a fungicide, *P* < 0.0001.

PRACTICAL APPLICATIONS

The challenges for aerial blight management is the early recognition of disease progress underneath the crop canopy and fungicide contact with the pathogen in the lower canopy The new strategy of early fungicide applications demonstrated good efficacy in limiting colonization of *R. solani* on soybean plants during the season by; 1) getting the fungicide to where the pathogen is developing on the soybean plant and 2) halting or interrupting the colonization of the plant prior to yield-limiting disease development.

ACKNOWLEDGEMENTS

This material is based upon work that was supported, in part, by the Arkansas Soybean Promotion Board and a USDA National Institute of Food and Agriculture Hatch Project. Support was also provided by the University of Arkansas System Division of Agriculture.

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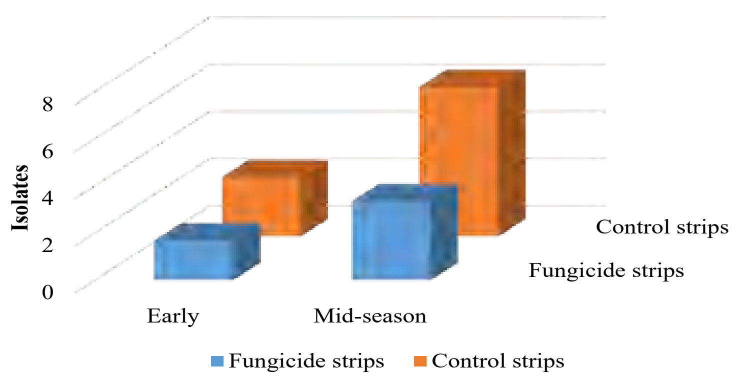


Fig. 1 Number of isolates of *Rhizoctonia solani* AG1-IA recovered before (Early) and after fungicide application (Mid-season) for a field near Stuttgart.

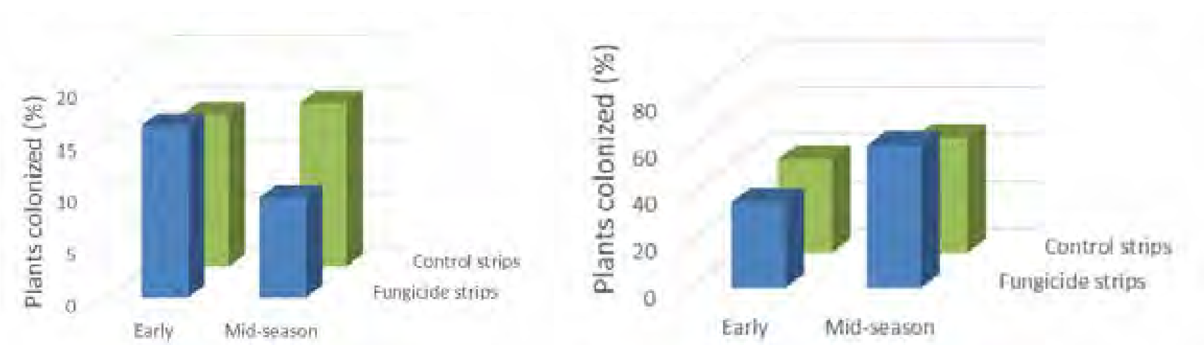
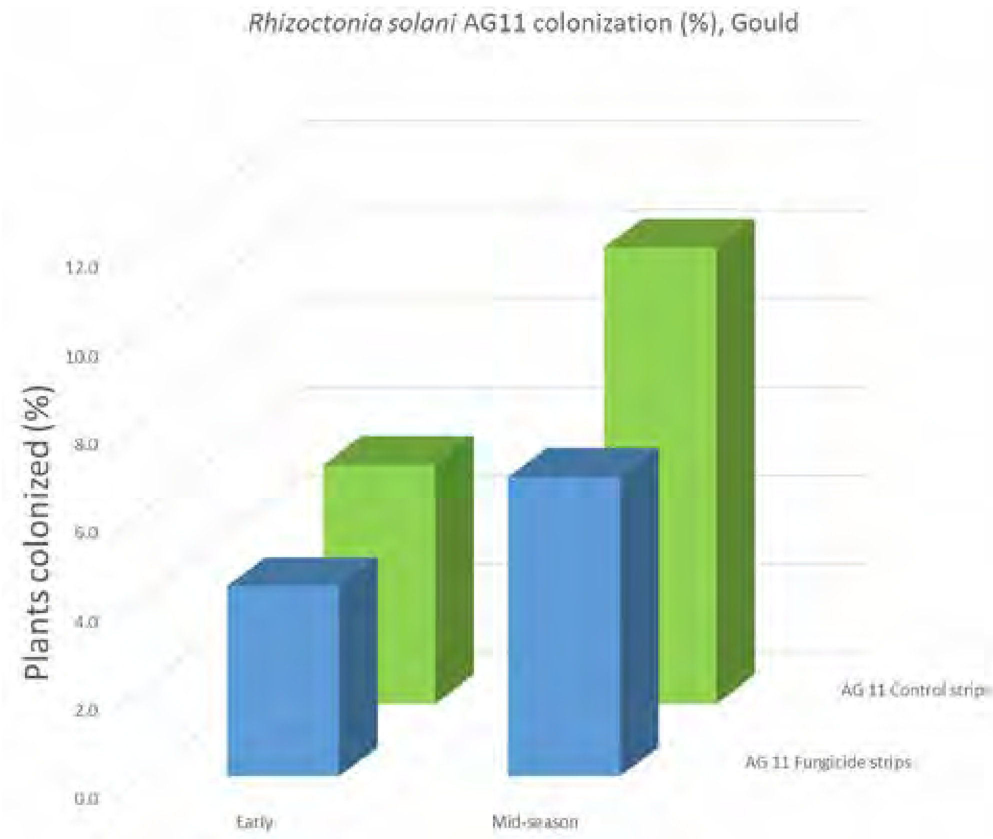
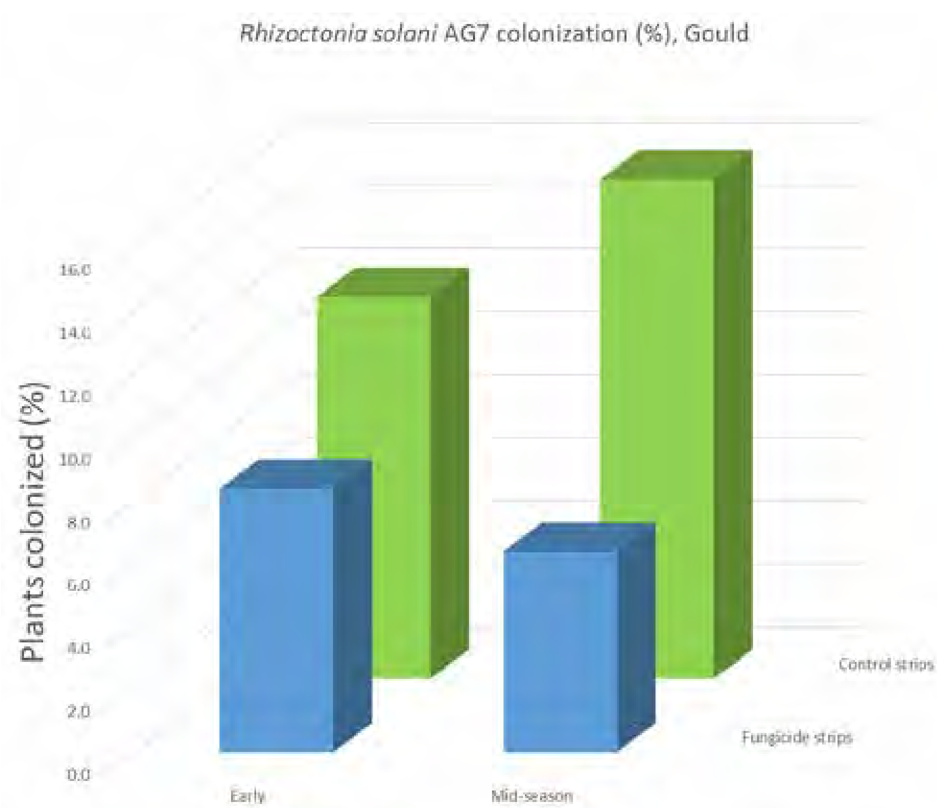


Fig. 2. Colonization of *Rhizoctonia solani* before (Early) and after fungicide application (Mid-season) for a field near Dumas (left) or Weiner (right) in 2014.

a


Rhizoctonia solani AG11 colonization (%), Gould
Plants colonized (%)
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Early
Mid-season
AG 11 Control strips
AG 11 Fungicide strips

b


Rhizoctonia solani AG7 colonization (%), Gould
Plants colonized (%)
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
Early
Mid-season
Control strips
Fungicide strips

c

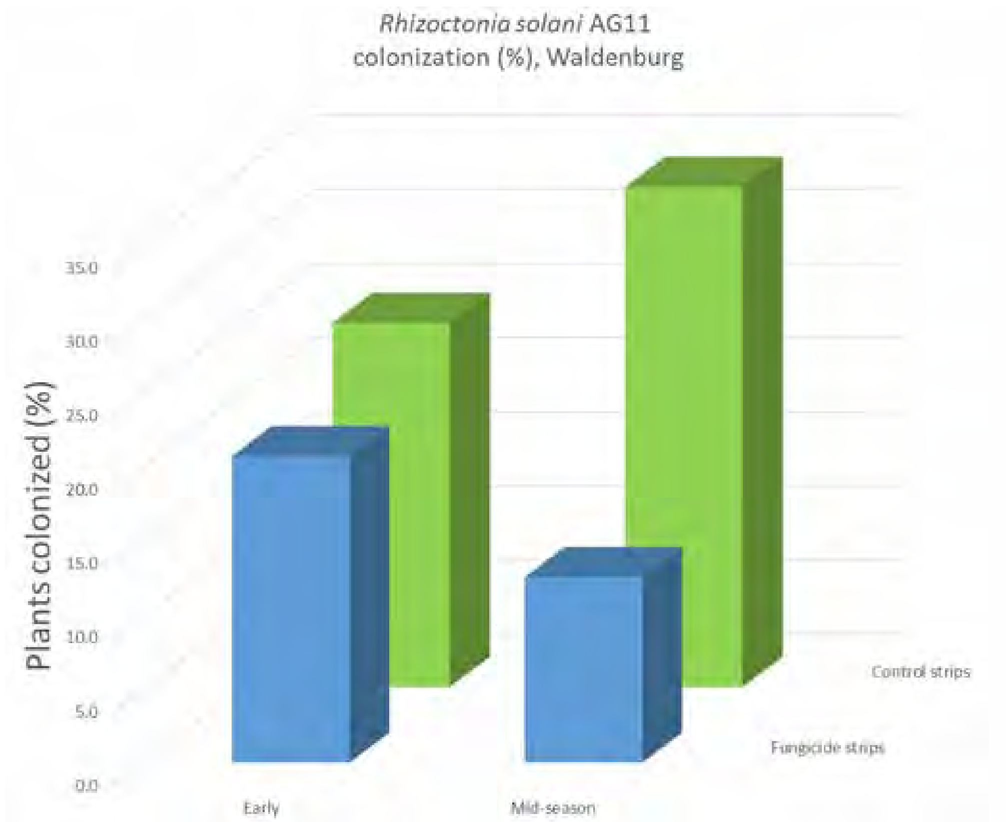


Fig. 3. Colonization of *Rhizoctonia solani* before (Early) and after fungicide application (Mid-season) for a field near Gould (a,b) or Waldenburg (c) in 2015

Comprehensive Disease Screening of Soybean Varieties in Arkansas

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

ABSTRACT

Since 1990, thanks to the ongoing support of the Soybean Promotion Board, Arkansas has maintained 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. Each year, our results form the basis for our annual Soybean Update and the SOYVA cultivar selection program to inform growers of the strengths and weaknesses of new soybean cultivars relative to disease resistance. Results are also reported in full on the Arkansas Variety Testing website.

INTRODUCTION

The soybean disease screening program has historically been conducted at various locations throughout the state. Currently, we have field disease nurseries established at the University of Arkansas System Division of Agiculture's 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 and Extension Center in Hope and the Cralley Warren laboratory on the Fayetteville campus farm.

PROCEDURES

In 2015, 276 cultivars were screened for root-knot, reniform, soybean cyst (races 2 and 5) nematode, stem canker, and frogeye leaf spot.

Root-Knot. The screen 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. The screen was conducted in Fayetteville at the Cralley Warren Laboratory greenhouse by Dr. Bob Robbins. It consisted of 116 new cultivars for 2015. Each cultivar was planted and replicated 5 times 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. The screens 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 and 5 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.

Stem Canker. The screen was conducted at the Newport Extension Center by Kim Rowe and Michael Emerson on 276 cultivars. Each cultivar was planted and replicated three times. In each rep, the stems of 10 plants were inoculated with toothpicks infested with *Diaporthe phaseolorum var. meridionalis* fungus at V5 stage of growth. 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.

Frogeye Leaf Spot. This screen was also conducted at the Newport Extension Center by Michael Emerson and Kim Rowe on 276 cultivars. Each cultivar was planted and replicated three times. *Cercospora sojina* spores in a water suspension were applied using a sprayer twice, once 6 weeks post planting, and then again several weeks later. Visual ratings were taken approximately 12 weeks post planting as percentage of leaf area affected.

RESULTS AND DISCUSSION

The results of the 2015 disease screens were consistent with previous years' results. On average, the nematode screens showed that greater than 60% of entries were susceptible to reniform, root-knot, and soybean cyst nematodes (Figs. 1, 2, 3, and 4). An increase in the number of resistant varieties was noted in the soybean cyst screen when compared to previous years. The stem canker screen results showed that 93% of entries were resistant to the disease, 0% were moderately resistant, 1% were moderately susceptible,

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and 5% were susceptible (Fig. 5). 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 7% of varieties in the susceptible category could mean trouble for growers (Fig. 6). A copy of all data from the 2015 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, 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. Soybean 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, 2014). Diseases result in yield losses of 10% annually some estimate. By this figure, last year nearly $200 million was lost to soybean diseases in Arkansas (Faske et al., 2014). Each year, well over 200 new soybean cultivars become available to Arkansas growers. Many of these cultivars are accompanied by little or no information on their resistance to diseases or nematodes. Since only one variety will be grown in a particular field, 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.

ACKNOWLEDGEMENTS

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

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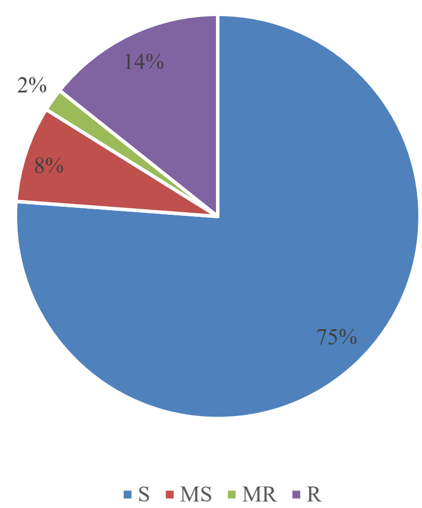

Fig. 1. Percent of soybean cultivars screened (N = 276) that were susceptible (S), moderately susceptible (MS), moderately resistant (MR), or resistant (R) to soybean cyst nematodes (race 2).

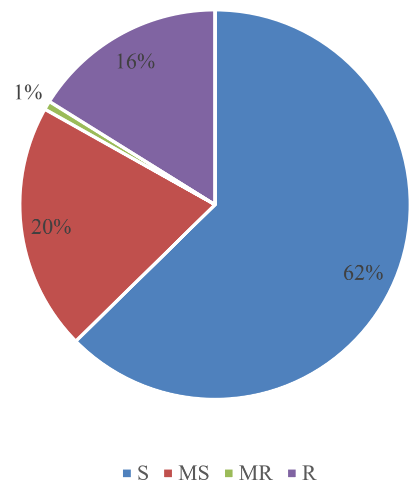

Fig. 2. Percent of soybean cultivars screened (N = 276) that were susceptible (S), moderately susceptible (MS), moderately resistant (MR), or resistant (R) to soybean cyst nematodes (race 5).

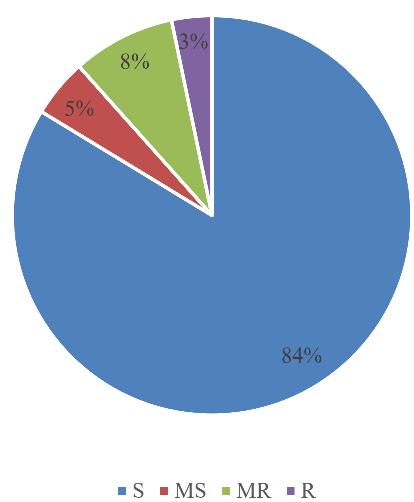

Fig. 3. Percent of soybean cultivars screened (N = 276) that were susceptible (S), moderately susceptible (MS), moderately resistant (MR), or resistant (R) to root-knot nematodes.

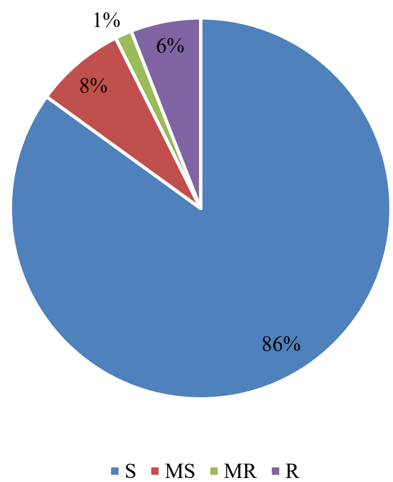

Fig. 4. Percent of soybean cultivars screened (N = 276) that were susceptible (S), moderately susceptible (MS), moderately resistant (MR), or resistant (R) to reniform nematodes.

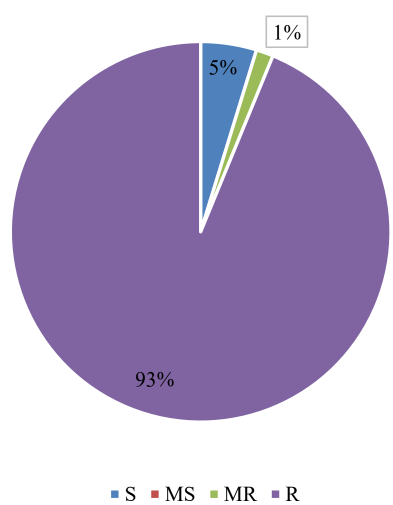

Fig. 5. Percent of soybean cultivars screened (N = 276) that were susceptible (S), moderately susceptible (MS), moderately resistant (MR), or resistant (R) to southern soybean stem canker.

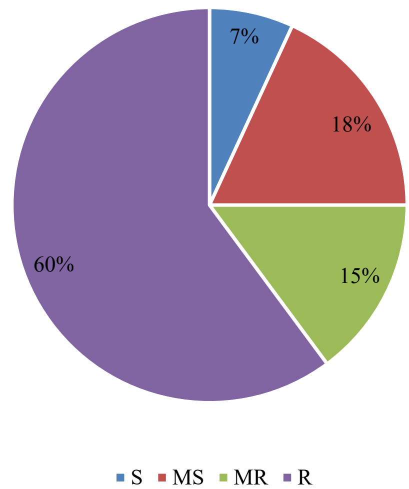

Fig. 6. Percent of soybean cultivars screened (N = 276) that were susceptible (S), moderately susceptible (MS), moderately resistant (MR), or resistant (R) to frogeye leaf spot.

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

T. Kirkpatrick[1]

ABSTRACT

The recent increase in soybean production in Arkansas is likely a result of declining cotton prices that resulted in a more diverse agricultural cropping system. Many formerly monocultured cotton fields are now regularly rotated into soybean and corn. With the increase of soybean production, there has also been an influx of the type and population of nematodes present in these former cotton fields. The second of the three year survey funded by the Arkansas Soybean Promotion Board shows that the soybean cyst, root-knot, lesion, and reniform nematodes tested positive in 28%, 28%, 20%, and 2% of the fields, respectively. In 2015, county agents, crop consultants, and growers submitted 890 nematode samples total and 149 samples were set up for a race assay. The majority of soybean cyst nematode populations assayed to date have been races 2, 5, or 6 with a few incidences of race 9 included. With the three year survey, it will help us to better understand which nematodes are present, the population of nematodes present, and how to manage the nematodes present.

INTRODUCTION

The agricultural landscape is changing in Arkansas. Historical acreage of agronomic crops has changed significantly in the last few years. For example, cotton acreage in the state has decreased 80% since 2005, while in the same period of time corn acreage has almost tripled, grain sorghum acreage has increased twofold, and soybean acreage has increased about 10% per year since 2009. Soybean are now grown on approximately 3.2 million acres in the state (USDA-NASS, 2015). Nematodes account for a significant loss in yield in Arkansas soybean 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* (SCN), the southern root-knot nematode (*Meloidogyne incognita*), the reniform nematode (*Rotylenchulus reniformis*), and lesion nematodes (P*ratylenchus* spp.). Historically, SCN was widely distributed and of major concern statewide, and this nematode was 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 that are associated with soybean or the soybean cyst nematode races that are associated with the Arkansas soybean crop in about 30 years—the most recent survey of nematodes associated with soybean in Arkansas was a conducted from 1978-1986 (Robbins et al., 1987). Given the changes in cropping system dynamics recently, it is vital that we learn what nematodes are associated with the crop.

PROCEDURES

The second year of a three-year survey, sponsored by the Arkansas Soybean Promotion Board was conducted statewide during the 2015 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 University of Arkansas System Division of Agriculture's Arkansas Nematode Diagnostic Laboratory (ANDL) was developed for potential surveyors. This course is accessible via the Division of Agriculture Cooperative Extension website at: http://courses.uaex.edu/course/index.php?categoryid=63. County agents, consultants, and in some cases growers were enlisted to sample fields that were either in soybean in 2015 or would be going into soybean in 2016. Procedures were as follows. Sampling occurred from 1 Sept.-1 Dec. Fields of 40 acres or less were sampled as a unit by collecting a minimum of 20 soil cores (1 in. diameter) randomly from 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 sub-sample 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 were increased sufficiently, (ca. 45 days), they were inoculated on three plants each of Lee 74, Pickett, PI 88788, PI 90763, and Peking—the differentials used to identify races of the nema-

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tode—and grown for 30 days in the greenhouse to determine the race. Results from the race tests are pending.

RESULTS AND DISCUSSION

County agents, crop consultants, and growers collected and submitted 890 samples for assay during the September-December period (Fig. 1). Soybean cyst nematodes and root-knot nematodes were each detected in 28% of the samples that were submitted (Fig. 2). Lesion nematodes, *Pratylenchus* spp. were the second most frequently encountered nematode with 20% of fields having detectable populations. Reniform nematodes were recovered from 2% of the fields. It is interesting that soybean cyst and root-knot nematodes were found at almost the same incidence.

Although, based on a relatively limited number of samples, it appears that SCN incidence has declined from the 66% of fields reported in the 1978-1986 survey of the state's soybean acreage (Robbins, et al., 1987). Twenty-eight percent is still, however, a significant and troubling incidence. In contrast with soybean cyst nematodes, the southern root-knot nematode was not a commonly encountered inhabitant of the soybean fields in Arkansas in 1978-1986. However, 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 soybean, 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.

The reniform nematode was not found in the 1978-1986 soybean nematode survey, but was detected in 2% of the fields sampled in 2015. 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 20% of the 2015 fields had lesion nematodes. Identification to species has not been done for the *Pratylenchus* found in the 2014 and 2015 surveys, 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. The majority of populations assayed to date 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. A few race 9 populations were detected in the 2015 Arkansas survey.

PRACTICAL APPLICATIONS

The relative population densities of plant-parasitic nematodes in soybean fields change in response to crop history, but the overall incidence of nematode species is an indication of the potential for nematode-induced crop loss within an area. Since the last nematode survey of soybean in the state was conducted about 30 years ago, we have no idea which nematodes are present today, how high their populations are, or if there is cause for concern. Because nematodes are microscopic and soilborne, the only way to know if they are a potential threat to soybean production in any particular field is through a nematode assay.

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. This knowledge will in turn allow development of effective nematode management strategies on a field-by-field basis.

ACKNOWLEDGEMENTS

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 was also provided by the University of Arkansas System Division of Agriculture.

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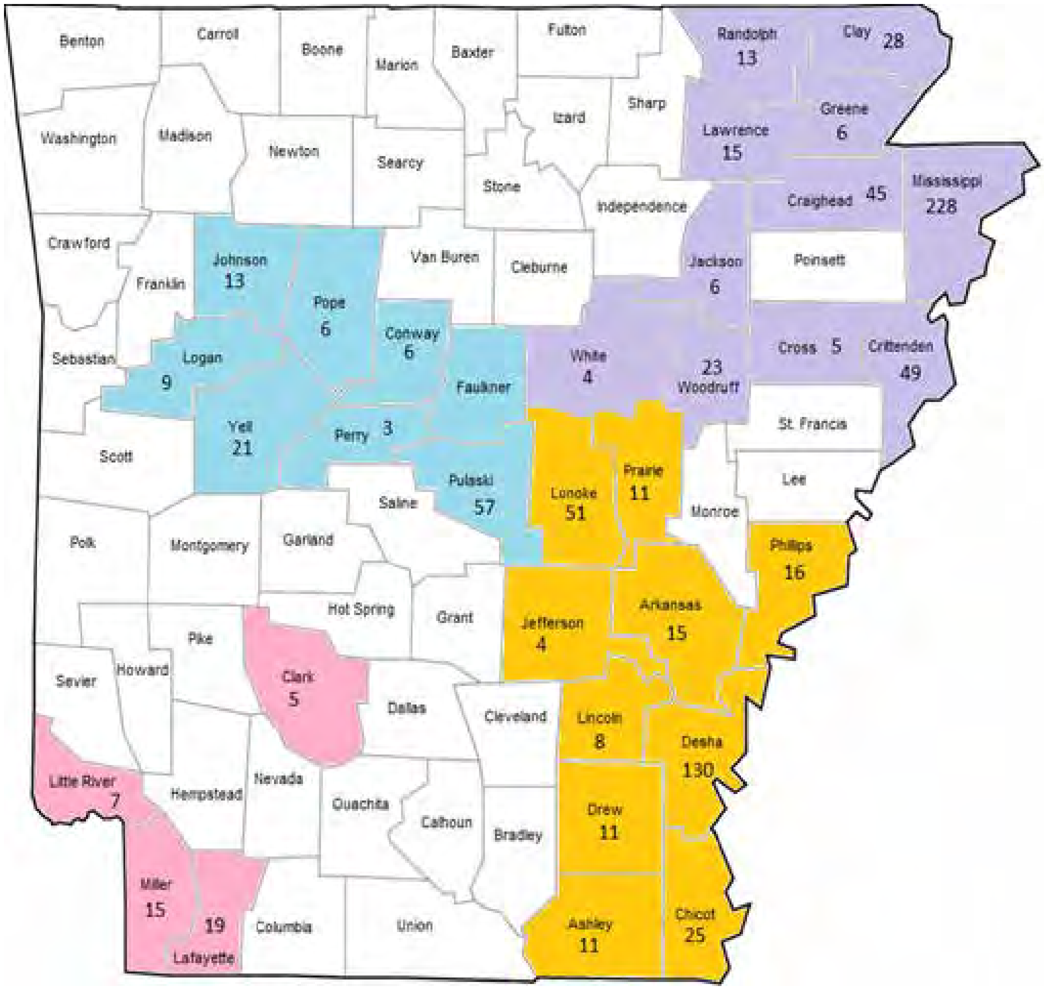

Fig. 1. Counties represented in the 2015 Soybean Promotion Board sponsored soybean survey, and the number of fields that were sampled.

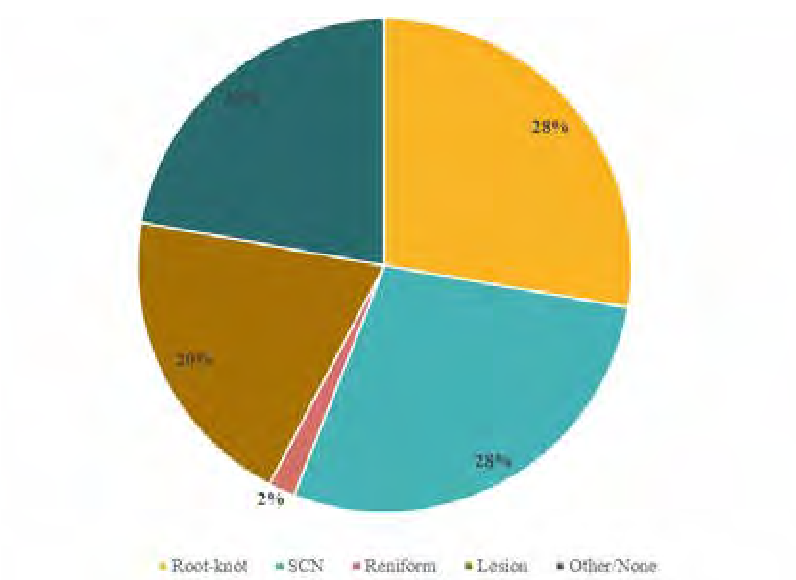

Fig. 2. Percent of Arkansas soybean fields with soybean cyst, root-knot, lesion, and reniform nematodes, 2015.

Assessment of ILeVO® for Management of *Meloidogyne incognita* on Soybean, 2015

C.S. Jackson[1], T.R. Faske[2], and T.L. Kirkpatrick[3]

ABSTRACT

Fluopyram-treated soybean seed (ILeVO®, Bayer CropScience) was registered in 2014 to manage soilborne fungi and plant-parasitic nematodes. Few studies have investigated the use of ILeVO against root-knot nematode (RKN), *Meloidogyne* spp. The objective of this study was to evaluate the field response of ILeVO for suppression of RKN on two soybean cultivars, Delta Grow DG4940 and Delta Grow DG4970. Treatments consisted of ILeVO (fluopyram) applied as an in-furrow (IF) spray, Avicta® (abamectin), Poncho/VOTiVO® (*Bacillus firmus* + clothianidin), ILeVO + Poncho/VOTiVO, and a non-treated control (NTC). Phytotoxicity (necrotic ring on the edge of cotyledon leaves) was observed with ILeVO, but had no effect on plant stand or seedling vigor. A lower percent root galling and nematode reproduction was observed on the moderately resistant cultivar, DG4940 than the susceptible, DG4970. Of these nematicides, a lower root galling was observed with Avicta than ILeVO, fluopyram IF, or the NTC. Lower nematode reproduction was observed with ILeVO + Poncho/VOTiVO, Avicta, and Poncho/VOTiVO than fluopyram IF. Yield was similar between DG4940 and DG4970, and averaged 55 bu/ac. Numerically, a higher yield was observed with ILeVO than the other seed treatment nematicides. The field performance of ILeVO was similar to Avicta and Poncho/VOTiVO in terms of nematode reproduction and yield.

INTRODUCTION

Root-knot nematodes (RKN) are among the most economically important pathogens that affect soybean production in the United States (Kinloch and Rodriguez-Kabana, 1999). In 2012, it was estimated that 2.5 million bushels of soybean were lost, resulting in a loss of $31.3 million in Arkansas (Koenning, 2013; USDA-NASS, 2012). Current management strategies for RKN include host-plant resistance, crop rotation, and nematicides. Although resistance is the most economical and effective strategy, resistant cultivars are limited for the most common soybean maturity group (Group IV) grown in the state. Therefore, many producers rely on nematicides to manage RKN in soybean.

Historically, nematicides were categorized as insecticides; however, there have been a few reports of fungicides with nematicidal activity. Pentachloronitrobenzene (PCNB) and thiophanate-methyl were reported to have some activity against plant-pathogenic nematodes, but performed poorly in field trials to suppress nematode reproduction on row crops (Adams et al. 1979; Faghihi et al., 2007). Currently, fluopyram-treated soybean seed (ILeVO®) is being marketed for use to control plant-pathogenic nematodes. This succinate dehydrogenase inhibitor (SDHI) fungicide, was reported to be toxic to *M. incognita* (Faske and Hurd, 2015), but little is known on how fluopyram performs in the field. Thus, the objective of this study was to evaluate the field performance of ILeVO to suppress RKN in soybean.

PROCEDURES

The study was conducted in a commercial soybean field, with a history of root-knot nematode, near Pine Bluff, Ark. Soybean cultivars, Delta Grow DG4970 (RKN-susceptible) and Delta Grow DG4940 (moderately RKN-resistant) were planted on 6 May at a rate of 150,000 seed/ac. Nematicide treatments consisted of ILeVO (0.15 mg fluopyram/seed, Bayer CropScience, Research Triangle Park, N.C.) Avicta®500 FS (0.15 mg abamectin/seed, Syngenta Crop Protection, Greensboro, N.C.), Poncho/VOTiVO® (0.13 mg B. firmus + clothianidin/seed, Bayer CropScience), ILeVO + Poncho/VOTiVO, an in-furrow (IF) application of fluopyram (41% ai) at 8.5 oz/ac and a non-treated control. Fluopyram as an IF treatment was applied in the seed furrow through a Rebounder Y-Not Split-it in-furrow applicator (Schaeffert Manufacturing Co., Indianola, Neb.) using a pressurized sprayer. The sprayer was calibrated to deliver 6 gal/ac at 50 psi. The experimental design was a split plot with soybean cultivar as the whole plot and nematicide treatments as the sub-plots. Whole plots were randomized in four complete blocks. Individual sub-plots consisted of four, 25-ft rows spaced 30-in. apart, separated by a 3-ft fallow alley. Seedling vigor and plant stand were assessed 14 days after planting by using a five-point scale (1 = most vigorous plants) and counting 10-ft of row, respectively. Nematode infection was estimated at 45 DAP based on the percentage of galls per root system from ten arbitrarily sampled plants per plot. Nematode reproduction was based on eggs collected from two root systems that had the greatest percentage of root galling. Eggs were extracted with 1.0% NaOCl and

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counted using a stereoscope. Plots were harvested on 29 Sept using a K Gleaner combine equipped with a Harvest Master weighing system. Data was subject to mixed GLM model using SPSS (version 19.0) and means were separated by Tukey's honestly significant difference (HSD) test where indicated by a significant ($P = 0.10$) test effect.

RESULTS AND DISCUSSION

The population density of RKN at planting was low (5 second-stage juveniles (J2/100 cm^3 soil), which is the damage threshold of when seed treatment nematicides are recommended for use in soybean. Phytotoxicity, a necrotic ring on the edge of cotyledon leaves, was observed with all fluopyram treatments, and the greatest ($P = 0.10$) incidence of phytotoxicity was observed with ILeVO compared to the other seed treatment nematicides (Table 1). Further, a greater ($P = 0.082$) incidence of phytotoxicity was observed on DG4940 than DG4970, suggesting that phytotoxicity differs among soybean cultivars. Phytotoxicity had had no effect on plant stand or seedling vigor (Table 1). There was no interaction between cultivar and root galling or reproduction, but there was a significant effect between cultivars and among nematicides. Percent root galling and nematode reproduction were lower ($P \leq 0.07$) on DG4940 than DG4970, which corresponds to the level of RKN susceptibility reported by Delta Grow for these two cultivars. Root galling was lower ($P = 0.10$) with Avicta at 45 days after planting (DAP) compared to ILeVO, fluopyram IF, and NTC (Fig. 1). Similarly, nematode reproduction was lower ($P = 0.10$) with Avicta, Poncho/VOTiVO and ILeVO compared to fluopyram IF treatment (Fig. 2). In general, ILeVO + Poncho/VOTiVO contributed to lower root galling and nematode reproduction than ILeVO alone, which is similar to that reported by Hurd et al. (2015). Fluopyram as an IF treatment was less effective at suppressing RKN in soybean compared to that reported in cotton (Lawrence et al., 2015). Soybean yield was similar between cultivars and nematicides, and averaged 55 bu/ac. Numerically, a higher yield was observed with ILeVO + Poncho/VOTiVO, ILeVO and fluopyram IF, which contributed to a yield benefit of 6, 8, and 5 bu/ac, respectively, over the non-treated control yield of 43 bu/ac (Table 1). A similar level of yield protection against RKN has been reported with fluopyram-treated soybean and cotton seed (Hurd et al. 2015; Lawrence et al. 2015). ILeVO provided early season root protection against RKN and yield protection that was similar in magnitude to Avicta and Poncho/VOTiVO.

PRACTICAL APPLICATIONS

Root-knot nematodes are among the most important group of nematodes affecting soybean production in Arkansas. These data support the use of ILeVO as a nematicide, which provided a similar level of RKN control as Avicta and Poncho/VOTiVO. As a new mode of action, ILeVO provides an option for rotating seed treatment nematicides to prolong the usefulness of these tools to manage RKN on soybeans in Arkansas.

ACKNOWLEDGEMENTS

The authors would like to thank Bayer CropScience and the Arkansas Soybean Promotion Board for their funding of this research. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Effect of ILeVO on plant stand, vigor, phytotoxicity and yield.

Cultivar	Stand[†] (14 DAP)	Vigor[‡] (14 DAP)	Phytotoxicity[§] (14 DAP)	Yield (bu/ac)
DG 4940	5.7	2.5	7.6 b	55
DG 4970	6.1	2.8	2.0 a	54
Treatment and rate				
Non-treated control	6.2[¶]	2.8	0.0 a[#]	51
ILeVO (0.15 mg ai/seed)	5.4	2.5	18.3 b	56
Avicta (0.15 mg ai/seed)	6.0	2.9	0.0 a	54
ILeVO (0.15 mg ai/seed)				
Poncho/VOTiVO (0.13 mg ai/seed)	6.0	2.5	9.4 ab	56
Poncho/VOTiVO (0.13 mg ai/seed)	6.1	2.8	0.0 a	54
Fluopyram (41% ai, 8.5 fl oz/ac)	6.1	2.6	1.6 a	55
Statistics: Prob (F)				
Cultivar	0.35	0.12	0.08	0.64
Treatment	0.25	0.67	0.001	0.29
Cultivar x Treatment	0.58	0.67	0.01	0.60

[†] Plant population per ft of row.

[‡] Vigor was based on a 5-pt scale with 1 being the most vigorous.

[§] Percent of plot with phytotoxic seedlings.

[¶] Values are averages of two soybean cultivars, DG 4970 and DG 4940.

[#] Data within columns with a different letter indicate a significant difference at $P = 0.10$ according to the Tukey's honestly significant difference test.

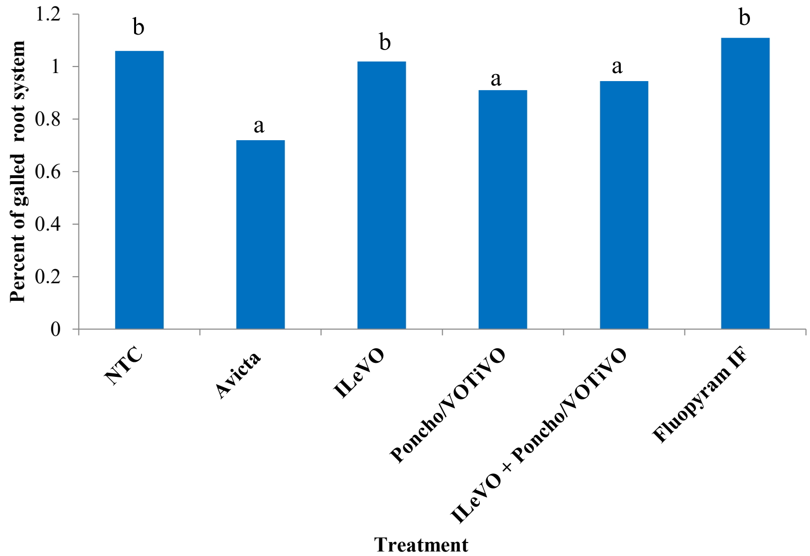

Fig. 1. Effect of fluopyram as a seed treatment and in-furrow applications on suppressing *Meloidogyne incognita* infection on soybean. Different letters over bars indicate a significant difference at *P* = 0.10 according to Tukey's honestly significant difference test.

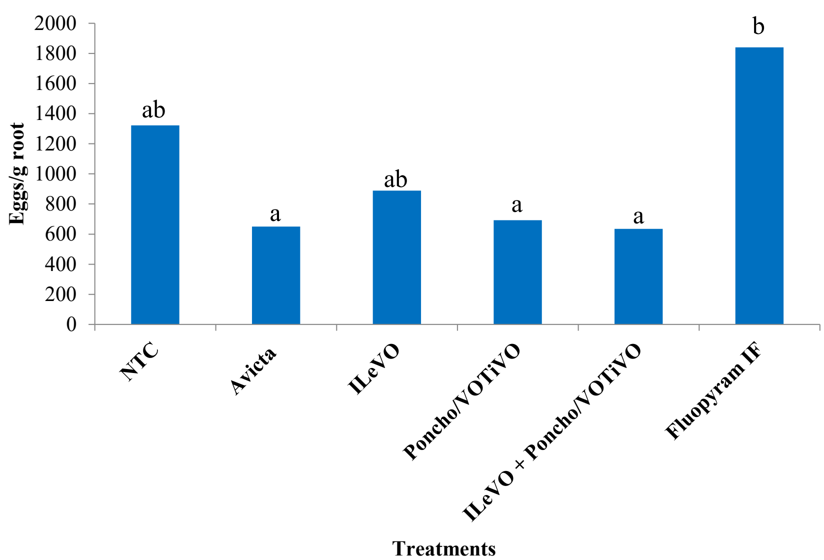

Fig. 2. Effect of fluopyram as a seed treatment and in-furrow applications on suppressing reproduction of *Meloidogyne incognita* on soybean. Different letters over bars indicate a significant difference at *P* = 0.10 according to Tukey's honestly significant difference test.

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

T.R. Faske[1], M. Emerson[1], and K. Hurd[1]

ABSTRACT

Frogeye leaf spot (FLS), caused by *Cercospora sojina*, is an important foliar disease of soybean in Arkansas. Strobilurin-resistant isolates of *C. sojina* were confirmed in 2012 in Arkansas, and now have spread across the majority of the soybean-producing counties (n = 27). Currently, few studies have investigated the efficacy of triazole fungicides to control FLS. The objective of this study was to determine the field performance of five triazole fungicides to control strobilurin-resistant FLS. Fungicides included Domark®, Alto®, Proline®, Topguard®, and Tilt®. These fungicides were applied at the low labeled rates for soybean when FLS severity was low (~0.1%) at R4 stage of growth. Disease development was recorded at 7, 14, and 21 days after application. A lower degree of FLS severity was observed for all triazole fungicides compared to the non-treated control and a standard strobilurin fungicide, Quadris®. Numerically, Domark, Topguard, and Proline provided the best disease suppression and yield protection among these triazole fungicides. Triazole fungicides are effective tools to manage strobilurin-resistant FLS; however, good fungicide management practices should be adopted to prolong the usefulness of these fungicides.

INTRODUCTION

Frogeye leaf spot (FLS) of soybean, caused by *Cercospora sojina,* is one of the most important foliar diseases across the mid-southern United States. Generally, yield losses range from 12% to 15%, but can reach as high as 30% on susceptible soybean cultivars (Phillips, 1999). Estimated losses due to FLS in Arkansas, Louisiana, Mississippi, Missouri, Tennessee, and Texas in 2014 was $96 million (Allen et al., 2015; USDA-NASS, 2014).

Fungicides are commonly used to control FLS with the most common fungicides consisting of the quinone outside inhibitors (QoI; also known as strobilurin) and demethylation inhibitors (DMI; also known as triazole). In 2010, isolates of *C. sojina*, collected from Lauderdale Co., Tenn. were confirmed to be resistant to strobilurin fungicides (Zhang et al., 2012a; 2012b). As a result, strobilurin fungicides like Quadris® and Headline® are no longer effective at controlling these resistant strains of FLS. The first isolates of strobilurin-resistant *C. sojina* were detected in 2012 in Arkansas. Since then, fungicide-resistant isolates have been detected in 27 counties, which plant over 90% of the soybean crop grown in Arkansas. Currently, there are few data on the efficacy of triazole fungicides to manage strobilurin-resistant FLS. Thus, the objective of this study is to evaluate five commercially available triazole fungicides for control of strobilurin-resistant FLS.

PROCEDURES

Triazole fungicides were applied at the low labeled rates for control of strobilurin-resistant FLS. This trial was located at the University of Arkansas System Division of Agriculture's Newport Extension Center in Newport, Ark. in a field of Dundee silt loam previously cropped in soybean. The soybean cultivar 'Armor DK4744' was planted on 4 June at a seeding rate of 150,000 seed/ac. Weeds were controlled using Gramoxone® + Valor® + NIS (48.0 fl oz/ac + 2.0 oz/ac + 0.25 % v/v) applied pre-plant on 4 June followed by Roundup® + Dual II Magnum® (1 qt/ac + 1 pt/ac) applied post-plant 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 *C. sojina* at the R1-R2 growth stage. Fungicides were broadcast through flat-fan nozzles (Tee-Jet® 110015VS) spaced 30 in. apart over the two center rows per plot using an air pressurized multi-boom plot sprayer. The sprayer was calibrated to deliver 15 gal/ac at 32 psi. Fungicides consisted of Quadris (azoxystrobin; fungicide-resistant control), Domark® (tetraconazole), Alto® (cyproconazole), Proline® (prothioconazole), Topguard® (flutriafol), Tilt® (propiconazole), and a non-treated control (NTC). Fungicides were applied at the R4 growth stage on 8 Aug. Frogeye leaf spot severity was assessed at 7, 14, and 21 days after treatment based on a 10-point rating scale of the upper one-third of the plant canopy. These data were converted to percent severity and used to calculate the area under the disease progress curve (AUDPC). Plots were harvested on 19 Oct using a K Gleaner combine (AGCO, Duluth, Ga.) equipped with a Master Scales Weighing System (System Scales, Indianapolis, Ind.). Data were subject to GLM procedure and mean separation by Tukey's honestly significant difference (HSD) test at $P = 0.05$ using Agricultural Research Manager Software v. 9.0 (Gylling Data Management, Brookings, S.D.).

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RESULTS AND DISCUSSION

Fungicides were applied at a low degree of FLS severity (~0.1%) at R4 growth stage. During the 2015 cropping season, environmental conditions were favorable for FLS development as 15% of the upper canopy was infected at 21 days after treatment (DAT) on the non-treated control (NTC). A lower ($P = 0.05$) AUDPC was observed in plots treated with Domark, Alto, Proline, Topguard, and Tilt compared to the NTC (Fig. 1). Of these triazole fungicides, Domark, Proline, and Topguard had the lowest FLS severity 21 DAT of 4.3%, 7.5%, and 3.3%, respectively. As expected, the Quadris fungicide provided the poorest disease control which suggests the majority of the FLS population present are resistant to strobilurin fungicides. No phytotoxicity was observed for any treatment. Numerically, yield protection was greater with Domark, Proline, and Topguard compared to the NTC (Fig. 2). However, Quadris provided an equal level of yield protection, which was likely due to other foliar diseases and variation among treatments. Similar studies reported good efficacy by triazole fungicides to suppress FLS and protect yield potential across the mid-South (Emerson et al., 2014; Kelly, 2014; Price et al., 2014; Wilerson et al., 2014). Triazole fungicides applied at low rates were effective at suppressing disease development of strobilurin-resistant FLS and protecting soybean yield potential.

PRACTICAL APPLICATIONS

Triazole fungicides are effective tools to manage strobilurin-resistant FLS on susceptible soybean cultivars. Of these triazole fungicides, Proline, Topguard, and Domark provided a greater level of control, which may be related to fungicide resistance in older generation triazole fungicides such as Tilt or Alto. Thus, fungicide resistance management should be a common practice to prolong the usefulness of these fungicides to manage strobilurin-resistant FLS.

ACKNOWLEDGEMENTS

The authors would like to thank the Arkansas Soybean Promotion Board for funding this research project. Support was also provided by the University of Arkansas System Division of Agriculture.

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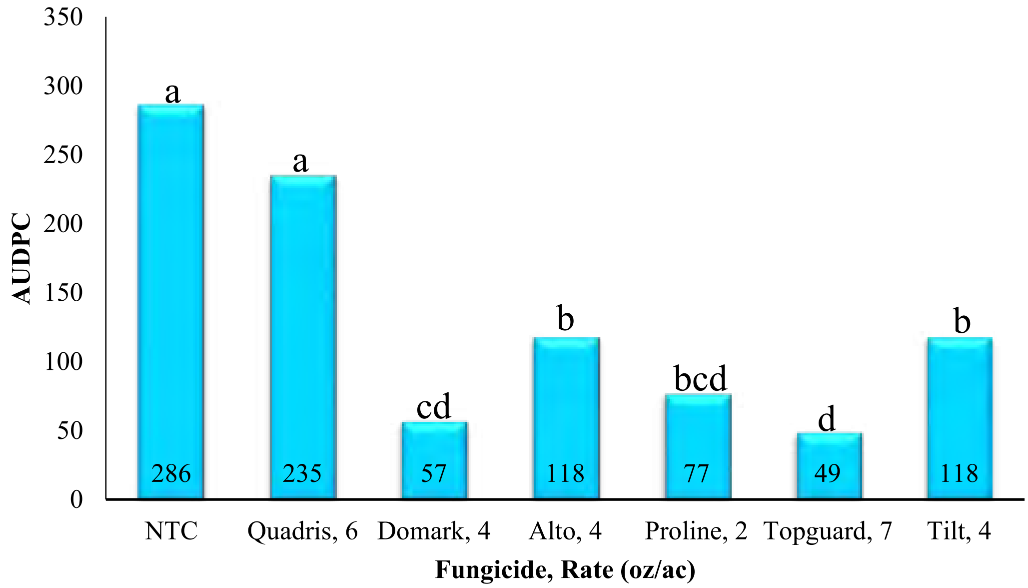

Fig. 1. Effect of five triazole fungicides to control strobilurin-resistant frogeye leaf spot. Different letters over bars indicate a significant difference at α = 0.05 according to Tukey's honestly significant difference test. AUDPC = area under the disease progress curve.

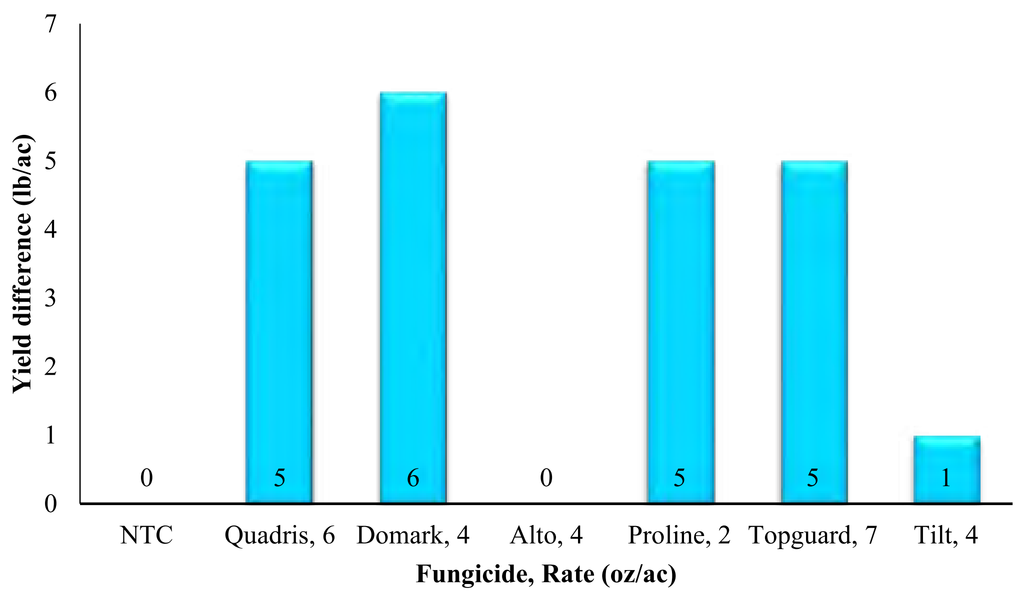

Fig. 2. Effect of five triazole fungicides to protect soybean yield potential. Yield of non-treated control (NTC) was 43 bu/ac. Yield was adjusted to 13% moisture.

2015 Soybean Seed Treatment Results

J. Rupe[1], A. Steger[1], and R. Holland[1]

ABSTRACT

Sixteen soybean seed treatments were compared at three locations and two planting dates in 2015. The locations were the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), the Lon Mann Cotton Research Station (LMCRS) and the Rice Research and Extension Center (RREC). Rain in April delayed plantings until May and June. Seed treatments resulted in significantly greater stand than the untreated control at NEREC and LMCRS in May, at LMCRS and RREC in June. All seed treatments had significantly greater stands than the untreated control in at least one test, while ApronMaxx® had significantly greater stands than the untreated control in four of the five tests. Seed treatments resulted in significantly greater yields than the control in the June planting at RREC with the greatest yield from Avicta® Complete Beans 500 and EverGol® Energy treatments. Yields were not significantly different from the control at the other planting dates and locations.

INTRODUCTION

Establishing a healthy, vigorous stand is important for Arkansas soybean producers at any planting date. Poor stands may necessitate replanting, increase competition from weeds, and result in low yield. The best protection against stand loss is the use of a seed treatment. Seed treatments vary in the types and concentrations of fungicides, insecticides and nematicides they contain. The potential for seedling diseases occurs across all planting dates and soil types. These diseases are caused by a wide range of pathogens so knowing which seed treatments are most effective under Arkansas conditions is important information for our soybean producers. This study compares the effects on stands and yield of the most commonly available seed treatments across a range of planting dates, soil types, and locations.

PROCEDURES

Sixteen seed treatments were selected for testing based on MP-154 Arkansas Plant Disease Control Products Guide 2015 (Faske et al., 2015) and discussions with extension pathologists. Soybean cv. 'Armor 49R56' seeds were treated with the recommended rates of each fungicide (Table 1). Besides containing one or more fungicides, some of the seed treatments also contained an insecticide and some a nematicide. The control was treated with water alone. Tests were planted at 69,000 to 87,000 seed/ac at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Keiser Ark., on 8 May and 10 June; at the Lon Mann Cotton Research Station (LMCRS), Marianna Ark., on 5 May and 5 June; and at the Rice Research and Extension Center (RREC), Stuttgart Ark., on 16 June. Rain prevented an April planting at all locations and a May planting at RREC. Stands were counted at two and four weeks after planting (only the four week results are presented) and yield were taken at the end of the season. The plots were observed for other diseases during the season. Each planting date at each location was analyzed separately with PROC MIXED SAS v. 9.2 (SAS Inc., Cary, N.C., USA). The significant difference between treatments was determined with LSMEANS.

RESULTS AND DISCUSSION

Seed treatments resulted in significantly greater stands than the control in four of the five tests (Table 2). Avicta® Complete Beans 500 resulted in the greatest stand in the May planting at NEREC, but there were 12 other treatments that had stands significantly greater than the control at this location. Trilex® 2000 resulted in the greatest stand in the May planting at LMCRS and there were four other treatments with stands significantly greater than the control. All treatments in the June planting at LMCRS were significantly greater than the control with ApronMaxx® + Dynasty® resulting in the greatest stands. In the June planting at RREC, CruizerMaxx® Vibrance had the greatest stands and ten other treatments were significantly greater than the control. Yield was also significantly affected in this test with the greatest yield coming with Avicta Complete Beans 500 and EverGol® Energy seed treatments. Three other treatments had significantly higher yield than the control in this test. These five treatments resulted in 5.33 to 7.49 bu/ac greater yield than the control. While there was not a significant effect of seed treatment on yield at the other locations or planting dates, the control generally had the lowest yield in these tests. ApronMaxx, while not resulting in the greatest stands, resulted in stands significantly greater than the control in four of the five tests, while 12 of the other treatments were effective in three of the four tests. There was no clear advantage to including an insecticide or nematicide in the seed treatment, but that might reflect low insect or nematode

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pressure in these fields. In 2014, ILeVO® was registered by Bayer CropScience for control of sudden death syndrome of soybean (SDS) and suppression of nematodes. While ILeVO was included as a seed treatment with EverGol Energy + PonchoVOTiVO®, SDS was not observed in any of our tests probably because rain prevented the April plantings which would have favored SDS development.

PRACTICAL APPLICATIONS

This research demonstrates the importance of seed treatments in establishing a soybean crop across typical planting dates in Arkansas. While no one seed treatment was best across all environments, all effectively increased stand in at least one environment and these treatments can lead to greater yield compared to the untreated control. These data demonstrate that growers should use a seed treatment whenever they plant soybean.

ACKNOWLEDGEMENTS

This research was funded by the Arkansas Soybean promotion board. The authors want to thank Fred Bourland and Shawn Lancaster at the Northeast Research and Extension Center, Claude Kennedy at the Lon Mann Cotton Research Station, and Charles Wilson and Jonathan McCoy at the Rice Research and Extension Center for their help in managing the plots. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Seed treatment, active ingredients and application rates used in the seed treatment comparison trials in 2015.

Seed Treatment	Active ingredients	Rate (fl oz./cwt)
ApronMaxx®RTA	Fludioxonil (0.73%) Mefenoxam (1.1%)	5
ApronMaxxRTA + Dynas®	Fludioxonil (0.73%) Mefenoxam (1.1%) Azoxystrobin (9.6%)	5 + 0.153
ApronMaxxRTA + Dynasty + Cruiser® 5FS	Fludioxonil (0.73%) Mefenoxam (1.1%) Azoxystrobin (9.6%) Thiamethoxam (47.6%) [a]	5 + 0.153 + 1.3
CruiserMaxx® Vibrance	Mefanoxam (3.13%) Fludioxonil (1.04%) Sedaxane (1.04%) Thiomethoxam (20.8%)	3.22
CruiserMaxx Vibrance + Clariva® PN	Mefanoxam (3.13%) Fludioxonil (1.04%) Sedaxane (1.04%) *Pasteuria nishizawae*-PN1[b] Thiomethoxam [a] (20.8%)	3.22 + 2
Avicta® Complete Beans 500	Abamectin [b] (22.02%), Thiamethoxam [a] (11.01%), Mefenoxam (1.67%), fludioxonil (0.55%)	6.2
PCNB + Vitavax®	Pentachloronitrobenzene (17%) Carboxin (17%)	4
EverGol® Energy	Metalaxyl (6.74%) _Penflufen (3.59%) Prothioconazole (7.18%)	1
EverGol Energy + Gaucho®	Metalaxyl (6.74%) _Penflufen (3.59%) Prothioconazole (7.18%) Imidacloprid [a] (48.7%)	1 +1.6
EverGol Energy + Poncho Votivo + Ilevo®	Metalaxyl (6.74%) _Penflufen (3.59%) Prothioconazole (7.18%) Clothianidin 40.3%) *Bacillus firmus* (8.1%) [b]	1 + 2 + 2.38
EverGol Energy + PonchoVotivo + ILeVO	Metalaxyl (6.74%) _Penflufen (3.59%) Prothioconazole (7.18%) Clothianidin [a] (40.3%) *Bacillus firmus* [b] (8.1%) Fluopyram (48.4%)	1 + 2 + ?
Allegiance® FL	Metalaxyl (28.35%)	1.5
Maximv	Fludioxonil (21%) Metalaxyl (8.4%)	0.08
Trilex® 2000	Trifloxystrobin (7/12%) Metalaxyl (5.62%)	1
Trilex 2000 + Gaucho	Trifloxystrobin (7/12%) Metalaxyl (5.62%) Imidacloprid [a] (48.7%)	1 + 1.6
Vibrance®	Sedaxane (43.7%)	1

[a] Insecticide
[b] Nematicide

Table 2. Effect of seed treatments on stands (plants/ac) and yields (bu/ac) of the soybean cultivar Armor 49R56 planted at the Northeast Research and Extension Center (NEREC), the Lon Mann Cotton Research Station (LMCRS) and the Rice Research and Extension Center (RREC) in May and June†, 2015.

	NEREC				CRS				RREC	
	May		June		May		June		June	
Seed Treatment	Stand	Yield	Stand	Yield	Stand	Yield	Stand	Yield	Stand	Yield
ApronMaxx® RTA	55490 ab‡	85.6	45245	52.5	62641ab	48.1	60372 abc	40.5	63946 bc	53.3 abcd
AMRTA® + Dynasty	52746 abc	81.8	44351	42.8	62160 abc	48.2	60716 a	39.3	62204 c	51.1 bcdef
AMRTA +Dyn + Cruiser 5FS®	54999 ab	83.7	48820	52.3	62160 abc	47.6	58791 abc	39.7	69870 abc	51.29 bcdef
CruiserMaxx® Vibrance	56109 ab	82.2	45382	55.4	61541 abc	47.8	59753 abc	38.3	74575 a	51.6 bcdef
CruiserMaxx Vibrance+Clariva® PN	55903 ab	82.9	45382	56.1	61197 abc	49.8	58997 abc	39.4	70132 abc	52.5 abcde
Avicta® CompleteBeans 500	57622 a	85.7	46620	54.4	60578 a-d	48.4	56934 abc	40.8	70654 ab	56.4 a
PCNB + Vitavax®	45932 d	83.7	44351	55.3	59066 bcd	50.8	45932 d	40.0	61071 cd	55.1 ab
EverGol® Energy	55971 ab	84.8	43526	52.8	62916 a	45.3	56521 abc	37.2	58109 d	56.4 a
EE + Gaucho®	52533 bc	84.5	43319	57.9	57347 d	49.2	58309 abc	39.4	71613 ab	54.9 ab
EE + PV + ILeVO®	53840 abc	82.9	48270	56.1	61266 abc	49.6	49989 d	36.9	74400 a	54.2 abc
EE + Poncho Votivo®	54784 ab	83.1	46895	45.9	61335 abc	50.0	56521 abc	36.9	67605 abc	48.4 ef
Allegiance® FL	54802 ab	81.2	38987	50.0	62572 ab	49.9	52877 cd	39.8	60897 cd	46.9 f
Maxim® 4FS	48958 cd	83.7	42907	53.4	62572 ab	50.3	54734 cd	37.8	53579 d	50.5 bcdef
Trilex® 2000	55146 ab	82.0	43526	52.8	63191 a	53.8	58447 ab	37.9	60026 d	49.3 def
Trilex 2000 + Gaucho®	53358 bc	81.6	46620	54.7	52740 e	50.0	54252 cd	35.9	67344 abc	51.5 bcdef
Vibrance®	47926 d	80.6	44763	51.3	62022 abc	49.8	50608 d	39.2	64730 bc	49.9 cdef
Water (control)	48270 d	80.6	44007	52.4	58791 cd	46.8	41394 e	35.1	57151 d	48.9 def

† Planting dates were 8 May and 10 June at NEREC, 5 May and 5 June at LMCRS, and 16 June at RREC. Planting rates ranged from 69,000 to 87,000 seed/ac.

‡ Numbers followed by the same letter within a column were not significantly different ($P < 0.05$) based on the differences in LSMEANS as determined by PROC MIXED.

Potential for the Integration of Brassica Winter Cover Crops into Soybean Production Systems for the Suppression of Nematodes and Other Soilborne Diseases

C.S. Rothrock[1] *and T.L. Kirkpatrick*[2]

ABSTRACT

Plant parasitic nematodes are an increasing problem on soybean in Arkansas. Recent research has suggested the value of brassica cover crops for suppression of plant pathogens. University of Arkansas System Division of Agriculture Agricultural Experiment Station and producers' fields were identified for trials where nematodes were limiting soybean yields. Locations included sites with root-knot nematodes or soybean cyst nematodes. Winter cover crops were established in one producer field and two Experiment Station sites. The brassica crops planted were the Indian mustard 'Fumus', tillage radish, and rapeseed 'Coahoma'. These brassicas cover crops were compared to wheat, rye, the legume cover crop hairy vetch, and winter fallow. For the 2015 soybean crop, winter cover crop biomass was variable, with one site having tillage radish being winter killed. No significant differences were found in the value of winter cover crops for management of the soybean cyst nematode in 2015. This research is designed to give soybean producers an additional cost-effective method for nematode management.

INTRODUCTION

Plant parasitic nematodes are an increasing problem on soybean in Arkansas. The soybean cyst nematode has historically been the most important nematode, but the root-knot nematode is increasing in importance in part as a result of soybean being planted in fields historically used for cotton production. Options for economical control of nematodes are limited, with the most effective treatment being the use of preplant fumigants, such as Telone® II (1,3-dichloropropene). This study is evaluating the value of winter cover crops for the management of nematode problems on soybean.

Winter cover crops have historically been examined for minimizing soil erosion and nutrient management. However, more recent research has focused on selected cover crops to suppress plant pathogens. Winter cover crops fit well in production systems in the Southeast because of moderate winter temperatures and adequate rainfall allowing the production of a subsequent cash crop. Much of the recent work on winter cover crops has examined the value of brassica crops, which include canola and mustard crops. Many brassicas contain high quantities of glucosinolates which break down into toxic compounds when the plant tissue is destroyed at crop termination (Kjaer, 1976; Sarwar et al., 1998). The process of incorporating plant material into the soil to control pathogens or pests through the release of toxic decomposition chemicals is termed biofumigation. Brassica residues have been used to reduce diseases on a number of crops, including soybean (Lodha et al., 2003). Research conducted in Arkansas on cotton has demonstrated the value of Indian mustard (*Brassica juncea*) cv. 'Fumus' to suppress nematodes and diseases on cotton (Bates and Rothrock, 2006).

The goals of this research are to establish a sustainable soybean production system for nematode infested fields by growing a high-glucosinolate brassica winter cover crop and to quantify the impact of incorporating brassica cover crops on soilborne pathogens.

PROCEDURES

Winter cover crop studies were established in one producer field and two University of Arkansas System Division of Agriculture Agricultural Experiment Station sites in late September 2014. The replicated field trial at Rohwer Research Station was established on a field with a history of root-knot nematode with the treatments winter fallow and the winter cover crops Indian mustard 'Fumus', Tillage radish, and wheat. Another location with a history of root-knot nematode damage was a producer's field near Star City and included the cover crop treatments rye, Fumus, Tillage radish, wheat, hairy vetch, and winter fallow. At the Lon Mann Cotton Research Station near Marianna, a trial was established on a field with a history of soybean cyst nematode problems. Treatments include the winter cover crops, rapeseed 'Coahoma', tillage radish, Fumus, hairy vetch, and wheat and winter fallow.

The cover crops were desiccated using herbicides prior to incorporation, at least four weeks prior to planting soybean. Cover crop biomass was measured prior to destruction on 31 March 2015 for Star City and 6 April for Marianna by harvesting 10.8 ft^2. Soybeans were managed by standard production practices.

Soil samples were collected from plots prior to cover crop establishment, at planting of the soybean crop, mid-season, and at harvest. Nematode population densities were evalu-

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ated for each of the above-mentioned sampling dates. Destructive samples were taken to assess soybean development mid-season to assess nematode reproduction.

RESULTS AND DISCUSSION

Cover crop biomass was determined for the Star City and Marianna locations. The cover crop trial at Rohwer was abandoned as a result of poor cover crop establishment. Cover crop biomass was variable among the two other sites (Table 1). All cover crops and winter weeds had greater biomass at Marianna than at Star City, except tillage radish which was winter-killed at Marianna. Hairy vetch had the greatest biomass among the cover crops, with the brassica crops and cereals having similar biomass production in the winter of 2014.

At Marianna, the fall 2014 soybean cyst nematode populations ranged between 23 and 69 juveniles prior to cover crop establishment. Mid-season soybean cyst nematode counts ranged from 503 nematodes/soybean root system following the Indian mustard cover crop to 746 for winter fallow (Table 2). Although all winter cover crops resulted in lower nematode numbers on the soybean root system, no significant differences were present. A similar trend was found for soybean cyst nematode populations after harvest. Soybean yields were not affected by winter cover crop treatment. The location at Star City was lost due to planting errors. In 2015, winter cover crops were not found to have a significant impact on important plant parasitic nematodes on soybean.

PRACTICAL APPLICATIONS

This winter cover crop soybean production system is designed to minimize losses from nematodes and diseases and thus increase yields. If successful, brassica winter cover crops should give soybean producers an additional cost effective method for nematode management.

ACKNOWLEDGEMENTS

This material is based upon work that was supported, in part, by the Arkansas Soybean Promotion Board and a USDA National Institute of Food and Agriculture Hatch Project. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Winter cover crops biomass production at two locations.

Winter cover crop	Fresh aboveground biomass (lbs/ac)	
	Marianna	Star City
Hairy vetch	31,503	8,046
Indian mustard	12,450	3,928
Tillage radish	0	4,015
Winter fallow	1,507	104
Rapeseed	12,477	
Rye		5,155
Wheat	12,767	3,984

Table 2. Winter cover crop effects on soybean cyst nematode population and soybean yield at Marianna.

Cover crop	Soybean cyst nematode/root system (mid-season)	Soil population Fall 2015	Soybean yield (bu/ac)
Hairy vetch	646	13	33
Indian mustard	503	10	32
Tillage radish		25	32
Winter fallow	746	61	31
Rapeseed	516	31	31
Wheat	513	38	33

Foliar Fungicide Efficacy at Multiple Timings on Frogeye Leaf Spot in Maturity Group 4 and 5 Soybean Cultivars

T.N. Spurlock[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 caused by the fungus *Cercospora sojina* on soybean. Chemistries included strobilurins, triazoles, carboximides, and mixed modes of action to account for growing strobilurin-resistant populations. Two plantings were made, a group 4 cultivar as a full-season production system and a group 5 cultivar planted to simulate a double cropping system. In the maturity group 5 timing trial, Headline® (strobilurin) did not provide as much control as Domark® (triazole) or Quilt Xcel® (strobilurin + triazole). In the maturity group 4 timing trial, disease severity remained less than 1% throughout the growing season. In the group 4 fungicide performance trial, frogeye leaf spot levels remained less than 1% throughout the growing season and fungicide applications were made at beginning seed (R5). In the group 5 fungicide performance trial, Domark® and Equation® (strobilurin) provided the most control compared to the untreated check. No statistical differences were shown in yield in either maturity group.

INTRODUCTION

Cercospora sojina, a fungal pathogen on soybean, causes a foliar disease called frogeye leaf spot (FLS), and can be found anywhere soybeans are grown. Frogeye leaf spot can cause yield reductions of up to 30% in susceptible cultivars (Phillips, 2008). Symptoms present on leaves as purple water soaked spots, developing into circular to angular brown lesions surrounded by dark reddish-brown margins. On the lower surface of the leaves, spots are darker in color and have light to dark grey centers while sporulating. The fungus survives the winter on infected seeds and infested soybean residue (Phillips, 2008). Due to the increasing acreage of soybean in Arkansas, and more fields planted to soybean in successive years, disease pressure from FLS is likely to be high each year given weather favorable for disease development. Therefore, making the best management choices such as resistant cultivars, high quality seed selection, deep tillage of residues, crop rotation, and foliar fungicides are 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 resistant to strobilurin fungicides and data indicate strobilurin fungicides do not provide adequate control (Emerson et. al., 2014 and Spurlock et al., 2015). 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 University of Arkansas System Division of Agriculture's Rohwer Research Station near Rohwer, Ark. and arranged in a randomized complete block design. Each trial contained three fungicide treatments and an untreated check replicated five times, differing only in maturity group. The maturity group 4 (MG 4) test was planted 9 June, with AgVenture47E1RR, a full-season soybean production system, and the maturity group 5 MG 5) test was planted 9 June, with AgVenture52B2RR, simulating a double-crop soybean production system. Both tests were planted on 38-in. row spacing at a seeding rate of 140,000 seed/ac and divided into 4-row plots 20-ft long. The center two rows of each plot were sprayed at multiple timings: beginning flowering (R1), 6th trifoliate (V6 on MG 5), V6+R1, beginning pod (R3), beginning seed (R5) or as needed according to integrated pest management practices, and R1+R3. 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 weekly intervals post-application. The center two rows were harvested 20 Oct (MG 4) and 22 Oct (MG 5) with a plot combine at an average of 8.8% moisture content. Data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects (fungicide treatments) using Fisher's protected least significant difference test (LSD) $P = 0.10$.

Fungicide Performance Trials. Two separate trials were conducted in a silt loam field at Rohwer Research Station and arranged in a randomized complete block design. Each trial contained 11 fungicide treatments and an untreated check replicated five times, differing only in maturity group. The MG 4 and MG 5 tests were planted 9 June, both on 38-in.

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row spacing at a seeding rate of 140,000 seed/ac and divided into 4-row plots 20-ft. long. The center two rows of each plot were sprayed at beginning seed (R5) on 26 Aug on both tests. Fungicides were applied with a MudMaster sprayer 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 22 days post-application for both maturity groups. The center two rows were harvested with a plot combine 20 Oct and 21 Oct for MG 4 and MG 5, respectively. Data were subjected to ANOVA followed by means separation of fixed effects using Fisher's protected LSD test $P = 0.10$.

RESULTS AND DISCUSSION

Fungicide Timing Trials. Frogeye leaf spot severity remained below 1% for the duration of the season in the MG 4 trial as the variety grown was moderately resistant to the disease. No other diseases were observed in the trial and there were no statistical differences in yield (Fig. 1). Yield ranged from 44.5 to 50.0 bu/ac among treatments indicating a fungicide application would likely not be economical at any timing tested at this level of disease severity.

In the MG 5 trial FLS ratings and yield, Figs. 2 and 3 respectively, lacked significant differences; although 21 days after the R5 application, Headline® (strobilurin) ratings were as high as or higher than the untreated check for all timings. All treatments had been applied on 27 Aug, although, numerically, some timings × fungicide did improve disease control over the untreated check.

Fungicide Performance Trials. Frogeye leaf spot severity remained below 1% for the duration of the season in the MG 4 trial. No other diseases were observed and statistical differences were absent in yield (Fig. 4). In the MG 5 trial, FLS was rated 21 days after the R5 application. Domark® and Equation® were the only treatments with ratings statistically significant from the untreated check (Fig. 5); however, none of the treatments had any effect on yield (Fig. 6).

PRACTICAL APPLICATIONS

These results support the practice of sound IPM where scouting and spraying is likely more effective than applying a fungicide at a given growth stage "automatically". There was no significant yield gain over the untreated checks by any product applied indicating an economic disadvantage to fungicide application with low disease severity. Additionally, in the soybean production area of Arkansas, the population of *C. sojina* is largely resistant to strobilurin fungicides due to repeated applications selecting out the tolerant population of isolates. Due to this resistance issue, and subsequent repeated failures of strobilurin fungicides applied alone in attempts to control FLS, products with mixed modes of action have been used. In many cases, these fungicides are more expensive than a fungicide with a single chemistry and cause the farmer to incur even greater expense and profit loss when disease is absent or at lower levels as was the case in 2015 in these tests. These data support findings from other studies and indicate that regardless of product used and timing, fungicides do not increase yield significantly. When disease is active on a susceptible cultivar, a well-timed fungicide application with a chemistry effective on the disease will likely keep the yield that would have been lost had the disease not been controlled.

AKNOWLEDGEMENTS

The authors 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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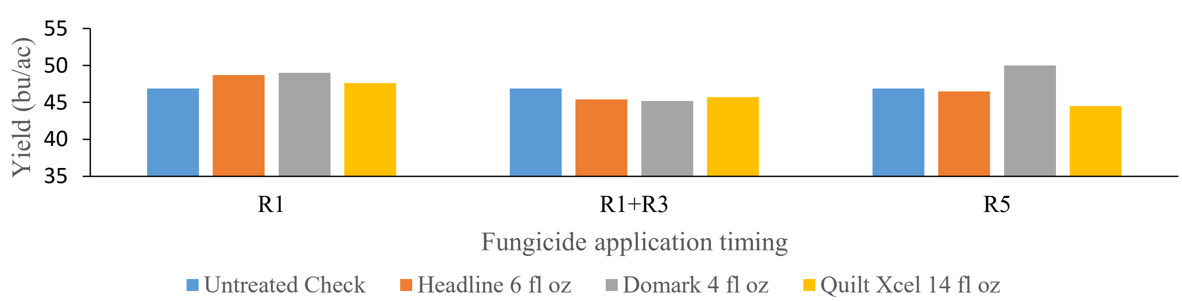

Fig. 1. Maturity group 5 soybean timing trial yields (bu/ac) by fungicide timing for soybean variety 47E1RR®.

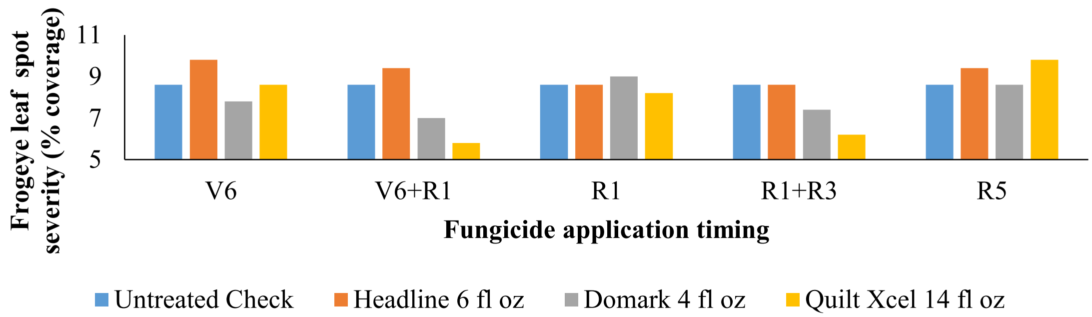

Fig 2. Timing trial for frogeye leaf spot severity on maturity group 5 soybean 21 days after R5 application for soybean variety 52B2RR®.

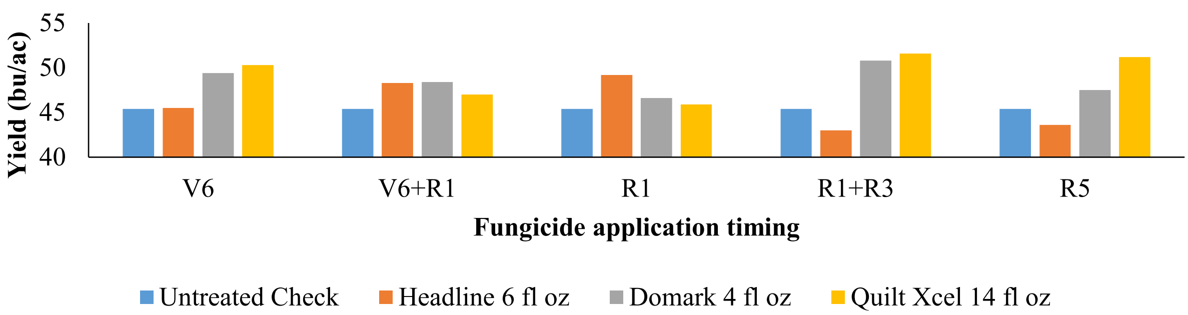

Fig. 3. Maturity group 4 soybean timing trial yields (bu/ac) by fungicide timing for soybean variety 47E1RR®.

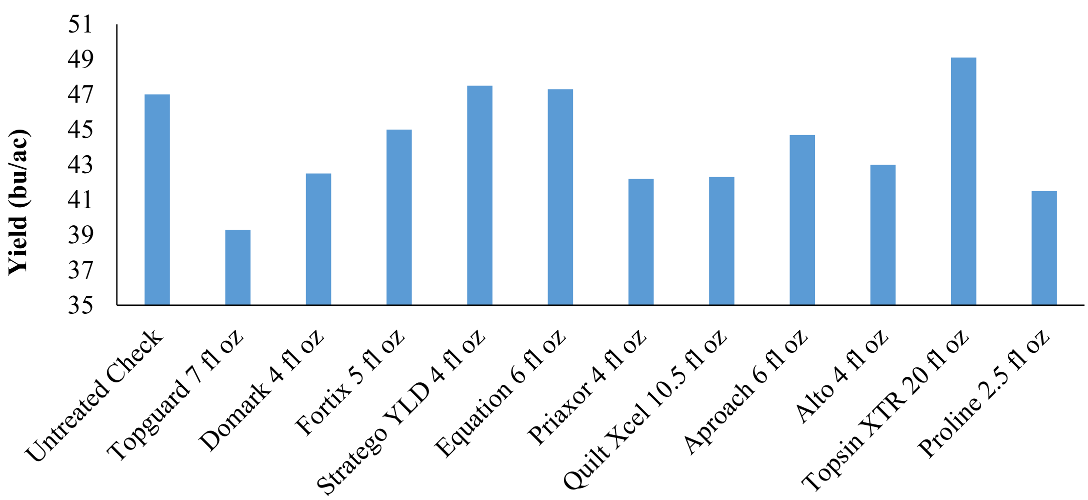

Fig. 4. Maturity group 4 soybean fungicide performance trial yields (bu/ac) for soybean variety 47E1RR®.

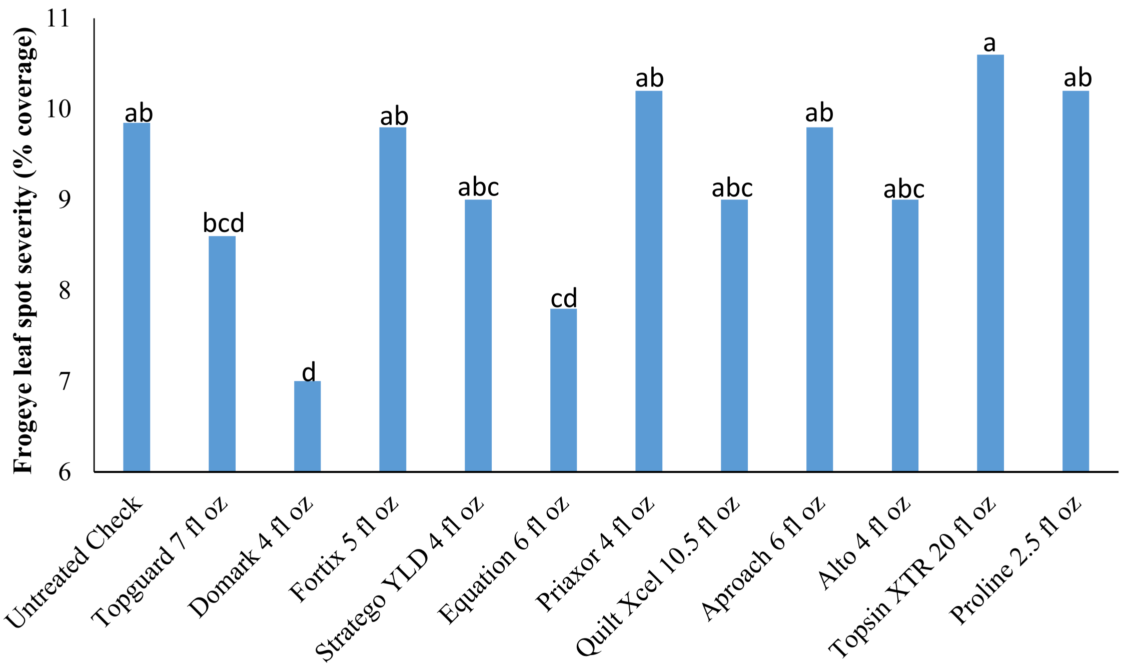

Fig. 5. Fungicide performance trial frogeye leaf spot percentages on maturity group 5 soybean 22 days after R5 application for soybean variety 52B2RR®. Values with the same letter are not significantly different at *P* = 0.10 according to Fisher's protected least significant difference test.

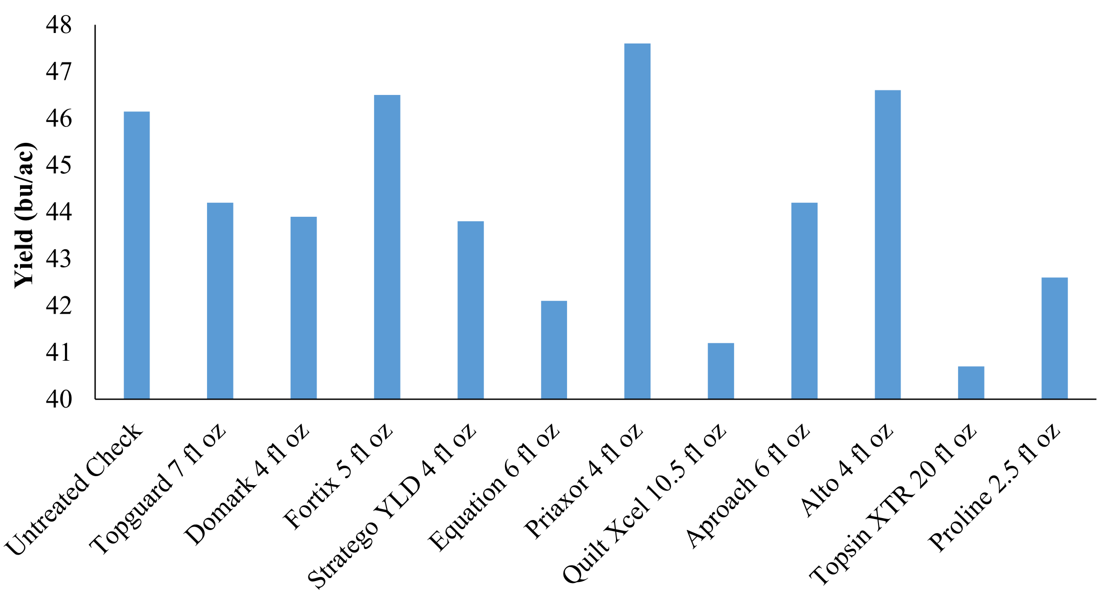

Fig. 6. Maturity group 5 soybean fungicide performance trial yields (bu/ac) for soybean variety 52B2RR®.

Evaluation of a Protoporphyrinogen Oxidase (PPO)-Resistant Palmer amaranth Population to Residual and Post-Emergence Applications of Common PPO Inhibiting Herbicides

R.C. Scott[1], J.C. Moore[2], T.W. Dillon[1], and J.K. Norsworthy[2]

ABSTRACT

A population of Palmer amaranth (pigweed) from Woodruff County, Arkansas was evaluated in the summer and fall of 2015 to determine the degree to which it is resistant to the protoporphyrinogen oxidase (PPO)-inhibiting herbicides applied both pre-emergence (PRE) and post-emergence (POST). This population was also evaluated against several other modes of action (herbicide groups). In the field, it was obvious from the grower's applications as well as some small-plot evaluations conducted in situ that this pigweed population was resistant to not only POST applications of fomesafen (Reflex®) but also glyphosate (Roundup®) and the acetolactate synthase (ALS)-inhibiting herbicides. In the greenhouse, this population was found to be resistant to POST applications of fomesafen and a wide array of PPO inhibitors applied PRE including: Valor® (flumioxazin), Spartan Charge® (sulfentrazone), Reflex, and Sharpen® (saflufenacil). In addition, this population was resistant to PRE-applied Prowl® (pendimethalin). Of the herbicide products evaluated, the only effective treatment was metolachlor plus metribuzin applied PRE as Boundary® herbicide, which contains two classes of chemistry with no known Palmer amaranth resistance at this time. This is the first population of Palmer amaranth with documented resistance to at least four classes of chemistry.

INTRODUCTION

The recent confirmation of protoporphyrinogen oxidase (PPO)-resistant Palmer amaranth in the mid-South threatens the ability of growers to manage this weed in Arkansas and throughout the mid-South (Salas et al., 2016). Although Palmer amaranth from fields throughout the mid-South have been tested for resistance either through bioassays or molecular assays (Lee et al., 2008; Thinglum et al., 2011; Weurffel et al., 2015), the true extent of resistance in these populations is for the most part unknown (Fig. 1). The objectives of this research were to: (1) better understand the degree of herbicide resistance in one of these alleged reported PPO-resistant populations; and (2) evaluate the population's tolerance to not only pre-emergence (PRE) and post-emergence (POST) PPO herbicide applications, but also to other chemistries.

PROCEDURES

In the summer of 2015, a population of Palmer amaranth was evaluated in the field and determined to likely to be resistant to glyphosate, Scepter® (imazaquin), and Flexstar® (fomesafen) herbicides (data not shown). The field was treated with the following PPO inhibitors: generic flumioxazin (the active ingredient in Valor®) applied at 2 oz/ac PRE followed by Flexstar at 1.5 pt/ac POST followed by Blazer® at 2.0 pt/ac POST, all PPO inhibitors. In addition, small plots were sprayed with glyphosate, Scepter, and Flexstar, and a large majority of the Palmer amaranth had no response. In the fall of 2015, Palmer amaranth seed from a 3-acre portion of the treated field, located in Woodruff County, Ark., was collected for further evaluation.

A greenhouse experiment was conducted in the winter of 2015 at the University of Arkansas System Division of Agriculture's Lonoke Extension Center, near Lonoke, Arkansas to screen commonly used PPO herbicides against the Woodruff county population of Palmer amaranth. Seed collected from the site were grown in 10 × 10 inch square trays filled with a commercial potting mix to which approximately a teaspoon full of seed and chaff was applied evenly across each tray and shallowly incorporated. Herbicide treatments were then applied to these trays with 4 replications. Treatments included: an untreated check, Sharpen® (2 oz/ac), Valor (1 and 2 oz/ac), Reflex (4, 8, and 16 oz/ac), Spartan Charge® (6 oz/ac) , Boundary® (2.0 pints/ac), and Prowl H_2O® (2.4 pt/ac) applied PRE and irrigated immediately after application. Treatments also included POST applications of Flexstar applied at 0.75, 1.0, and 1.5 pints/ac to 3-inch tall Palmer amaranth. Treatments were applied in a 1-liter mix, using a 4-nozzle spray boom (10002XR tips) calibrated to deliver 15 gallons per acre using CO_2 as a propellant. POST treatments included a 1% (v/v) crop oil concentrate. Plots

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were visually rated 7 and 14 days after application treatment (DAT). At 21 days after application DAT, counts were also made to determine the number of live plants in each tray. At this time, the study was terminated. Plots were analyzed and means separated by Fisher's protected least significant difference test with a probability of $P = 0.05$.

RESULTS AND DISCUSSION

At 7 days after treatment (DAT), Reflex applied PRE at any rate evaluated and Boundary were the only treatments to provide greater than 60% Palmer amaranth control (Table 1). Control with all other herbicides ranged from 10% to 42%. However by 14 DAT, Sharpen, Valor at 1 and 2 oz/ac, and Boundary were controlling this population of pigweed from 80% to 99%, with Boundary providing the highest visual rating of control at 99%. Post-emergence application of Flexstar, regardless of rate, provided no more than 10% control of Palmer amaranth, confirming earlier observations made in the field. Although Valor and Sharpen delivered a significant level of control by 14 DAT, actual stand counts taken at 21 DAT revealed that a commercially acceptable level of control was not obtained with survivors present in each of these treatments (Table 1).

By 21 DAT, an average of over 250 plants were present in the small 100 square inch (10 × 10 inch) trays (Table 1). This seems excessive and if the trial were repeated, lower populations would be attempted. However, this weed is known to exist at these high populations in nature as Palmer amaranth is a prolific seed producer (Doherty, 2012) and resistance can spread quickly (Norsworthy et al., 2014). Even though Valor applied at 2 oz/ac resulted in only 11% survival 89% control, this still resulted in approximately 27 plants per 10 inch square tray. Based on previous research with PPO-resistant populations, we know that this herbicide resistance is heritable (Salas et al., 2016); therefore, it can be assumed that survivors of PRE applications like this are more likely to be resistant to PPO herbicides. Other PPO herbicides evaluated in this study resulted in different survivor rates. For example, Sharpen (22%), Reflex (64-72%), and Spartan Charge (24%) slightly differed in effectiveness, suggesting that resistance may vary by PPO herbicide used. In addition, one-half of the plants in this population were resistant to Prowl H_2O herbicide, with 42% survival at 21 DAT. These greenhouse results again confirm the field observations that POST applications of Flexstar were ineffective, based on 90% to 96% survival.

While some significant levels of control were observed with PPO herbicides in this Palmer amaranth population, there were a significant number of survivors documented with all PPO treatments. Boundary (two non-PPO modes of action) resulted in almost no survivors, making it the better choice for resistance management where PPO-resistant populations have been confirmed or are suspected.

PRACTICAL APPLICATIONS

Knowledge of the existence of these PPO resistant populations (which include multiple herbicide resistances) may provide growers with not only information to control weeds in known fields, but also with the opportunity to prevent the further development of PPO resistance throughout the state. This information has been incorporated into county production meetings and is the focus of much future research, including several on-site trials at Woodruff County and two other locations identified in the state for 2016 summer field work.

ACKNOWLEDGEMENTS

The authors would like to thank the Arkansas Soybean Promotion Board for funding of this project. Also the assistance of our fellow researchers Jason Bond, Nilda Burgos, Jim Heiser and Larry Steckel for the development of the map (Fig. 1) is appreciated. Support was also provided by the University of Arkansas System Division of Agriculture.

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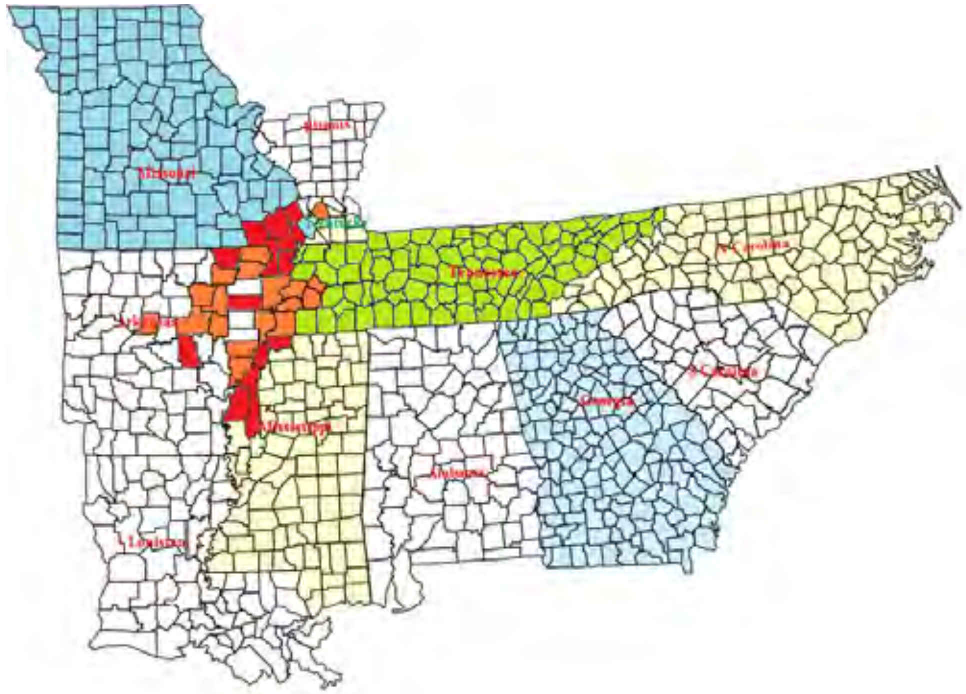

Fig. 1. The distribution of known protoporphyrinogen oxidase (PPO)-resistant Palmer amaranth populations by presence or absence in counties indicated. Red denotes counties with at least one field having confirmed resistance by a herbicide bioassay while orange denotes confirmation by a molecular assay. (Other colors help distinguish state lines.)

Table 1. Percent Palmer amaranth control at 7 and 14 days after treatment (DAT) and average number of survivors in each tray (converted to % survivors) taken at 21 DAT.

	Rates	Visual Weed Control Estimates		#Plants/Tray (% Survivors)
Treatments	**(ounces product/ac)**	**7 DAT**	**14 DAT**	**21 DAT**
Check, untreated	0	0	0	250 (100)
Sharpen	2	20	80	56 (22)
Valor	1	13	85	33 (13)
Valor	2	10	85	27 (11)
Reflex	4	72	60	181 (72)
Reflex	8	67	60	168 (67)
Reflex	16	64	65	160 (64)
Spartan Charge	6	24	75	61 (24)
Prowl H_2O	38.4	42	60	105 (42)
Boundary	32	99	99	2 (0)
Flexstar[a]	12	0	0	225 (90)
Flexstar	16	0	10	223 (90)
Flexstar	24	0	10	240 (96)
LSD $_{(0.05)}$		12	18	32 (13)

[a] Flexstar treatments were applied post-emergence to 3-inch tall Palmer amaranth.

Resistance of Two Palmer amaranth Populations to Protoporphyrinogen Oxidase-Inhibiting Herbicides

L. M. Schwartz[1], J. K. Norsworthy[1], R.C. Scott[2], and L.T. Barber[2]

ABSTRACT

Protoporphyrinogen oxidase (PPO)-inhibiting herbicides failed to control Palmer amaranth in many soybean fields in northeast Arkansas in 2015. The objective of this research was to determine which of the most commonly used PPO-inhibiting herbicides have the greatest effect on PPO-resistant Palmer amaranth populations when applied pre-emergence (PRE) and post-emergence (POST). A dose-response greenhouse study was conducted that examined five PRE herbicides and four POST herbicides on one PPO-susceptible and two PPO-resistant populations. Regardless of a PRE or POST application, the herbicides achieved poor Palmer amaranth control unless at very high rates. Since there was no effect on the PRE followed by POST application of the various PPO-inhibiting herbicides, it is likely that this mode of action cannot be relied on in the field. Thus, the use of multiple effective modes of action along with other integrated weed management tactics need to be focused on for the management of this species.

INTRODUCTION

Palmer amaranth control has become a challenge because of its ability to evolve herbicide resistance, continual flushes of germination throughout the growing season, rapid growth, high fecundity, and high resource use (Keeley et al., 1987; Jha et al., 2008). To date, Palmer amaranth has been confirmed resistant to five herbicide sites of action: acetolactate synthase inhibitors, 4-hydroxyphenylpyruvate dioxygenase inhibitors, 5-enolpyruvyl shikimate-3-phosphate synthase inhibitor, mitosis inhibitors, and photosystem II inhibitors (Heap, 2016). The continual evolution of resistance to highly used and effective sites of action has led to increasing use of protoporphyrinogen oxidase (PPO)-inhibiting herbicides for Palmer amaranth control.

In Arkansas, PPO-resistance to Palmer amaranth was first found in 2011 (Heap, 2016). Since then, there has been little research conducted on the level of resistance or the level of pre-emergence (PRE) and post-emergence (POST) control of Palmer amaranth that can be expected across PPO-inhibiting herbicides from differing classes. Thus, the objective of this study was to determine which of the most commonly used PPO-inhibiting herbicides have the greatest effect on PPO-resistant and -susceptible Palmer amaranth populations when applied PRE and POST.

PROCEDURES

A greenhouse experiment was conducted at the University of Arkansas System Division of Agriculture's Altheimer Laboratory in Fayetteville, Ark. in 2015. The experiment examined three populations of Palmer amaranth which included one known susceptible standard population and two known PPO-resistant populations (hereafter referred to as Crittenden and Gregory). All of the populations were subjected to a PRE and POST dose response to various PPO-inhibiting herbicides.

The PRE experiment was conducted by filling 4- by 6-in. flats with sieved silt loam field soil. One hundred seeds of each population were placed into individual flats. The experiment was conducted as a randomized complete block design with 4 replications and 2 temporal replications. Thus, there were 8 total replications, for a total of 800 Palmer amaranth seeds per herbicide per dose. Herbicide treatments, for the resistant populations, consisted of 8 doses of fomesafen (Reflex® 2 LC) applied at 0.016 to 2 lb ai/ac, flumioxazin (Valor® 51 WDG) applied at 0.004 to 0.504 lb ai/ac, sulfentrazone (Spartan® 4 F) applied at 0.016 to 2 lb ai/ac, saflufenacil (Sharpen® 2.85 SC) applied at 0.003 to 0.352 lb ai/ac, and oxadizon (Ronstar® 50 SP) applied at 0.25 to 32 lb ai/ac. These rates are equivalent to 1/16× to 8× field use rates. The susceptible population was sprayed with the same herbicides ranging from 1/128× to 1× rates. Herbicide applications were made using a laboratory sprayer equipped with two flat fan spray nozzles (TeeJet spray nozzles; Spraying Systems Co., Wheaton, Ill.) delivering 40 GPA at 40 PSI. Seedling counts were taken 7 and 10 days after treatment (DAT). The PRE flats were followed by a POST application of fomesafen (Flexstar® 1.88 EC) applied at 0.38 lb ai/ac when the largest plants were at the 3-leaf stage. Follow-up counts were taken 10 and 14 DAT.

The POST experiment was set up similar to the PRE experiment, where there was a total of eight replications and 160 plants per herbicide per dose. Twenty individual plants were transplanted into celled trays which were sprayed at the 3-leaf stage with fomesafen, flumioxazin, saflufenacil, and carfentrazone (Aim® 2EC) applied at 0.001 to 0.128 lb ai/ac. The resistant populations were sprayed with ten doses

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ranging from a 1/2× to a 512× rate; whereas the susceptible population was sprayed with seven doses ranging from 1/16× to 4×. Herbicide applications were done the same way as the PRE experiment. Live/dead counts were taken 10 and 14 DAT.

RESULTS AND DISCUSSION

Regardless of the PRE or POST application, the susceptible standard was proven to be highly sensitive to all of the herbicides used in the experiment. For the PRE application on the resistant populations, there was very poor control regardless of the herbicide evaluated. However, Reflex and Ronstar (not labeled in soybean) proved to have the poorest control of 50% seedling survival at the 1× rate (Table 1). Full control was not achieved at the 8× rate with any herbicide, except Ronstar; however, all herbicides at this rate had 5% or less seedling survival. The follow-up application of Flexstar controlled none of the plants from either resistant population that emerged following exposure to the PRE-applied herbicides (data not shown). At the extremely low doses for the susceptible population, some plants did emerge and all of these plants were controlled with the subsequent Flexstar application (data not shown). Additionally, the resistant to susceptible (R/S) ratios based on the response of the populations to PRE-applied herbicides were higher for all herbicides, except Sharpen and Ronstar, for the Crittenden population in comparison to the Gregory population (Table 3). Regardless, the R/S ratios were at minimum a 7.5-fold increase per herbicide.

The POST application results verified that the putative resistant populations were in fact resistant to all tested PPO-inhibiting herbicides. Complete control of the resistant populations was only obtainable at rates well above those labeled for use in soybean (Table 2). For example, Sharpen achieved complete control at the 32× rate, Valor at the 64× rate, Aim at the 128× rate, and Reflex at the 256× rate. At the labeled rates tested, Sharpen achieved the highest percent mortality (65%) whereas Valor and Reflex caused 12% and 15% mortality, respectively. The R/S ratios for all herbicides showed that Crittenden was the more resistant population in comparison to Gregory (Table 3).

PRACTICAL APPLICATIONS

Protoporphyrinogen oxidase inhibitors have been profoundly used in past years to combat herbicide-resistant Palmer amaranth in various cropping systems, especially soybean. In other greenhouse research, it was documented that these populations exhibit resistance to ALS inhibitors and glyphosate as well as some DNA resistance. With Palmer amaranth resistant to these sites of action, limited herbicide options remain for Palmer amaranth control. The evolution of resistance to PPO inhibitors in Palmer amaranth is a recent phenomenon in the southern United States; thus, best management practices are vital to managing the spread of resistance.

ACKNOWLEDGEMENTS

The authors would like to thank the University of Arkansas System Division of Agriculture for support of this project.

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Table 1. The percent seedling survival of the three Palmer amaranth populations (susceptible standard, Crittenden, Gregory) to various doses of pre-emergence applied protoporphyrinogen oxidase-inhibiting herbicides at 10 days after application. A dash (-) indicates that the dose was not examined for that population or herbicide.

	Susceptible Standard					Crittenden					Gregory				
Rate (×)	Valor	Reflex	Sharpen	Spartan	Ronstar	Valor	Reflex	Sharpen	Spartan	Ronstar	Valor	Reflex	Sharpen	Spartan	Ronstar
8	-	-	-	-	-	16.5	9.4	3.0	11.0	6.5	3.0	6.5	11.5	0	14.1
4	-	-	-	-	-	25.0	22.5	8.2	24.0	10.0	7.5	15.0	18.0	2.0	22.8
2	-	-	-	-	-	36.2	34.9	16.5	27.1	13.0	19.3	23.2	25.9	7.0	37.5
1	0	0	1.6	0	0	38.8	51.7	25.7	40.1	23.1	22.5	27.8	31.0	10.8	50.4
0.5	0	0	3.3	0	0	53.0	54.3	31.0	51.7	44.1	60.1	46.4	58.2	38.5	59.5
0.25	0	1	7.4	0.8	1.2	67.2	65.0	58.2	69.8	42.5	64.7	52.6	65.9	51.0	72.4
0.125	3.2	4.7	9.7	5.3	1.6	80.2	81.3	65.9	89.2	54.9	78.7	61.1	80.2	58.8	99.6
0.0625	9.7	11.3	13.8	13.5	19.5	92.5	94.5	80.2	99.0	60.3	83.6	66.5	95.5	73.5	100.0
0.0313	19.5	18.5	33.5	21.5	25.0	-	-	-	-	-	-	-	-	-	-
0.0156	25.0	26.0	45.0	29.0	38.0	-	-	-	-	-	-	-	-	-	-
0.0078	38.5	34.0	52.5	37.5	50.0	-	-	-	-	-	-	-	-	-	-

Table 2. Percent mortality of the three Palmer amaranth populations (susceptible standard, Crittenden, Gregory) to various doses of post-emergence-applied protoporphyrinogen oxidase-inhibiting herbicides at 14 days after application. A dash (-) indicates that the dose was not examined for that population or herbicide.

	Susceptible Standard				Crittenden				Gregory			
Rate (×)	Valor	Reflex	Sharpen	Aim	Valor	Reflex	Sharpen	Aim	Valor	Reflex	Sharpen	Aim
512	-	-	-	-	100	88.5	100	99.0	100	82.3	100	100
256	-	-	-	-	100	67.5	100	94.0	100	77.5	100	100
128	-	-	-	-	98.2	55.0	100	80.5	99.5	75.0	100	97.0
64	-	-	-	-	91.4	42.5	100	67.5	96.2	45.0	100	82.5
32	-	-	-	-	87.5	32.5	100	67.5	90.0	27.5	100	78.5
16	-	-	-	-	85.0	20.0	97.5	50.0	85.0	22.5	100	75.0
8	-	-	-	-	65.0	15.0	97.5	42.5	70.0	14.5	100	52.5
4	100	100	100	100	62.5	8.5	80.0	22.0	65.0	9.5	90	41.1
2	100	100	100	100	30.0	2.5	77.5	9.5	37.5	5.0	75	35.0
1	97.5	82.5	100	95.0	12.5	0	65.0	5.0	20.0	1.5	60	15.0
0.5	95.0	61.5	100	87.5	5.0	0	52.5	2.0	5.0	0	55	6.5
0.25	92.5	58.9	98.0	87.5	-	-	-	-	-	-	-	-
0.125	87.5	44.8	90.0	85.0	-	-	-	-	-	-	-	-
0.0625	56.1	30.0	85.5	77.5	-	-	-	-	-	-	-	-

Table 3. Estimates of the herbicide dose resulting in a 50% reduction in accumulated dry matter (GR_{50}), and resistance ratios for the Crittenden and Gregory protoporphyrinogen oxidase-resistant populations relative to the susceptible standard for both the pre-emergence and post-emergence experiments. Data from two runs were pooled for all populations. Dashes indicate that the herbicide was not used in that experiment. Nomenclature: R = resistant, S = susceptible.

	PRE						POST					
	Susceptible Standard		Crittenden		Gregory		Susceptible Standard		Crittenden		Gregory	
Herbicide	GR_{50} (lb ai/ac)	R/S Ratio	GR_{50} (lb ai/ac)	R/S Ratio	GR_{50} (lb ai/ac)	R/S Ratio	GR_{50} (lb ai/ac)	R/S Ratio	GR_{50} (lb ai/ac)	R/S Ratio	GR_{50} (lb ai/ac)	R/S Ratio
Reflex	0.016	1	0.5	31.25	0.125	7.81	0.031	1	16.0	516.13	16.0	516.13
Valor	0.004	1	0.063	15.75	0.063	15.75	0.004	1	0.126	31.5	0.126	31.5
Sharpen	0.003	1	0.022	7.33	0.044	14.67	0.003	1	0.022	7.34	0.022	7.34
Spartan	0.016	1	0.25	15.63	0.125	7.81	-	-	-	-	-	-
Ronstar	0.25	1	1	128	4	16	-	-	-	-	-	-
Aim	-	-	-	-	-	-	0.001	1	0.256	256	0.064	64

Differential Response of Foliar- and Soil-Applied Protoporphyrinogen Oxidase-Inhibiting Herbicides on Palmer amaranth Populations from Arkansas

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ABSTRACT

Palmer amaranth is one of the most troublesome weeds in field crops in the southern U.S. The widespread occurrence of glyphosate-resistant Palmer amaranth has led to increasing use of protoporphyrinogen oxidase (PPO)-inhibiting herbicides in soybean. This research was conducted to evaluate the efficacy of foliar-applied fomesafen and four soil-applied PPO-inhibiting herbicides (fomesafen, flumioxazin, sulfentrazone, saflufencacil) on 22 Palmer amaranth populations collected in 2015. Whole-plant bioassays were conducted in the greenhouse. One-hundred plants were grown in cellular trays and sprayed with 0.235 lb ai/ac fomesafen when seedlings were three in. tall. Field dose of fomesafen, flumioxazin, saflufenacil, and sulfentrazone were applied to trays containing soil sown with Palmer amaranth seeds. Eighteen populations were not completely controlled (19% to 87%) with foliar-applied fomesafen. Soil-applied flumioxazin, saflufenacil, and sulfentrazone were equally effective on these populations. Soil-applied fomesafen was not effective on three populations (<90% control). This suggests resistance to both soil-and foliar-applied fomesafen. This study showed the spread of resistance to fomesafen in Palmer amaranth populations in Arkansas.

INTRODUCTION

Palmer amaranth (*Amaranthus palmeri* S. Watson) is one of the most common, troublesome, economically damaging weeds in soybean crop production. Infestation of Palmer amaranth can reduce soybean yield by 78% (Bensch et al., 2003). The widespread occurrence of acetolactate synthase (ALS)- and glyphosate-resistant Palmer amaranth populations has led to increasing use of protoporphyrinogen oxidase (PPO)-inhibiting herbicides. Foliar- and soil-applied PPO herbicides have become essential tools for managing ALS- and glyphosate-resistant Palmer amaranth in soybean. Resistance to foliar-applied PPO herbicide in Palmer amaranth was first reported in Arkansas (Salas et al., 2016). This study aims to investigate the response of Palmer amaranth populations collected in 2015 to foliar- and soil-applied PPO-inhibiting herbicides.

PROCEDURES

Plant Materials. Palmer amaranth seeds from 22 fields were sampled in Arkansas in late summer 2015. Inflorescences of at least 10 female Palmer amaranth plants per field were collected, dried, threshed, and cleaned for herbicide bioassay in the greenhouse. A known herbicide-susceptible Palmer amaranth accession (SS) was also included.

Foliar-Applied PPO Herbicide Screening. The experiment was conducted in a randomized complete block design with two replications. Each replication consisted of one 11 × 21.25 in. cellular tray with 50 seedlings, grown at one seedling per cell. Recommended 1× dose of fomesafen (0.235 lb ai/ac) (Flexstar®) was applied to 3-in. tall seedlings using a laboratory sprayer equipped with a flat fan spray nozzle delivering 20 gallons per acre at 32 psi. The plants were assessed visually relative to non-treated plants 21 days after treatment (21 DAT) using a scale of 0 to 100, where 0 = no visible injury and 100% = complete desiccation. Data were analyzed using hierarchal clustering in JMP Pro v. 12 (SAS Institute, Inc., Cary, N.C.).

Soil-Applied PPO Herbicides Screening. The experiment was designed as randomized complete block with two replications. Each replication consisted of one tray. One-hundred twenty Palmer amaranth seeds were sown in a 9 × 6.5 × 2.5 in. tray filled with 1.4 lb of 5:1 (silty-loam field soil: commercial potting soil) soil mixture. Trays were sprayed with 0.25 lb/ac fomesafen (Reflex®), 0.063 lb/ac flumioxazin (Valor®), 0.044 lb/ac saflufenacil (Sharpen®), and 0.25 lb/ac sulfentrazone (Spartan®). The trays were sprinkler-irrigated overhead following herbicide application to activate the herbicide. Thereafter, each tray was sub-irrigated as needed, to avoid physical damage to tender seedlings. Seedling emergence was counted 21 DAT and expressed as percent reduction relative to the emergence in non-treated flats. Data were analyzed separately by herbicide using JMP Pro v. 12 (SAS Institute, Inc., Cary, N.C.).

RESULTS AND DISCUSSION

Differential Response to Foliar-Applied Fomesafen. The majority of Palmer amaranth populations were not controlled 100% with fomesafen. Of the 22 Palmer amaranth populations, 18 were controlled 19% to 87% while the re-

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maining four populations showed >93% control (Table 1). Mortality and injury of surviving plants differed within and among populations. The majority of survivors showed <60% injury. The populations differentiated into 3 clusters based on mortality and levels of injury of the survivors (Fig. 1 and Table 2). The first cluster, comprised of the 11 most recalcitrant populations, showed the highest frequency of survivors (19% to 70% mortality). The survivors from these populations incurred <60% injury and were healthy enough to produce seeds. The second cluster, composed of 5 populations, showed 87% to 100% mortality with the least frequency of survivors. These populations were sensitive to fomesafen. The third cluster, composed of 7 populations, showed 52% to 95% mortality with survivors showing a wider range of injury (0% to >90%) than those in the other clusters. Some of these survivors, especially those that were injured <50%, were more likely to reproduce. This indicates that resistance to fomesafen in Palmer amaranth populations in Arkansas is expanding and spreading. The evolution of PPO-resistant Palmer amaranth is a recent phenomenon in the southern U.S.; thus, best management practices such as diversification of herbicide modes of action with integration of cultural and mechanical practices are vital to manage the spread of resistance.

Response to Soil-Applied PPO Herbicides. Response to soil-applied flumioxazin, saflufenacil, and sulfentrazone among Palmer amaranth populations was similar, in which relative seedling emergence reduction ranged from 84% to 100%. Although these herbicides were effective on most populations, a few populations had some emerged Palmer amaranth with minimal injury (0% to 40%). These survivors are likely to mature and produce seeds if not controlled with post-emergence herbicides.

The efficacy of soil-applied fomesafen differed across populations, with >78% emergence reduction. The number of populations with escapes from soil-applied fomesafen was higher than those escaping other soil-applied PPO herbicides. A similar response was reported with PPO-resistant tall waterhemp biotypes where soil-applied fomesafen was least effective compared with flumioxazin and sulfentrazone (Wuerffel et al., 2015). The most recalcitrant populations to soil-applied fomesafen (15-CLA-A, 15-GRE-A, 15-MIS-E) showed <90% reduction in seedling emergence. These same populations were also resistant to foliar-applied fomesafen with <60% control (Tables 1 and 3), indicating resistance to both soil-and foliar-applied fomesafen. The risk of losing the effectiveness of soil-applied fomesafen, as well as other soil-applied PPO herbicides, is increased if we continue to rely most heavily on these herbicides and if survivors are allowed to produce seeds.

PRACTICAL APPLICATIONS

Some Palmer amaranth populations from Arkansas show a higher risk for escapes from foliar- and soil-applied fomesafen, indicating high propensity for PPO resistance evolution. Populations resistant to foliar application of fomesafen are most likely also resistant (to a lesser degree) to soil-applied fomesafen. Other soil-applied PPO herbicides (flumioxazin, sulfentrazone, and saflufenacil) are still effective on most populations; however, a few populations are already showing low frequencies of resistant individuals. Resistance to PPO inhibitors in Palmer amaranth populations is spreading in Arkansas, thus monitoring for survivors and implementing holistic weed management programs are essential to hinder the spread of resistance evolution.

ACKNOWLEDGEMENTS

The authors thank the Arkansas Soybean Promotion Board, Syngenta Crop Protection, and the University of Arkansas System Division of Agriculture for providing financial support.

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Table 1. Response of Palmer amaranth populations to recommended dose of foliar-applied fomesafen.

Population	Mortality	Minimum injury	Percent frequency of survivors [a]				
			HR	R	MR	SR	S
	--------------------	--------------------	%	--------------------			
15-CLA-A	27	5	HR	R	MR	SR	S
15-CLA-B	100	100	73	0	0	0	27
15-CON-A	93	90	0	0	0	0	100
15-CRI-A	28	0	0	0	0	0	100
15-CRI-B	74	20	31	41	0	0	28
15-CRI-C	39	5	0	8	18	0	74
15-CRI-D	52	10	46	15	0	0	39
15-GRE-A	19	5	34	14	0	0	52
15-IND-A	40	10	81	0	0	0	19
15-LAW-A	95	0	35	25	0	0	40
15-LAW-B	83	10	5	0	0	0	145
15-LAW-C	52	40	5	0	0	12	83
15-LEE-A	64	30	0	0	24	24	52
15-LEE-B	87	90	0	36	0	0	14
15-MIS-A	100	100	0	0	0	0	100
15-MIS-B	63	40	0	0	0	0	100
15-MIS-C	69	10	0	0	13	24	63
15-MIS-D	70	15	4	0	0	27	69
15-MIS-E	60	5	0	30	0	0	70
15-MIS-F	49	10	40	0	0	0	60
15-PHI-A	63	10	15	36	0	0	49
15-PRA-A	80	5	9	28	0	0	63
SS[b]	100	100	5	0	0	15	80
$LSD_{0.05}$[c]	12	-	-	-	-	-	-

[a] HR = highly resistant (0% to 10% injury); R = resistant (11% to 30% injury); MR = moderately resistant (31% to 60% injury); SR = slightly resistant (61% to 89% injury); S = susceptible (90% to 100% injury).
[b] SS = sensitive standard.
[c] Fisher's protected least significant difference test was used to compare treatment means within each column.

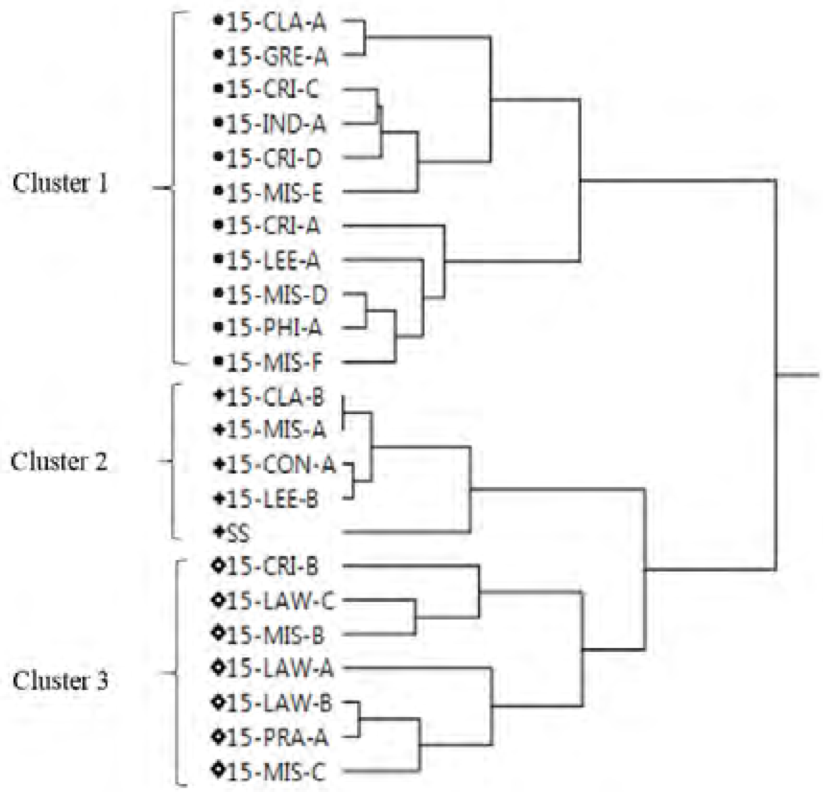

Fig. 1. Hierarchal clustering of Palmer amaranth populations treated with foliar-applied fomesafen at 0.235 lb/ac.

Table 2. Population cluster analysis of Palmer amaranth populations treated with foliar-applied fomesafen at 0.235 lb/ac.

Cluster	No. of populations	Mortality (%) Mean	Min	Max	Mean frequency of plants at different levels of injury (%) 0-10% injury	11-30% injury	31-60% injury	61-89% injury	91-100% injury
1	11	46	19	70	33	20	0	0	42
2	5	84	87	100	0	0	0	0	84
3	7	81	52	95	3	1	8	15	81

Table 3. Response of Palmer amaranth populations to soil-applied protoporphyrinogen oxidase-inhibiting herbicides.

Population[a]	Seedling emergence without herbicide treatment	Seedling emergence reduction at 21 DAT (%, relative to nontreated control)			
		Flumioxazin (0.063 lb/ac)	Fomesafen (0.25 lb/ac)	Saflufenacil (0.044 lb/ac)	Sulfentrazone (0.25 lb/ac)
15-CLA-A	78	96	79	93	84
15-CLA-B	74	99	99	100	100
15-CON-A	50	100	98	100	100
15-CRI-A	71	99	91	96	98
15-CRI-B	46	100	99	100	100
15-CRI-C	52	100	91	100	98
15-CRI-D	38	95	93	100	91
15-GRE-A	66	94	88	100	93
15-IND-A	32	100	100	100	100
15-LAW-A	62	100	100	100	100
15-LAW-B	44	100	100	100	100
15-LAW-C	49	98	100	100	100
15-LEE-A	25	100	100	100	97
15-LEE-B	43	100	100	100	100
15-MIS-A	55	100	100	100	100
15-MIS-B	58	100	99	100	100
15-MIS-C	58	99	100	100	100
15-MIS-D	71	96	92	100	100
15-MIS-E	45	98	86	99	100
15-MIS-F	42	96	94	99	100
15-PHI-A	39	99	95	99	100
15-PRA-A	38	100	100	100	100
SS[b]	83	100	100	100	100
$LSD_{0.05}$[c]	20	NS	8	NS	NS

[a] Approximately120 Palmer amaranth seeds planted.
[b] SS = sensitive standard.
[c] Fisher's protected least significant difference was used to compare treatment means within each column; NS = not significant.

Crop Response of Edamame Soybean Varieties to Foliar and Soil-Applied Herbicides

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ABSTRACT

The demand for edamame soybean is increasing in the U.S. and the soybean breeding program at the University of Arkansas System Division of Agriculture has started releasing locally bred edamame varieties. Field studies were conducted in 2015 at the Vegetable Research Station, Kibler and at the Arkansas Agricultural Research and Extension Center, Fayetteville, Arkansas to evaluate the response of edamame to pre-emergence application of flumioxazin, metribuzin, pyroxasulfone, and sulfentrazone and the post-emergence application of fomesafen. The study was conducted in a randomized split-plot design with four replications. Crop injury was evaluated at 21 days after planting for pre-emergence herbicides and 7 days after post-emergence application of fomesafen. Of the soil-applied herbicides, metribuzin caused the highest crop injury (42% in Fayetteville and 90% in Kibler). Crop injury from other soil-applied herbicides was higher in Kibler (flumioxazin, 50%; pyroxasulfone, 40%; and sulfentrazone, 50%) than in Fayetteville. Post-emergence application of fomesafen caused minimal injury (≤ 8%). Because Edamame varieties responded differently to soil-applied herbicides it is important to continue screening edamame varieties for herbicide tolerance to identify sensitive varieties much the same as commercial soybean cultivars.

INTRODUCTION

Edamame (*Glycine max* L.) is a specialty soybean harvested as a vegetable when the seeds are immature (Fehr et al., 1971). In Arkansas, the demand for edamame is projected to increase 12-15% annually (UAEX, 2013). Progressive development of new edamame soybean varieties is an important factor to meet the demand for appropriate crop morphology, yield, and palatability. The availability of herbicides for edamame is important (Williams and Nelson, 2014). Spartan Charge® (sulfentrazone + carfentrazone) is one of the herbicides recently approved for edamame in Arkansas (Scott et al., 2016). Still, more herbicides are necessary to diversify chemical weed management options. This, in addition to new varieties, is necessary to support growth of the new edamame industry in Arkansas and the southern U.S. This study was conducted to evaluate the response of new varieties of edamame in comparison to grain soybean to selected herbicides currently labeled for grain soybean.

PROCEDURES

A field experiment was conducted at the University of Arkansas System Division of Agriculture's Vegetable Research Station, Kibler and at the Arkansas Agricultural Research and Extension Center, Fayetteville, Ark. in 2015 to determine the effect of pre-emergence (PRE) herbicides (sulfentrazone, flumioxazin, pyroxasulfone, metribuzin) and post-emergence (POST) application of fomesafen on edamame soybean varieties and advanced lines. Eleven entries consisting of vegetable and grain soybean were planted in single-row plots, at 3-ft. spacing and 20-ft. length. The experiment was arranged in a split-plot design (herbicide treatment as whole plot and varieties as subplot) with four replications. A broadcast PRE treatment of S-metolachlor (Dual Magnum®; 1 lb ai/ac) was applied 1 day after planting to keep the plots weed-free. S-metolachlor was applied with a tractor-mounted sprayer fitted with 12 Teejet (110015VS) nozzles spaced 18-in. apart, delivering 20 gallons per acre (GPA) of spray volume at 28 psi boom pressure for Fayetteville. In Kibler, the broadcast spray was applied with a tractor-mounted sprayer fitted with four Teejet (110015VS) nozzles spaced 18 in. apart delivering 20 GPA of spray volume at 40 psi boom pressure.

All herbicide treatments were applied using a CO_2 backpack sprayer with four flat fan nozzles (Tee Jet XR11003) spaced 18-in., delivering 20 GPA of spray volume at 40 psi boom pressure. The crop was irrigated as needed. Fomesafen was applied to 2- to 3- trifoliate soybean, with a nonionic surfactant (Induce®) at 0.25% by volume. Stand count was recorded 21 days after planting (DAP). Visual ratings for injury were recorded at 21 DAP for all PRE treatments and at 7 days after treatment (DAT) for fomesafen only. Crop injury was evaluated relative to the respective non-treated plants of each variety.

Mature pods were harvested from 6.5-ft. of the middle row to estimate crop yield. At harvest, four plants were randomly selected and the total number of pods per plant was recorded. All pods were mechanically dehulled after harvesting to determine seed weight per plot.

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RESULTS AND DISCUSSION

The effect of PRE herbicides on edamame and grain soybean was significant only in Fayetteville (Table 1). Metribuzin (Tricor®; 0.63 lb ai/ac) caused the highest crop injury (42%) among the herbicide treatments. Crop injury caused by flumioxazin (Valor® SX; 0.08 lb ai/ac), pyroxasulfone (Zidua®; 0.13 lb ai/ac) and sulfentrazone (Spartan®; 0.24 lb ai/ac) ranged from 25% to 29%. At Kibler, significant herbicide by variety interaction was observed (Table 2). Metribuzin caused 90%, 84% and 76% crop injury on edamame varieties R07 7645, AVS 8080 and R08 4004, respectively. Grain soybean tolerance to metribuzin varies and metribuzin can cause high crop injury when soil moisture condition is high (Moshier and Russ, 1981). Flumioxazin and sulfentrazone caused 50% crop injury on grain soybean varieties 5002 T and UA 4913 C, respectively. Osage, a grain soybean variety, treated with Zidua had 40% crop injury. Crop injury from POST application of fomesafen (Flexstar®; 0.26 lb ai/ac) was <8% and 5% to 6% in Fayetteville and Kibler, respectively at 7 DAT (Tables 3 and 4). Previous research showed that POST application of fomesafen can cause 12% crop injury to edamame soybean (Williams and Nelson, 2014). All of the edamame and grain soybean varieties used in this study were tolerant to foliar application of fomesafen, just like grain soybean

PRACTICAL APPLICATIONS

Metribuzin applied PRE, with S-metolachlor, can cause high crop injury and cannot be recommended for the edamame varieties tested. Pyroxasulfone is a safe herbicide for edamame. Sulfentrazone and flumioxazin, on top of S-metolachlor, can cause injury when high rainfall occurs close to the time of applications, but can be good alternative PRE herbicides. Post-emergence application of fomesafen is safe for all the varieties tested.

ACKNOWLEDGEMENTS

The authors thank the Arkansas Soybean Promotion Board for funding the study, the University of Arkansas System Division of Agriculture, the Vegetable Research Station at Kibler and the Arkansas Agricultural Research and Extension Center at Fayetteville, Arkansas for support provided.

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Table 1. Effect of pre-emergence herbicide treatments on edamame varieties at 21 DAP grown in 2015 at the Arkansas Agricultural Research and Extension Station, Fayetteville, Arkansas. [a,b]

		Crop injury											
Treatments	Rate	5002 T	AVS 4002	AVS 8080	Osage	R07 7645	R07 7722	R08 4004	R10 2890	UA 4913C	UA 5213C	UA 5612	Mean
	lb ai/ac	%											
flumioxazin	0.08	31	30	29	25	30	30	29	24	31	26	36	29 b
metribuzin	0.63	43	46	61	34	43	39	35	40	44	38	44	42 a
pyroxasulfone	0.13	25	25	21	26	26	26	25	25	25	21	25	25 b
sulfentrazone	0.24	35	25	31	25	33	28	28	24	35	23	30	29 b

[a] Abbreviation: DAP = days after planting.
[b] Means within a column followed by the same lowercase letter are not different according to Fisher's protected least significant difference test (α = 0.05).

Table 2. Effect of pre-emergence herbicide treatments on edamame varieties at 21 DAP grown in 2015 at the Vegetable Research Station, Kibler, Arkansas. [a,b]

		Crop injury											
Treatments	Rate	5002 T	AVS 4002	AVS 8080	Osage	R07 7645	R07 7722	R08 4004	R10 2890	UA 4913C	UA 5213C	UA 5612	Mean
	lb ai/ac	%											
flumioxazin	0.08	50e-h	36l-p	41h-o	45g-n	40h-o	38h-p	49e-l	34m-p	44g-n	41h-o	47f-m	42
metribuzin	0.63	69cd	70bcd	84ab	65c-f	91a	70bcd	76abc	60d-g	74bc	70bcd	65cde	72
pyroxasulfone	0.13	38h-o	34h-p	23p	40h-n	26op	37h-o	34h-p	32	31m-p	29m-p	28nop	32
sulfentrazone	0.24	50e-j	36k-p	34k-p	41h-o	36k-p	45g-n	33l-p	35k-p	50 e-j	36k-p	41h-o	40

[a] Abbreviation: DAP = days after planting.
[b] Means within a column and a row followed by the same lowercase letter are not different according to Fisher's protected least significant difference test (α = 0.05).

Table 3. Effect of POST application of fomesafen at 7 DAT on edamame varieties grown in 2015 at the Arkansas Agricultural Research and Extension Station, Fayetteville, Arkansas.[a,b]

		Crop injury											
Treatment	Rate	5002 T	AVS 4002	AVS 8080	Osage	R07 7645	R07 7722	R08 4004	R10 2890	UA 4913C	UA 5213C	UA 5612	Mean
	lb ai/ac	%											
fomesafen	0.26	6a	5a	6a	6a	6a	5a	6a	6a	6a	8a	5a	6

[a] Abbreviation: POST = post-emergence; DAT = days after treatment.

[b] Means within a row followed by the same lowercase letter are not different according to Fisher's protected least significant difference test (α = 0.05).

Table 4. Effect of POST application of fomesafen at 7 DAT on edamame varieties grown in 2015 at the Vegetable Research Station, Kibler, Arkansas. [a,b]

		Crop injury											
Treatment	Rate	5002 T	AVS 4002	AVS 8080	Osage	R07 7645	R07 7722	R08 4004	R10 2890	UA 4913C	UA 5213C	UA 5612	Mean
	lb ai/ac	%											
fomesafen	0.26	6a	6a	6a	5a	5a	5a	6a	5a	5a	6a	6a	6

[a] Abbreviation: POST, post-emergence; DAT, days after treatment.

[b] Means within a row followed by the same lowercase letter are not different according to Fisher's protected least significant difference test (α = 0.05).

Evaluating Insecticide Seed Treatments as a Means for Reducing Soybean Injury Caused by Herbicide Drift

N.R. Steppig[1], J.K. Norsworthy[1], R.C. Scott[2], and L.T. Barber[2]

ABSTRACT

In the state of Arkansas, soybean is commonly planted as part of a crop rotation with rice. As such, the incidence of soybean growing in close proximity to rice is high and drift of rice herbicides onto soybean fields can cause substantial crop injury. One way to reduce crop injury from herbicides is through the use of safeners. Crop safeners have been used with great success in a number of cropping systems in order to mitigate the risk of crop damage to herbicide applications, and are usually sprayed in combination with herbicides. Recently, however, it has been shown that some insecticide seed treatments may provide improved crop tolerance to herbicides as well. A field study was conducted at the Lonn Mann Cotton Research Station in Marianna, Arkansas in order to examine the potential for a similar occurrence in soybean. Two common insecticide seed treatments, NipsIt® INSIDE and CruiserMaxx®, were used to test for improved crop tolerance to drifts rates of eight post-emergence herbicides in treated seed. Results from the field experiment indicate that soybean injury from Permit® drift may be effectively reduced through the use of both insecticides. Because seed treatments are already commonplace for many soybean growers in the mid-South, the successful use of insecticide seed treatments to reduce injury from Permit provides added utility with no additional cost to the grower.

INTRODUCTION

Research conducted in 2013 showed that injury to conventional rice varieties from drift rates of Roundup® and Newpath® could effectively be reduced by treating seeds with the insecticide/fungicide CruiserMaxx® prior to planting (Scott et al., 2013). This incidence of safening presents a form of insurance to growers that plant treated varieties in close proximity to both Roundup Ready soybean and Clearfield® rice, which is common in the state of Arkansas. Based on the success of insecticide seed treatments being used to reduce herbicide damage in rice, examining similar occurrences in other crops is of great interest. As the largest acreage agronomic crop in Arkansas, injury reduction in soybean from seed treatments could provide even greater widespread grower benefits. Presently there are relatively few instances of effective safeners in soybean (Davies and Caseley, 1999). Thus, the use of insecticide seed treatments as a means of reducing crop injury from off-target herbicide movement would present a novel benefit for growers who utilize such treatments.

PROCEDURES

In order to explore the potential for safening via insecticide seed treatments in soybean, a field research trial was conducted at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station in Marianna, Arkansas in 2015. UA 5213C soybean, a conventional, non-STS variety, was planted into a silt loam soil in four row plots measuring 12.7-ft. wide and 25-ft. long, with a 38-in. row spacing. A fungicide seed treatment included in CruiserMaxx (mefonoxam+fudioxanil) was applied to all treatments in order to ensure any potential interactions were indeed a result of insecticides. In addition to fungicide, treatments included CruiserMaxx (thiamethoxam), NipsIt® (clothianidin), or no insecticide seed treatment. Eight post-emergence herbicides were applied to V3 soybean using a backpack sprayer calibrated to deliver a constant carrier volume of 15 gal/ac. Herbicides were applied using a 6-nozzle, handheld boom at 1/10× labeled rates for each herbicide and included Roundup PowerMax® (glyphosate), Weedar® (2,4-D), Clarity® (dicamba), Permit® (halosulfuron), Liberty® (glufosinate), Callisto® (mesotrione), Laudis® (tembotrione), and Riceshot® (propanil). Visual crop injury ratings were taken at 1, 2 and 4 weeks after herbicide applications (WAA) and grain yield data were collected at the end of the growing season. Data collected were subjected to analysis of variance using JMP Pro v. 12.1 (SAS Institute, Inc., Cary N.C.) with means separated using Fisher's protected least significant difference test (LSD) ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Overall, the 2015 experiment indicates that there is a potential for interaction between insecticide seed treatments and some of the herbicides applied in soybean. While most insecticide/herbicide combinations did not reduce crop injury compared to the absence of an insecticide seed treatment, injury from Permit was reduced significantly by both CruiserMaxx and NipsIt. At 1 WAA, soybean without an insecticide seed treatment that was treated with Permit displayed 74% injury, while soybean with NipsIt and CruiserMaxx seed treatments were injured only 10% and 23%, respec-

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tively (Fig. 1). Similarly at 4 WAA, injury to fungicide-only treated soybean was 45%, but with NipsIt and Cruisermaxx seed treatments injury was reduced to 3% and 13%, respectively (Fig. 2). With other herbicide treatments, however, no reduction in injury occurred. There were no differences observed between insecticide and non-insecticide-treated seed within an herbicide; however, treatments containing NipsIt yielded slightly higher than those without an insecticide seed treatment (data not shown). Variable plant responses are to be expected following exposure to a broad range of chemicals, and more research will be necessary under a range of environments in the future.

PRACTICAL APPLICATIONS

As demonstrated by this experiment, injury to soybean from Permit drift may be significantly reduced through the use of both NipsIt and Cruisermaxx insecticide seed treatments. Since Permit is a common herbicide in rice production, soybean grown near rice is at relatively high risk for injury from Pernit drift. However, through the use of insecticide seed treatments, that risk can be greatly reduced. Additionally, seed treatments provide protection from a number of plant pests such as insects and pathogens, so the adoption of insecticide seed treatments may greatly improve crop health throughout the growing season.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the Arkansas Soybean Promotion Board and the University of Arkansas System Division of Agriculture for funding this research.

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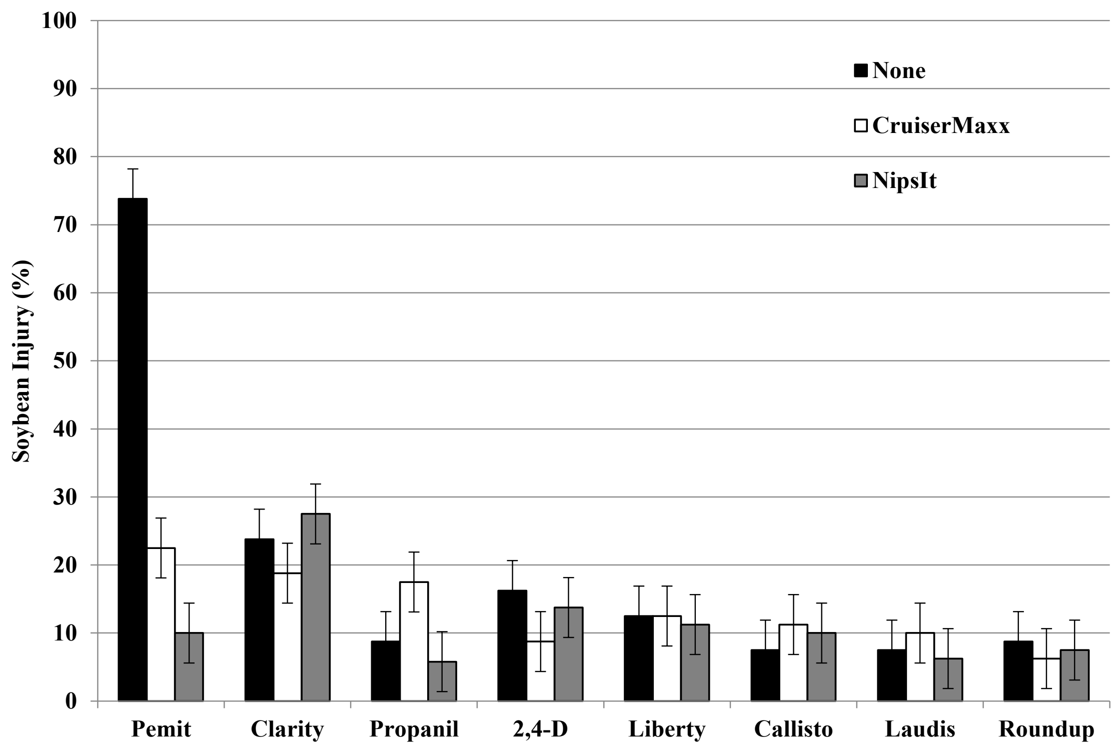

Fig. 1. Soybean injury 1 week after application for insecticide/herbicide combinations. Where error bars overlap, mean crop injury is not significantly different (α = 0.05).

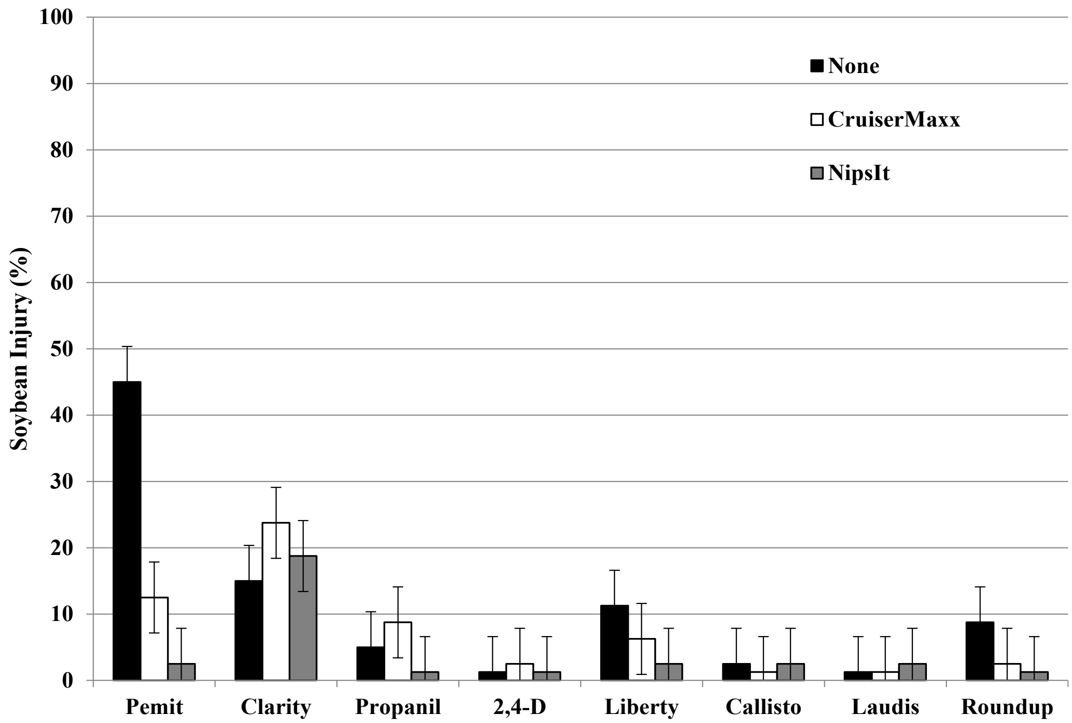

Fig. 2. Soybean injury 4 weeks after application for insecticide/herbicide combinations. Where error bars overlap, mean crop injury is not significantly different (α = 0.05).

Optimizing Rate and Interval Between Sequential Applications of Glufosinate in LibertyLink® Soybean

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

ABSTRACT

The use of glufosinate in U.S. agriculture is increasing and should continue to rise as more LibertyLink® acres are planted and new technologies that include glufosinate-resistant traits (e.g., Enlist®) are commercialized. An experiment was conducted at the University of Arkansas System Division of Agriculture's Agricultural Experiment Station in Fayetteville, Ark. in 2015 to identify post-emergence (POST)-application strategies that maximize the utility of glufosinate in glufosinate-resistant soybean. A randomized complete block design (RCBD) with a factorial treatment structure was used, in which factor 1 was glufosinate (Liberty®) rate (22, 29, 36, 43 fl oz/ac) and factor 2 was sequential application structure. The five levels for the sequential application structure were: no sequential application, initial application followed by (fb) a sequential application 7 days after the initial application (DAI), initial fb sequential 10 DAI, initial fb sequential 14 DAI, and initial fb sequential 21 DAI. The first herbicide application occurred when weeds reached approximately 10 in. tall. For treatments that contained a sequential application, the same rate used in the initial application (e.g., 22 fl oz) was also used in the sequential. A single application of 22 fl oz controlled Palmer amaranth and barnyardgrass 70% and 78%, respectively, 2 weeks after the final application (i.e., 21 DAI) occurred. A sequential application of the same rate improved control for both Palmer amaranth (96%) and broadleaf signalgrass (97%). Thus, to maximize weed control, glufosinate should be applied sequentially at the desired rate with a 7-14 day interval between applications, especially when the initial application is made to larger-than-label weed sizes.

INTRODUCTION

No weeds resistant to glufosinate have been identified on row crop acres in the U.S. (Heap, 2016). Proper management of glufosinate and the LibertyLink® technology is needed to mitigate the likelihood of resistance evolution as some research has already indicated is possible (Salas et al., 2015; Norsworthy et al., 2012). Glufosinate can be applied up to 36 fl oz/ac in a single application and up to 65 fl oz/ac per year in soybean. In cotton, a single application of 43 fl oz/ac and a yearly maximum of 72 fl oz/ac is allowed. Thus, in LibertyLink systems, glufosinate can be applied multiple times post-emergence (POST) to a single crop, with some degree of flexibility as to when the applications occur. Prior research has shown two applications of glufosinate 3-4 weeks apart provided greater than or equal control compared to single applications, depending upon rate (Aulakh and Jhala, 2015). The two objectives of this experiment were to evaluate various rates of glufosinate applied sequentially at four intervals between applications on large (~12 inches) weeds and determine if a sequential application of a lower rate provides greater control than a single application of a higher rate when the first application occurs to large weeds.

PROCEDURES

An experiment was conducted at the University of Arkansas System Division of Agriculture's Agricultural Experiment Station in Fayetteville, Ark. in 2015 to evaluate single and sequential glufosinate applications to determine optimum rate structure and interval between applications. Plots 12-ft by 30-ft were established on a Leaf silt loam, and a LibertyLink soybean variety (Credenz 4748 LL) was planted at the time of trial establishment. Herbicide treatments consisted of glufosinate applied at 22, 29, 36, and 43 fl oz/ac with either no sequential application, or a sequential application occurring 7, 10, 14, or 21 days after the initial application (DAI). The first application for all treatments occurred when weeds achieved a 12-in. height and included 21 fl oz/ac S-metolachlor.

Weed control was visually evaluated 2 weeks after the final herbicide treatment on a scale of 0 (no control) to 100% (complete death of all plants) relative to the non-treated check. At the end of the season, plots were harvested and yield data were collected. All data were subjected to an analysis of variance (ANOVA) using JMP 12 (SAS Institute Inc., Cary, N.C.), and means were separated using Fisher's protected least significant difference test ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Sequential applications that occurred 7-14 days after the initial application were typically superior to single applications, regardless of rate or weed species (Figs. 1 and 2). At a given rate, sequential applications that occurred 21 DAI provided less control than when the interval was ≤14 DAI for Palmer amaranth and broadleaf signalgrass (Figs. 1 and 2). A single application of 43 fl oz controlled Palmer ama-

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ranth 74% and broadleaf signalgrass 86%, showing that a treatment with a sequential application of a low rate (22 fl oz) is more effective than a single application of a high rate (43 fl oz). Control of both species with a sequential application of 22 fl oz 7, 10, or 14 DAI was not different from treatments with higher rates, at the same intervals (Figs. 1 and 2). In plots that received only a single application, the lower control ratings can likely be attributed to incomplete kill and regrowth of treated plants. No differences were observed between herbicide treatments for yield or injury (data not shown).

PRACTICAL APPLICATIONS

When sequential applications of glufosinate are required to achieve acceptable control, the second application should occur 7-14 days apart. Sequential applications of glufosinate provide superior control of Palmer amaranth and broadleaf signalgrass compared to single applications. This experiment examined post-emergence-only herbicide programs. In addition with POST treatments beginning well beyond the recommended timing or weed size which is around 2-3 in., these treatments could be considered salvage in nature. However, the POST-only programs did provide acceptable control. This is not a sustainable weed management strategy and would likely lead to the evolution of resistance (Norsworthy et al., 2012).

To mitigate the evolution of resistance, glufosinate should be applied in glufosinate-resistant crops as part of a comprehensive weed management program. If sequential applications of glufosinate are used in combination with a comprehensive weed control management program (i.e. using residual herbicides pre-emergence (PRE) and POST, tillage, etc.) the likelihood of evolving glufosinate-resistant weeds should be greatly reduced, and the LibertyLink technology should remain a valuable weed management tool for Arkansas soybean growers.

ACKNOWLEDGEMENTS

The authors thank Bayer CropScience and The Arkansas Soybean Promotion Board for funding this research and the University of Arkansas System Division of Agriculture for support.

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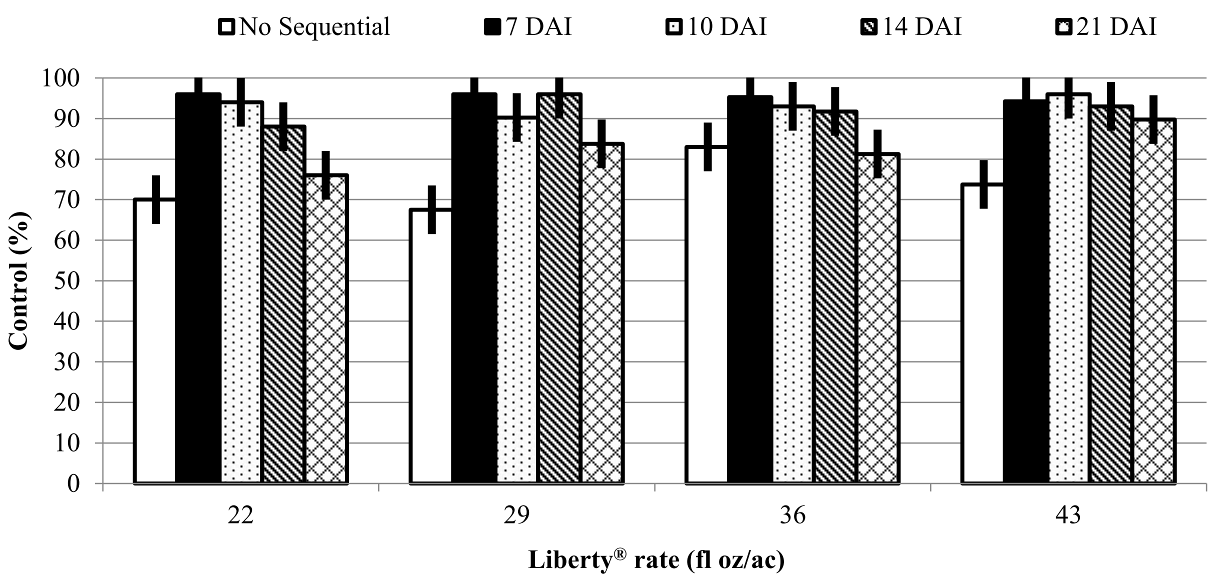

Fig. 1. Control of Palmer amaranth 2 weeks after the final application of glufosinate applied at various rates and sequential application intervals. The black lines above each bar represent the least significant difference (α = 0.05).

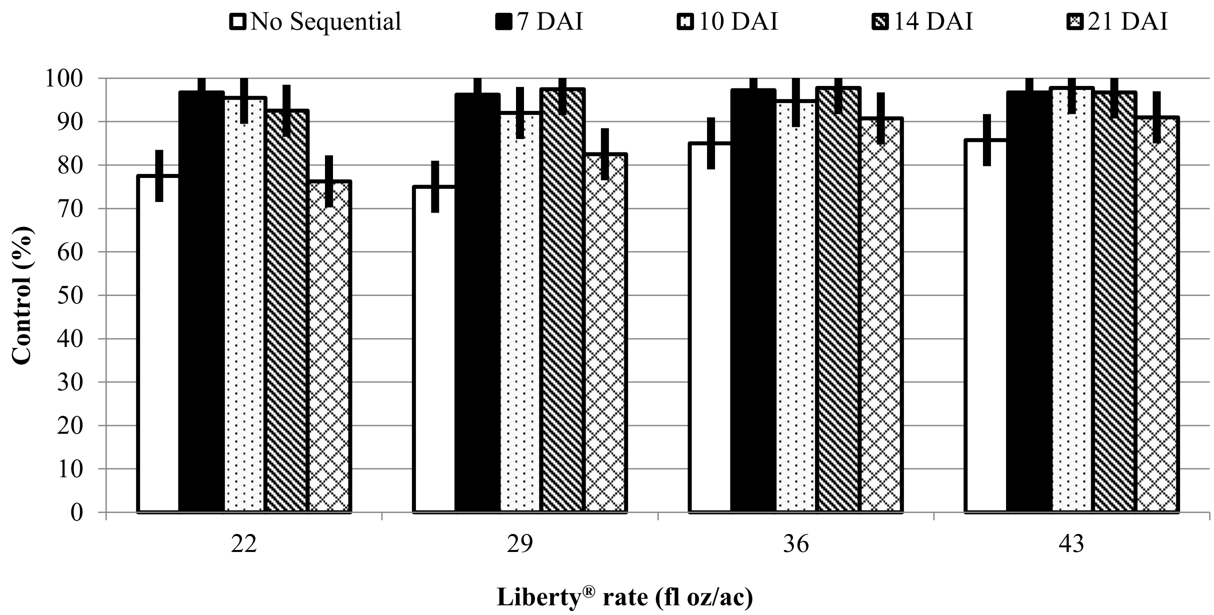

Fig. 2. Control of broadleaf signalgrass 2 weeks after the final application of glufosinate (Liberty®) applied at various rates applied at application intervals. The black lines above each bar represent the least significant difference (α = 0.05).

Chemical Termination Options for Cover Crops Prior to Planting Soybean

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

ABSTRACT

A field study was conducted in the fall of 2015 at the University of Arkansas System Division of Agriculture's Arkansas Agricultural Research and Extension Center in Fayetteville to evaluate burndown options for cover crops. This experiment was organized as a randomized complete block with a strip-plot, where herbicide treatment was the main plot and cover crop was the strip-plot. Treatments were composed of 13 termination options. Visual assessment of control was evaluated at 2 and 4 weeks after application. At 4 weeks after application, cover crop biomass samples were collected and fresh and dry biomass were determined. Cereal cover crops, such as wheat and cereal rye, were effectively terminated by glyphosate alone or any glyphosate-containing treatment. The legume cover crops hairy vetch, Austrian winterpea, and crimson clover were poorly controlled by glyphosate alone. However, better control was observed when auxin herbicides and saflufenacil were tank-mixed with glyphosate. Paraquat plus metribuzin effectively controlled both cereal and legumes cover crops. Rapeseed was not well controlled by any of the herbicide termination options. Earlier application of burndown herbicides might enhance the control of this cover crop or maybe growers should consider other easier to terminate cover crops.

INTRODUCTION

Cover crop acreage has substantially increased over the last few years due to the intent of growers to capitalize on federal conservation payments and incorporate sustainable practices into agricultural systems. Various reports have been published about benefits of cover crops in diverse areas of agriculture (Hartwig and Hans, 2002; Reeves, 1994). The weed suppression provided by cover crops has been widely researched as a means to decrease the selection pressure placed on the system by herbicide use (Teasdale, 1996; Creamer et al., 1996). The development and spread of glyphosate-resistant Palmer amaranth and the recent confirmation of protoporphyrinogen oxidase (PPO)-resistant Palmer amaranth in the mid-South threatens the ability of growers to manage weeds in the absence of the Liberty Link® trait (Culpepper, et al., 2006; Salas et al., 2016). Hence, successful weed management strategies have to rely heavily on integrated management approaches using cultural, mechanical, and chemical methods of control (Price et al., 2011; Jha and Norsworthy, 2009).

Despite all the known benefits, widespread adoption of cover crops still remains limited due to their potential cost and management requirements. Cover crop termination is crucial for the success of management strategies since a poorly terminated cover crop can become a weed and lessen the yield potential of the subsequent cash crop. There is a lack of information in the literature regarding chemical termination options for cover crops prior to planting soybean. Hence, an experiment was designed to evaluate herbicide options for controlling cover crops that would allow soybean to be planted in a timely manner following termination.

PROCEDURES

A field experiment was conducted in 2015 at the University of Arkansas System Division of Agriculture's Research and Extension Center in Fayetteville to evaluate chemical termination options for cover crops. Cover crops were planted on 9 September 2014 at recommended seeding rates (Table 1). The experimental design was a randomized complete block with a strip-plot replicated four times. Herbicide treatments served as the main plot and cover crops as the strip plot. Plots sizes were 6.2-ft. wide by 25-ft. long. All applications were made at 15 gal/ac using a 3-nozzle backpack sprayer on 12 April 2015. The amount of biomass produced by each cover crop at time of herbicide application is reported in Table 1. Effectiveness of the burndown treatments were evaluated at 2 and 4 weeks after treatment (WAT). Fresh and dry biomass were collected at 4 weeks after treatment. All data were subjected to analysis of variance using JMP 12 PRO (SAS Institute Inc., Cary, N.C.), and means were separate using Fisher's protected least significant difference test ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Efficacy of chemical termination options differed among the cover crops evaluated (Table 2). Glyphosate alone and all glyphosate-containing treatments provided complete control of cereal rye and wheat. Paraquat with metribuzin also provided complete control of cereal rye and 93% control of wheat. Complete termination of legume cover crops was more challenging to achieve than cereals. Glyphosate alone provided no more than 57% control of any legume cover crop (Table 3). The addition of saflufenacil, dicamba,

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or 2,4-D to glyphosate often improved control over glyphosate alone; however, none of the glyphosate premixes provided more than 76% control of crimson clover and Austrian winterpea. The tank-mix of parquant + metribuzin was the most effective termination option evaluated for Austrian winterpea and crimson clover, and no other herbicide combination provided greater control than paraquat + metribuzin when terminating hairy vetch. In regard to rapeseed, none of the herbicide treatments provided a level of control that would be deemed commercially acceptable (Table 4). The highest level of control was achieved with 1) paraquat 0.5 lb ai/ac + metribuzin at 0.5 lb ai/ac; 2) 2,4-D at 0.96 lb ai/ac; and 3) glyphosate at 0.87 lb ae/ac + 2,4-D at 0.96 lb ai/ac, even though none provided more than 71% control. Rapeseed appeared to be more sensitive to 2,4-D than to dicamba based on the higher control obtained with 2,4-D-containing treatments.

PRACTICAL APPLICATIONS

Based on the results obtained in this trial, cereal cover crops can be effectively terminated with glyphosate. Paraquat plus metribuzin may provide a quicker kill of a cover crop, if earlier planting is desired or where there is a possible mixture of legume and cereal cover crops. The high level of control obtained with the paraquat + metribuzin tank-mix was not completely surprising because it is well documented that tank-mixing a photosystem II inhibitor with paraquat can enhance weed control or crop removal in the case of a failed stand of corn (Norsworthy et al., 2011; Steckel et al., 2009). Besides the improved post-emergence control of cover crops, the addition of metribuzin to paraquat would provide residual control of weeds prior to soybean planting. As of today, we do not recommend planting rapeseed due to the difficulty experienced when trying to terminate the cover crop. Perhaps an earlier herbicide application would improve the control of rapeseed.

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Support for this trial was provided by the University of Arkansas System Division of Agriculture.

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Table 1. Cover crop seeding rate followed by the amount of cover crop biomass produced at time of herbicide application.

Cover crop	Seeding rate (lb/ac)	Biomass at herbicide application (lb/ac)
Cereal rye	80	4590
Wheat	80	3900
Austrian winterpea	80	2820
Hairy vetch	20	2750
Crimson clover	15	2700
Rapeseed	9	2910

Table 2. Treatment description with the respective cereal cover crops control at 4 weeks after treatment.

		Visual control			
Treatment[†]	Rate	Wheat[‡]		Cereal rye[‡]	
	lb ai or lb ae/ac	%	SE	%	SE
Glyphosate	0.77	100	0	100	0
Glyphosate + Saflufenacil	0.77 + 0.02	100	0	100	0
Glyphosate + Dicamba	0.77 + 0.25	100	0	100	0
Glyphosate + Dicamba	0.77 + 0.50	100	0	100	0
Glyphosate + 2,4-D	0.87 + 0.48	100	0	100	0
Glyphosate + 2,4-D	0.87 + 0.96	100	0	100	0
Glyphosate + Dicamba + 2,4-D	0.77 + 0.19 + 0.30	100	0	100	0
Paraquat	0.75	71	1	83	2
Paraquat + Metribuzin	0.5 + 0.5	93	1	100	0

[†] Dicamba and 2,4-D alone were excluded from analysis because these herbicides have no activity on grasses.
[‡] Cover crops that did not meet the assumptions of analysis of variance are reported as means followed by the standard error (SE) of the mean.

Table 3. Treatment description with the respective legume cover crops control at 4 weeks after treatment.

		Visual control		
Treatment	Rate	Austrian winterpea	Crimson clover	Hairy vetch
	lb ai or lb ae/ac	-----------------------------%-------------------------		
Glyphosate	0.77	56 g[†]	50 hi	57 h
Glyphosate + Saflufenacil	0.77 + 0.02	71 de	76 bc	74 fg
Glyphosate + Dicamba	0.77 + 0.25	75 cd	68 bc	78 ef
Glyphosate + Dicamba	0.77 + 0.50	85 b	77 bc	85 cde
Glyphosate + 2,4-D	0.87 + 0.48	66 ef	62 de	85 cd
Glyphosate + 2,4-D	0.87 + 0.96	76 cd	70 cd	94 a
Glyphosate + Dicamba + 2,4-D	0.77 + 0.19 + 0.30	70 de	60 fg	93 ab
Dicamba	0.25	60 fg	54 gh	69 g
Dicamba	0.50	73 cd	61 f	80 de
2,4-D	0.48	60 fg	45 i	80 de
2,4-D	0.96	69 de	52 h	91 ab
Paraquat	0.75	77 bc	78 b	87 bc
Paraquat + Metribuzin	0.5 + 0.5	96 a	93 a	95 a

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

Table 4. Treatment description with the respective brassica cover crop control at 4 weeks after treatment.

Treatment	Rate	Visual control
		Rapeseed
	lb ai or lb ae/ac	%
Glyphosate	0.77	21 f[†]
Glyphosate + Saflufenacil	0.77 + 0.02	60 bc
Glyphosate + Dicamba	0.77 + 0.25	33 e
Glyphosate + Dicamba	0.77 + 0.50	36 e
Glyphosate + 2,4-D	0.87 + 0.48	58 bc
Glyphosate + 2,4-D	0.87 + 0.96	67 ab
Glyphosate + Dicamba + 2,4-D	0.77 + 0.19 + 0.30	45 d
Dicamba	0.25	20 f
Dicamba	0.50	23 f
2,4-D	0.48	61 bc
2,4-D	0.96	66 ab
Paraquat	0.75	47 d
Paraquat + Metribuzin	0.5 + 0.5	71 a

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

Effect of an Actual Dicamba Drift Event on Soybean Progeny

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

ABSTRACT

Soybean is highly sensitive to dicamba as low rates may result in leaf and pod malformation depending on growth stage at time of exposure. With the advent of dicamba-resistant crops, there will be greater possibility for off-target movement of dicamba. In the occurrence of dicamba drift, it is not well understood what measurements from soybean plants would correlate with damage to soybean offspring; therefore, possible relationships are of great interest. Eight large-plot dicamba drift trials were established in 2014 at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NREC) in Keiser, Ark. A single 100-ft. pass with a 28-ft. wide high clearance sprayer was made in eight separate fields to simulate a drift event. Six of these drift events occurred at R1 growth stage and two were at R3 growth stage of soybean. Seed were collected from exposed plants in each drift trial and planted at the Arkansas Agricultural Research and Extension Center (AAREC) in Fayetteville, Ark., in 2015 at 140,000 seeds/ac. Measurements from the parent plants (leaf malformation, pod malformation, height, yield) were paired with offspring variables (emergence, vigor, injury, plants malformed, and yield) and data were subjected to multivariate and correlation analysis to determine pairwise correlations among parent and offspring observations. Auxin-like symptoms were more prevalent in offspring collected from plants from the R3 than the R1 drift events. When dicamba drift occurred at R1, offspring emergence, offspring vigor, injury to offspring at 21 DAP, and number of offspring plants malformed were most closely correlated with height of parent plants. When dicamba drift occurred at the R3 stage, offspring vigor and number of offspring plants malformed were most closely correlated with injury from dicamba at 28 days after the drift event. Offspring injury was most strongly correlated with parent height at 28 days after the drift event while offspring yield loss was most closely correlated with percentage of pod malformation on parent plants. This research shows that soybean damaged from dicamba drift during the early stages of reproduction can negatively impact offspring and that some measurements taken on the parent plants are better indicators of the offspring response than others.

INTRODUCTION

Even with new formulations of dicamba in the horizon, primary (physical) drift will still be a concern of growers. Soybean is highly sensitive to dicamba as low drift rates may cause injury or even yield loss (Griffin et al., 2013). Furthermore, soybean has been documented to be more sensitive to dicamba at certain growth stages (Barber et al., 2015). Soybean is more subject to leaf malformation at vegetative or early reproductive stages; whereas pod malformation has been documented to be greater at mid-reproductive stages (Bararpour et al., 2016). However, most of this work was conducted by making direct applications to plots rather than trying to re-create a drift event. In soybean, dicamba moves with the phloem therefore explaining the responses seen at the respective growth stages. At vegetative growth stages, growth is occurring at a rapid pace. Dicamba exposure in the vegetative stages results in injury to soybean foliage; however, yield loss is not certain. Once soybean reaches reproductive stages, dicamba exposure typically results in less leaf malformation than when exposed to drift at vegetative stages. However, yield loss is more probable at reproductive stages (Griffin et al., 2013). From growth stages R1 to R4, pod malformation could be a result of dicamba drift as flowers and pods are the sink at this place in time. At the later reproductive stages (R5 and R6), the sink shifts to seed fill. Therefore, dicamba present in the soybean plant at R5 and R6 growth stages likely moves to the seed. Some research has documented that soybean exposed to a simulated drift event at reproductive stages results in offspring that may display injury symptoms soon after emergence (Thompson and Egli, 1973). Previous research has not always documented parameters past the V3 stage of soybean nor were they conducted in field conditions. Therefore, a research experiment was designed to examine the effect an actual dicamba drift event has upon soybean offspring when planted in the field the subsequent season.

PROCEDURES

Field experiments were conducted in 2014 and 2015 at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) in Keiser, Ark., and the Arkansas Agricultural Research and Extension Center (AAREC) in Fayetteville, Ark., respectively. In 2014, eight drift events took place at NEREC with two occurring at the R3 growth stage and the remaining six at the R1 growth stage of soybean (Table 1). A single

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100-ft. by 28-ft. pass was made with a Bowman Mudmaster high-clearance sprayer to simulate the drift event. In the treated plot, dicamba was applied at 0.5 lb ai/ac using AIXR 11003 nozzles calibrated to deliver 10 gal/ac. If the wind at time of application was trending down rows, transects with 20-ft. plot lengths were established along the rows, extending from the center of the treated area until no visible injury was observed. Additional transects were laid out every 4 rows until no visible injury was observed from lateral drift. If wind at the time of application occurred across rows, three transects were established across rows in the center and each edge of a 200-ft. by 28-ft. pass. Transects began on the edge of the treated area and four-row by 20-ft. plots were established extending until no visible injury was observed. At the end of each transect, three consecutive plots where no injury occurred were established to constitute a check. Measurements on the parent plants included visual estimates of leaf malformation on a 0 to 100% scale with 100% being plant death at 14 and 28 days after application (DAA), soybean height at 28 DAA and maturity, percentage of malformed pods at maturity, and grain yield.

In 2015, seed collected from the 2014 drift trials were planted at AAREC at 7.5 seeds/ft. in 20-ft. single-row plots on 36-in. spacing. Initial planting date was 26 April; however, injury in the form of stand loss was documented from pre-emergence-applied flumioxazin and required the test to be replanted at a different location on 25 June. Measurements from the offspring included emergence (% of planted seed), vigor on a scale of one to five with five being best, injury at 21 days after planting (DAP) (% visible injury), plants malformed (#/plot), and grain yield (bu/ac). Data were subjected to multivariate and correlation analysis using JMP Pro 12 (SAS Institute, Inc., Cary, N.C.) to determine pairwise correlations among parent and offspring observations.

RESULTS AND DISCUSSION

When dicamba drift occurred at the R1 stage of soybean, height of parent plants at either 28 DAA or maturity was the best predictor of all offspring variables, except offspring yield loss which was not significant for any parent variable (Table 2). A delay of dicamba drift until the R3 stage of soybean resulted in offspring vigor, offspring injury at 21 days after planting, and number of malformed offspring plants being most correlated with injury symptoms at 28 days after the dicamba drift event (Table 3). Some yield loss was observed in the offspring, which was best predicted by the extent of pod malformation on the parent plants. Offspring emergence did not appear to be significantly correlated with any of the parent plant variables measured following dicamba drift at the R3 stage of soybean.

The highest correlation following the R3 drift event was between injury to parent plants at 28 days after application and the resulting offspring vigor (Fig. 1). It is hypothesized that the replanting of this study later in summer may have resulted in better growing conditions; therefore, even greater difference in vigor may be possible under less than ideal growing conditions following planting.

Yield loss is perhaps the most intriguing variable for most growers. This study indicated that parent percent pod malformation displayed the highest correlation with offspring grain yield (Fig. 2). At 28 days after the drift event, increased parent pod malformation resulted in an increase in yield loss for offspring soybean. The replanting of this trial coincided more so with a double-crop planting date. Typically, double-crop soybean is planted in narrow rows to maximize yield as reduced vegetative growth will occur when compared to full-season soybean (Johnson et al., 2002; Harder et al., 2007). It is quite possible that a decrease in row spacing would have compensated for any yield effects by increasing leaf area index (LAI) and shortening the amount of time until soybean canopy (Harder et al., 2007).

Based on this study, offspring from non-dicamba soybean exposed to a dicamba drift event at R1 or R3 reproductive stages conveyed symptoms to their offspring. However, correlation coefficients indicate a stronger relationship among offspring resulting from parent plants exposed to a drift event at the R3 growth stage. This is likely due to soybean at the R1 growth stage having sufficient time to metabolize dicamba prior to pod and seed formation, resulting in less dicamba molecules being transferred to the seed.

PRACTICAL APPLICATIONS

It is well known that soybean is highly sensitive to dicamba and exposure may result in decreased yield or poor seed quality. As seen in previous research conducted by Thompson and Egli (1973), this study identifies that the negative effects of dicamba drift may be transmitted to soybean offspring. One instance of great concern would be dicamba drift onto seed production fields as growers may not be aware of the damage caused until the subsequent generation displays auxin-like symptoms soon after emergence. In Arkansas, soybean has a wide window of planting time that ranges from April through July (USDA-NASS, 2010). Therefore, the potential to have vegetative application of dicamba being applied near fields of soybean that are already in reproductive stages is high. Furthermore, this research is important because it will aid in establishing relationships between soybean exposed to dicamba and their offspring.

ACKNOWLEDGEMENTS

We would like to thank the Arkansas Soybean Promotion Board for funding of this project. Further support was provided by the University of Arkansas System Division of Agriculture.

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Table 1. Cultivar and growth stage of soybean in 8 separate fields which experienced drift events.

Field	Cultivar	Growth Stage at Drift Event
1	Progeny 4819	R1
2	Halo 494	R1
3	Halo 494	R1
4	Halo 494	R1
5	HBK 4850	R1
6	HBK 4850	R1
7	Progeny 4819	R3
8	Progeny 4819	R3

Table 2. Correlation coefficients for parent and progeny variables when a dicamba drift event occurs at the R1 growth stage of soybean.

	Parent Variables (%)					
Progeny Variables	14 DAA Injury	28 DAA Injury	28 DAA Height	Mature Height	Pod Malformation	Yield Loss
Emergence	NS	NS	0.1390[b]	NS	NS	NS
Vigor	NS	NS	0.1905[c]	0.0974[a]	NS	NS
Injury	0.1887[c]	0.1549[c]	-0.2391[c]	-0.2670[c]	0.1856[c]	0.1839[c]
# Malformed	NS	NS	-0.1637[c]	-0.1358[b]	NS	NS
Yield Loss	NS	NS	NS	NS	NS	NS

[a] Significance to 0.05.
[b] Significance to 0.01.
[c] Significance to 0.00.
NS = not significant.
DAA = days after application.
DAP = days after planting.

Table 3. Correlation coefficients for parent and progeny variables when a dicamba drift event occurs at the R3 growth stage of soybean.

	Parent Variables (%)					
Progeny Variables	14 DAA Injury	28 DAA Injury	28 DAA Height	Mature Height	Pod Malformation	Yield Loss
Emergence	NS	NS	NS	NS	NS	NS
Vigor	NS	-0.2302[a]	0.1967[a]	NS	NS	NS
Injury	0.3271[c]	0.4320[c]	-0.4819[c]	-0.3214[c]	0.2448[b]	0.3371[c]
# Malformed	0.1963[a]	0.3585[c]	-0.3350[c]	NS	NS	0.2514[b]
Yield Loss	0.2915[b]	0.1977[a]	NS	-0.2067[a]	0.2999[c]	NS

[a] Significance to 0.05.
[b] Significance to 0.01.
[c] Significance to 0.001.
NS = not significant.
DAA = days after application.
DAP = days after planting.

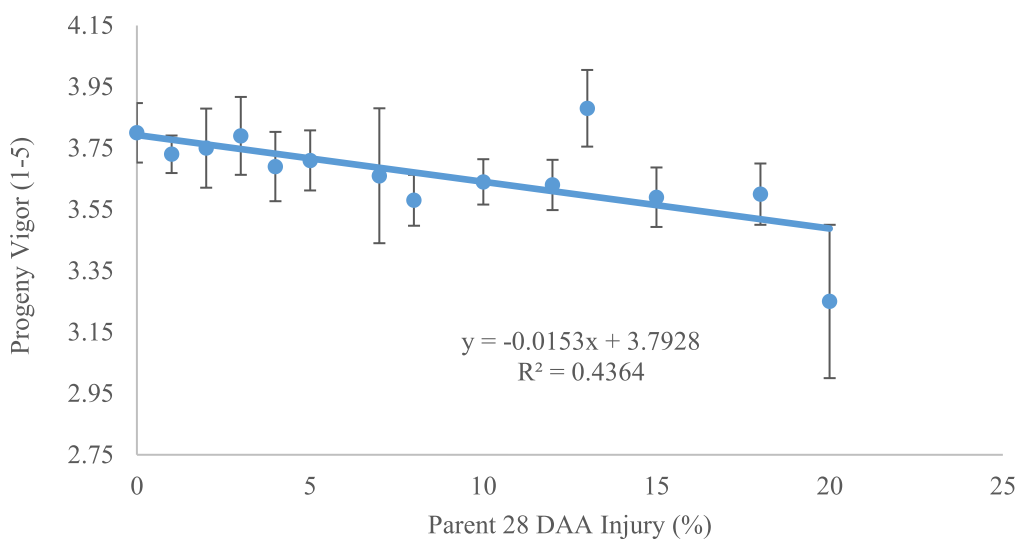

Fig. 1. Relationship between parent leaf injury at 28 days after application (DAA) of dicamba occurring at R3 and progeny vigor at 21 days after planting. Data points represent average progeny vigor at each parent leaf injury percentage. Error bars represent standard error.

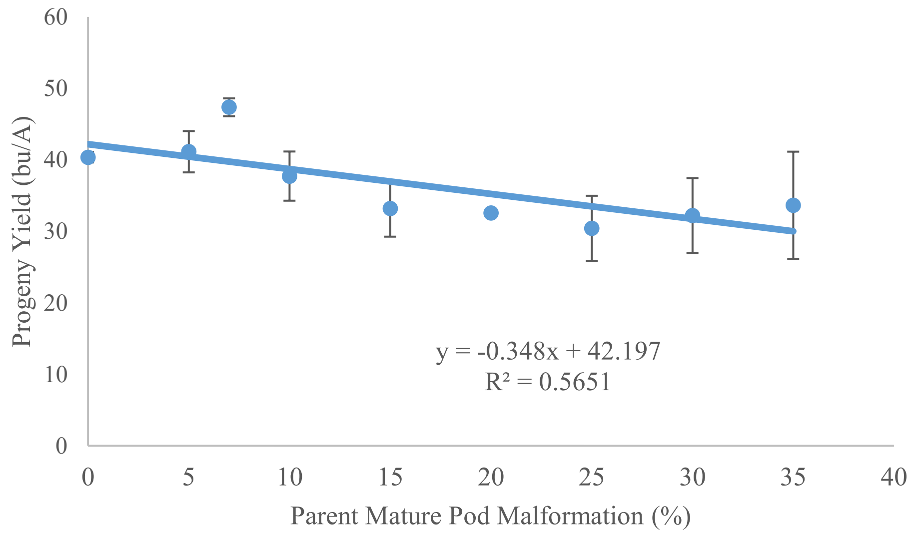

Fig. 2. Relationship between parent pod malformation (% of pods) in R3 experiments and progeny yield. Data points represent average progeny yield at each parent mature pod malformation percentage. Error bars represent standard error.

Comparison of Two Dicamba Formulations for Risk of Off-Target Movement to Soybean

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ABSTRACT

With current interest in labeling diglycolamine (DGA) dicamba (Clarity®, BASF) for use in dicamba-resistant soybean, it is of great importance to examine possible differences from the technologically advanced N,N-Bis-(aminopropyl) methylamine (BAPMA) dicamba that is expected to be released in the near future by BASF. The new BAPMA form of dicamba will be branded Engenia® and is expected to exhibit decreased volatility over previous forms of dicamba. A study was conducted in 2015 at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) in Keiser, Ark. to examine possible differences that these two forms of dicamba may display. Diglycolamine and BAPMA dicamba were applied simultaneously at 0.5 lb ae/ac in the center of two side by side 20-acre fields at V6/V7 growth stage of soybean. Eight transects were established radiating in each cardinal direction from each application area, and plots were established at varying distances along the transect to the field edge. Buckets, 5-gal in size, were used to protect plants from primary and secondary drift. On the same day, a rate titration experiment was established encompassing 9 different dicamba rates of each formulation. Injury ratings were taken at 7, 14, and 21 days after application (DAA) from each experiment. Results from the rate titration experiment were used to estimate the amount of dicamba reaching subplots in the larger experiment. Tissue samples were collected from both DGA experiments to examine dicamba present in the tissue. Distance to secondary drift injury of 5% occurred at 40-ft for each form of dicamba. However, secondary injury was seen at greater distances with DGA dicamba; albeit, injury was very minor. Analytical quantification of the concentration of dicamba in the plant tissue was a weaker indicator of dicamba presence than the occurence of dicamba-like symptoms. For the conditions under which dicamba was applied in this study, there were few differences in DGA and BAPMA formulations. It is likely that a rainfall event that occurred 6 hours after applying dicamba contributed to the inability to detect strong differences in secondary movement between the two dicamba formulations.

INTRODUCTION

The introduction of glyphosate and dicamba-resistant soybean cultivars is near; however, no formulation of dicamba is presently approved for over-the-top application in this new form of genetically modified soybean. Currently, the diglycolamine (DGA) form of dicamba (Clarity®) is being examined for such labeling. Furthermore, BASF is on track to release the N,N-Bis-(aminopropyl) methylamine (BAPMA) form of dicamba as early as 2016. This form of dicamba will be branded Engenia® and reportedly exhibits decreased secondary drift (volatility) over Clarity. Previous, peer-reviewed research examining the characteristics of Engenia after field application does not exist. However, there is some literature available observing differences between Clarity and the dimethylamine (DMA) forms of dicamba (Banvel®, BASF). In research compiled by Egan and Mortensen (2012), amount of dicamba leaving the application area via secondary drift was reduced by 94% when Clarity was used over Banvel. Furthermore, soybean was documented to be equally sensitive to these dicamba formulations. Other research also documented decreased secondary loss of Clarity compared to Banvel as detected by air samplers within the application area (Mueller et al., 2013). Although, Engenia is purported to have decreased secondary loss over previous forms of dicamba, necessary field research has not been completed. Therefore, a research experiment was designed to examine possible differences between Clarity and Engenia after application using commercial application techniques.

PROCEDURES

A field experiment was conducted in 2015 at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center in Keiser, Ark. Glufosinate-resistant soybean (Bayer Credenz 4950) was planted in two adjacent 20-acre fields, with the fields divided by a 20-ft wide grass roadway. In the center of each field, Clarity and Engenia were applied simultaneously at V6/V7 growth stage at a rate of 0.5 lb ae/ac to a 125 × 125-ft area. Bowman Mudmaster (Newport, Ark.) high-clearance sprayers were used, each having a 25-ft swath and traveling at 9.5 mph with an output of 10 gal/ac from 11003 TTI nozzles (Teejet Technologies, Glendale Heights, Ill.). Prior to application, three subplots were established by marking 5 to 6 soybean plants per subplot at prescribed distances radiating

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in eight cardinal directions along transects from the treated plot. Subplot sets were arranged every 10 ft from 10 to 40 ft from the application, every 20 ft from 60 to 120 ft, and every 30 ft from 150 to the edge of the field (approximately 240 ft). The subplots consisted of soybean plants that were exposed to a) combined primary (physical) drift plus secondary (vapor) drift; b) primary drift only; and c) secondary drift only. Prior to application, 5-gal buckets were placed over the soybean plants that were only exposed to secondary drift. Applications were made in mid-afternoon and the buckets were removed 30 minutes after application and immediately placed over the plants that were only exposed to primary drift. The buckets remained in place for 24 hours before being removed. Visible injury ratings were taken at 7, 14, and 21 days after application (DAA) for all primary, secondary, and combined subplots.

Bayer Credenz 4950 was also planted in a smaller field located one mile away for use as a Clarity and Engenia rate titration experiment that occurred on the same day as the large drift experiment. Applications of nine dicamba doses ranging from 1/10 to 1/100,000 of a 1× rate of 0.5 lb ae/ac were made using a CO_2-pressurized backpack sprayer with a 6.7-ft spray boom equipped with four 11003 TTI nozzles (Teejet Technologies, Glendale Heights, Ill.) with an output of 15 gal/ac. Injury ratings were taken at 7, 14, and 21 DAA and used to estimate the amount of dicamba reaching subplots in the larger experiment. Tissue samples were also collected from both the rate titration and larger drift experiment (Clarity formulation only) at 7 DAA and the concentration of dicamba in the tissue was determined by the Arkansas State Plant Board. Analysis of covariance (ANCOVA) was used to distinguish differences, in the non transformed data, between rate and response of soybean to Clarity and Engenia formulations. Equations generated from the rate titration data were used to predict dose by visible injury ratings in the Clarity and Engenia large-plot experiments.

RESULTS AND DISCUSSION

During the simultaneous applications of Clarity and Engenia, wind speed ranged from 3 to 6 mph. Winds were from a north/northeastern direction during and several hours after the application; therefore, injury was confined to the north, northeast, and east transects. Approximately 6 hours after application, a 1-in. rainfall event occurred at the test site. Primary drift from Clarity and Engenia resulted in an estimated 5% injury at 100-ft and 80-ft, respectively. Injury was seen at further distances in the Clarity experiment; however, it was minimal. Distance to secondary drift injury of 5% decreased to 40-ft for each form of dicamba. Yet, there were subtle differences between transects. Injury symptoms from both the north and northeast transects were similar between formulations; however, the distance traveled by secondary drift in the east transect by Engenia was reduced by 33% when compared to Clarity. Visible injury resulting from primary and combined drift from a field application of Engenia and Clarity formulations were similar. Injury resulting from secondary drift may need more evaluation as experiments indicate subtle differences that may have been somewhat affected by the unexpected rainfall event. However even a drift reduction of 33% could result in significantly less economic loss or the need to create larger buffers (Barber et al., 2015).

The analysis of covariance results indicated that there was no significant difference in the relationship between rate and injury in the Clarity and Engenia rate titration experiments. Hence, Bayer Credenz 4950 soybean was equally sensitive to Clarity and Engenia formulations. As a result, data for Clarity and Engenia were combined to construct a log-linear relationship between log-linear rate applied and visible injury symptoms (Fig. 1). The equation for the ln-linear relationship was then used to estimate dose (lb acid equivalent/ac) by using visible injury ratings from the large drift trials. Predicted dose in Engenia experiments was less than or equal to that of Clarity in all plots 10 and 20 ft from the treated area. However, values were similar beyond 20 ft from the treated area.

Based on the analysis of dicamba in the soybean sample evaluated by the Arkansas State Plant Board, there was no apparent patterns or relationships between the amount of the Clarity formulation of dicamba recovered and injury to soybean (Figs. 2 and 3). Even in plots having 25% to 40% leaf malformation, the presence of dicamba could not always be detected in the soybean tissue. The variability in data along with false negatives (plants showing symptoms with dicamba analytically detected) seem to indicate that visible injury ratings may detect dicamba more accurately and efficiently than current analytical methods.

PRACTICAL APPLICATIONS

Results from this study indicate that soybean is equally sensitive to the Clarity and Engenia formulations of dicamba when exposed to drift at vegetative stages. In research designed in a similar way, Egan and Mortensen (2012) also found no difference in soybean sensitivity between Clarity and Banvel formulations. Distance moved by primary and secondary drift were also similar; however, more research is needed in terms of secondary loss due to a rainfall event occurring shortly after application. Based on these results from 2015, it does not appear likely that analytical methods are sufficient for detecting the presence of dicamba in soybean, even when tissue samples are collected as soon as 7 days after a drift event. The fact that dicamba cannot be easily detected may be extremely important when trying to determine the actual auxinic herbicide responsible for injury to soybean, especially in light of multiple auxinic herbicides being used for burndown and in-crop applications in an array of Arkansas crops. As previous research has shown, even low doses of dicamba can have significant impact on soybean yields and pod development especially durning the reproductive stages (Barber et al., 2015).

ACKNOWLEDGEMENTS

We would like to thank the Arkansas Soybean Promotion Board and BASF for funding this project. Research facilities and additional support were provided by the University of Arkansas System Division of Agriculture.

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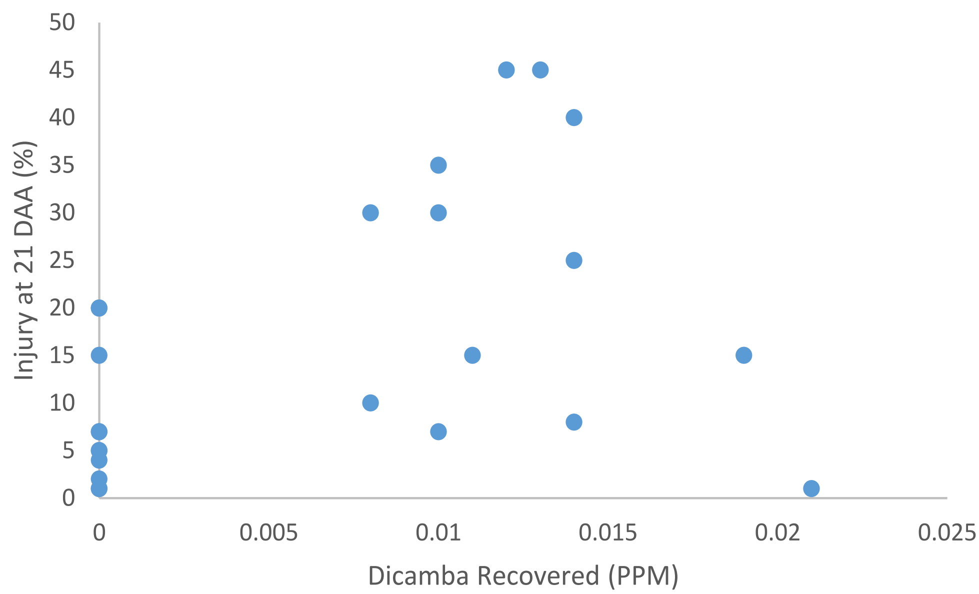

Fig. 1. Log-linear relationship between injury to soybean and dose in parts per million (ppm) recovered at 21 days after application (DAA).

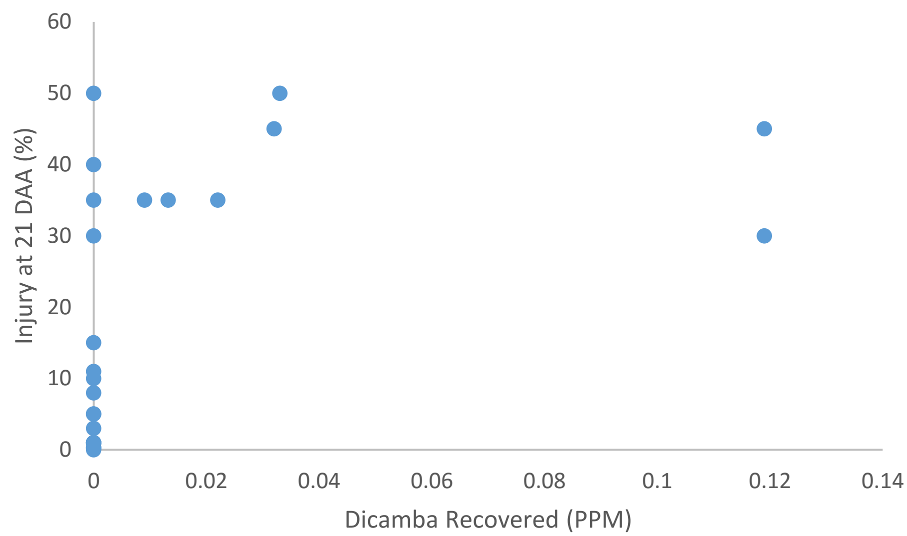

Fig. 2. Relationship between dicamba recovered in parts per million (ppm) from the large plot Clarity® drift experiment and percent injury to soybean seen at 21 days after application (DAA) .

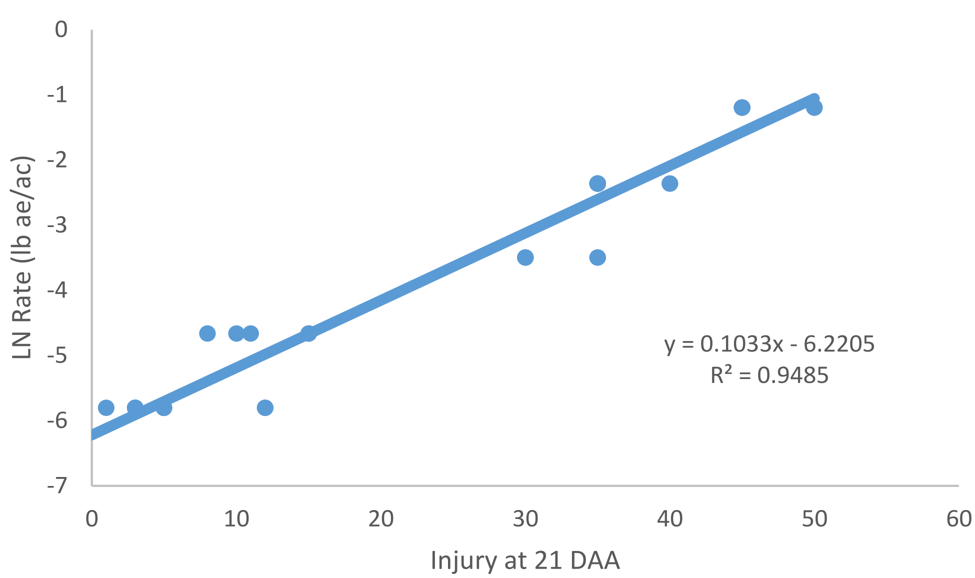

Fig. 3. Relationship between diamba recovered (LN Rate lb ae/ac) from the small plot rate titration Clarity experiment and percent injury seen at 21 days after application (DAA).

Effect of a Simulated Drift Event of Dicamba Alone and When Tank-Mixed with Glyphosate on Soybean Offspring

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

ABSTRACT

Dicamba herbicide can have deleterious effects upon soybean growth, quality, and yield. The number of off-target movement instances is likely to increase with the labeling of dicamba-containing products in dicamba-resistant soybean and cotton. It is likely that a premix of dicamba plus glyphosate will be applied to vast acres of dicamba- and glyphosate-resistant soybean and cotton if approved. Research has documented decreased vigor and an expression of dicamba-like symptoms on soybean exposed to an actual dicamba drift event; however; it is unclear if the addition of glyphosate may exaggerate these effects. Therefore, a greenhouse experiment was designed to examine the effect of a simulated drift event of dicamba alone and in combination with glyphosate on soybean offspring. The simulated drift event experiment occurred in the field in 2015 at the University of Arkansas System Division of Agriculture's Arkansas Agricultural Research and Extension Center (AAREC) in Fayetteville, Ark. Drift rates of 1/256× and 1/64× were used for each herbicide. Applications were made at R1 (initial flower), R3 (initial pod set), and R5 (initial seed formation) growth stages. A grab sample was collected from each plot at harvest and was immediately moved to cold storage. In March of 2016, a greenhouse trial was planted at the University of Arkansas Altheimer Laboratory in Fayetteville, Ark. Twenty-five seeds coming from a single plot grab sample were planted 1-in. deep in 13 by 7-in. trays filled with potting mix. At 21 days after planting (DAP), vigor, emergence (%), injury (%), and number of plants injured were recorded. The number of plants showing dicamba-like symptomology was not significantly increased with the addition of glyphosate. Overall, injury was similar in dicamba alone and dicamba plus glyphosate treatments; however, the number of plants injured was doubled at R3 and R5 growth stages when compared to R1 drift events. Vigor was significantly reduced in treatments including dicamba, but not in glyphosate alone treatments. The addition of glyphosate to dicamba had no effect on vigor of soybean offspring. Previous research has documented increased injury to parent plants when glyphosate is added to dicamba; however, this research demonstrates that the negative effects may not be transmitted to soybean offspring.

INTRODUCTION

Soybean cultivars engineered for resistance to dicamba have been deregulated by the EPA and approved for import by China. However, dicamba may still only be applied as a preharvest application or at a half or full rate as a preplant application 14 or 28 days before planting, respectively. A full registration for use of dicamba over the top of soybean is being sought, but the timeline for its approval is uncertain.Although a balanced pre-emergence followed by a post-emergence herbicide program is recommended, dicamba application in-crop will add a highly effective mode of action to control problem broadleaf weeds in soybean (Flessner et al., 2015; Spaunhorst and Bradley, 2013). Off-target drift of dicamba to non-dicamba soybean can be highly injurious and possibly reduce yield (Wiedenhamer et al., 1989). Some research has documented that soybean exposed to a simulated dicamba drift event at reproductive stages results in offspring that may display injury symptoms soon after emergence (Thompson and Egli, 1973). The addition of glyphosate to dicamba has been documented to increase leaf and pod malformation in soybean over dicamba alone (Bararpour et al., 2016); however, the effect of the tank-mix on offspring has yet to be examined. Therefore, an experiment was designed to examine the effect of a simulated drift event of dicamba and glyphosate alone and in combination on soybean offspring.

PROCEDURES

A field experiment was conducted in 2015 at the University of Arkansas System Division of Agriculture's Arkansas Agricultural Research and Extension Center in Fayetteville, Ark. Treatments were arranged as a full factorial, with herbicide treatment, drift rate, and growth stage being the three factors. Dicamba, glyphosate, or a tank-mix of the herbicides were applied at 1/64× or 1/256× the recommended rate. Applications were made at R1 (initial flower), R3 (initial pod set), and R5 (initial seed formation). At soybean maturity, a grab sample of approximately 500 seed were collected during harvest from each plot and immediately moved to cold storage.

A greenhouse experiment was conducted in 2016 at the Altheimer Laboratory in Fayetteville, Ark. Twenty-five seed

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from each grab sample were planted 1-in. deep into 13 by 7-in. trays, which were filled with potting mix. Trays were arranged in a randomized complete block design within the greenhouse. Twenty-one days after planting (DAP), vigor (1-5), emergence (%), injury (%), and number of plants injured were recorded for each tray (experimental plot). Plants were considered injured if they exhibited leaf cupping or strapping, which are common symptoms of soybean exposed to dicamba. Data were subjected to analysis of variance using JMP Pro 12 (SAS Institute, Inc., Cary, N.C.) and means were separated using Fisher's protected least significant difference test ($P = 0.05$).

RESULTS AND DISCUSSION

Emergence was not effected by the addition of glyphosate to dicamba. Furthermore, all treatements resulted in over 80% emergence. The interaction between herbicide and growth stage affected the number of plants showing dicamba-like symptoms (Fig. 1). The number of injured plants resulting from dicamba applied at R3 and R5 stages was significantly greater compared to dicamba applied at the R1 growth stage. This was expected, as it is likely that parent soybean plants had a greater amount of time after R1 exposure to metabolize dicamba before seed fill began. The addition of glyphosate to dicamba did not effect the number of soybean plants showing dicamba-like symptoms. Herbicide treatment had a significant impact on percent offspring injury. Overall, offspring injury was greater when glyphosate was added to dicamba; however, it was not significantly different from dicamba-alone treatments (Fig. 2). Offspring vigor was also significant across herbicide treatments. Vigor of offspring seedlings was similar and relatively high for non-treated and glyphosate-alone treatments; however, significant reductions in vigor were documented when dicamba was included (Fig. 3). An additional decline in offspring vigor was not recognized when glyphosate was added to dicamba. Overall, exposure of the tank-mix of dicamba and glyphosate to parent plants did not significantly magnify negative effects transmitted to soybean offspring by dicamba alone. This is contrary to the result seen in parent plants as the addition of glyphosate to dicamba consistently increased negative effects of leaf malformation at R1 and pod malformation at R3 growth stage (Bararpour et al., 2016).

PRACTICAL APPLICATIONS

Soybean has been documented to be highly sensitive to dicamba and sensitivity has been acknowledged to vary among growth stages (Weidenhamer et al., 1989). Furthermore, the addition of glyphosate to dicamba has been documented to increase leaf and pod malformation to parent plants further (Bararpour et al., 2016). Observations from this experiment suggest that negative effects resulting from the addition of glyphosate to dicamba may not transmit to soybean offspring. However, further research must be compiled under field conditions to examine the true effect the addition of glyphosate to dicamba has upon soybean offspring.

ACKNOWLEDGEMENTS

We would like to thank the Arkansas Soybean Promotion Board for funding of this project. Further support was provided by the University of Arkansas System Division of Agriculture.

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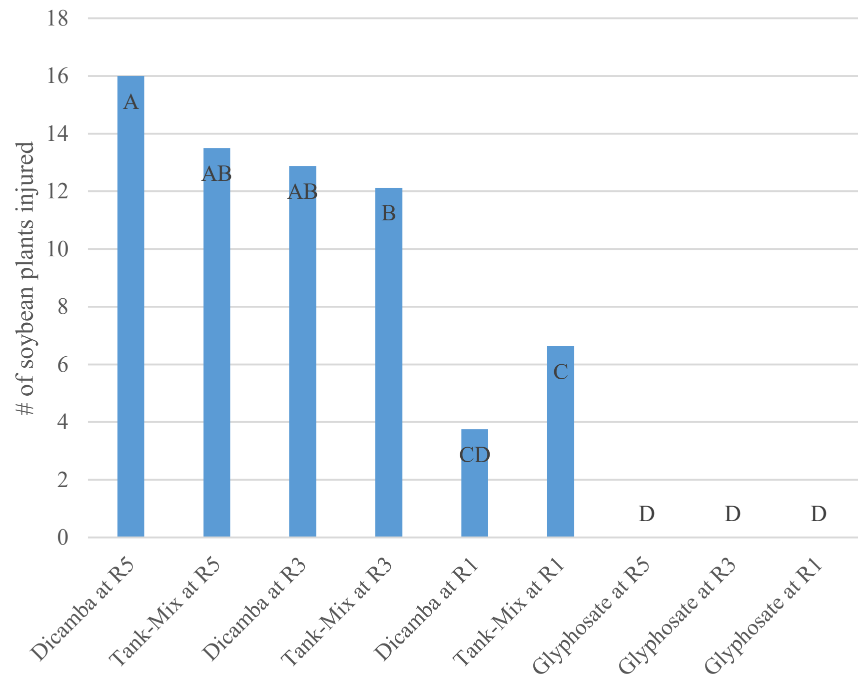

Fig. 1. The number of soybean progeny showing dicamba-like symptoms. Means represented by the same letter are not significantly different.

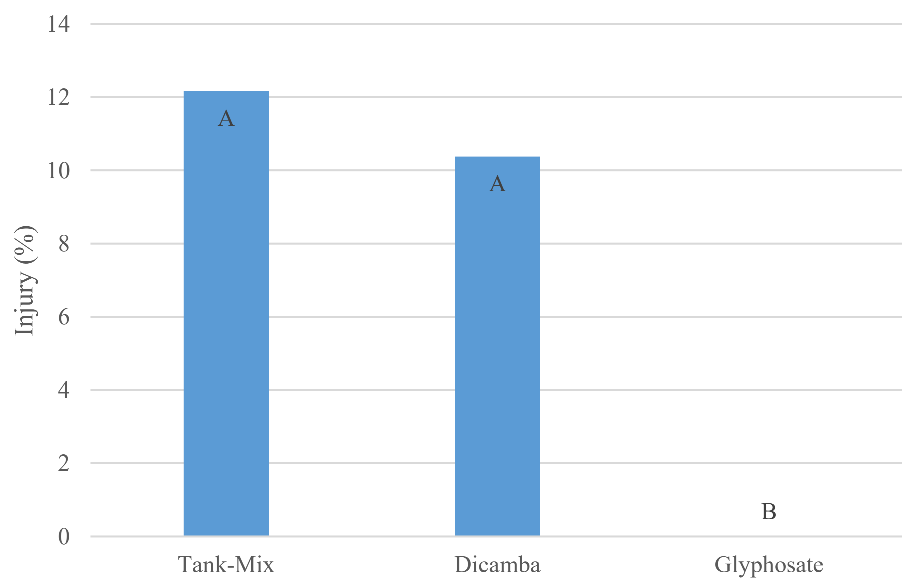

Fig. 2. Level of injury seen in the form of dicamba-like symptoms. Means represented by the same letter are not significantly different.

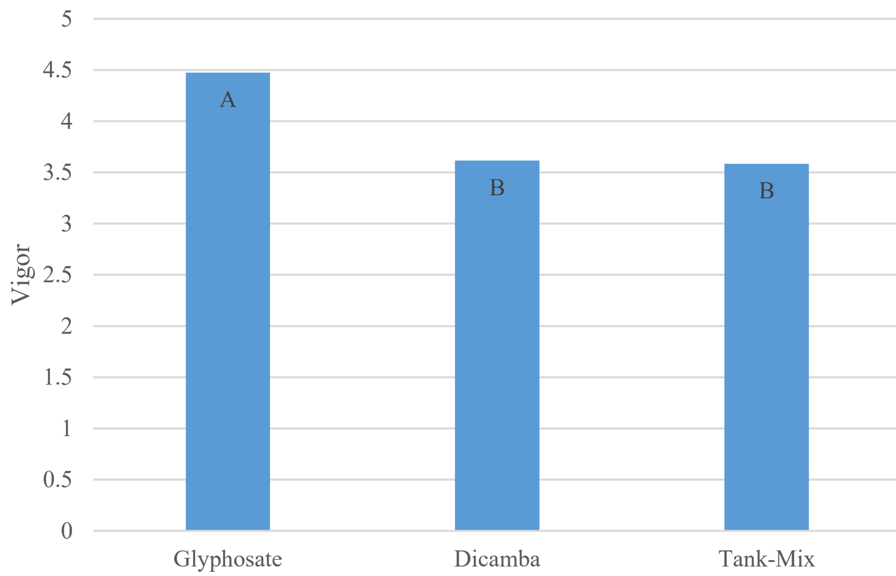

Fig. 3. Vigor exhibited by soybean progeny. Means represented by the same letter are not significantly different. The dotted line represents vigor of soybean progeny not exposed to simulated drift the previous year.

Does Pod Location on Soybean Influence the Degree of Dicamba-like Symptoms Observed on Progeny?

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

ABSTRACT

Studies were conducted to determine the potential carryover of dicamba residue in soybean progeny (next generation of seeds/plants) following tank contamination rates of dicamba over sensitive cultivars. The progeny were evaluated in the greenhouse at the University of Arkansas System Division of Agriculture's Altheimer Laboratory in Fayetteville, Arkansas following exposure of soybean plants to low rates of dicamba. The objective of this study was to determine if pod location during application influenced progeny growth and vigor. Progeny in this trial originated from a field trial conducted the previous year to determine the effect of low rates of dicamba and application timings on a susceptible determinate cultivar. Two low rates of dicamba (1/64× and 1/256×) were applied at several growth stages (V4-R6). From each plot, ten plants were collected at maturity and segmented into thirds. Seed from these plants were then planted in the greenhouse and evaluated for plant emergence, vigor, and dicamba symptomology based on pod location. Significant differences in plant emergence and seedling vigor were observed once progeny reached growth stage V3. Progeny response was found to be different depending on growth stage at time of application. Progeny emergence was reduced 62% relative to the nontreated for the R5 application, whereas the V4 application resulted in emergence comparable to the nontreated. A visual estimate of injury to soybean progeny increased as dicamba was applied at later reproductive stages (R4-R6); however, injury varied depending on the location of where seeds were collected on the plants. When averaged across all growth stages, seeds collected from the bottom portion of the plants expressed a statistically greater percentage of injury when compared to seeds collected from top and middle of the plant. On average 39% of the total pods collected from the middle of the plant were malformed; whereas the bottom and top of the plant had 30% to 31% pod malformation. Greater differentiation of pod malformation between locations was observed as dicamba was applied later in the reproductive growth stages. From these results, we can conclude that pod location does seem to have an influence on dicamba-like symptoms observed on progeny; however, there does not appear to be a strong correlation between pod malformation and injury to progeny.

INTRODUCTION

The movement of synthetic auxin herbicides in the plant is similar to that of photosynthate. When photosynthate is stored in the seed, dicamba may be stored in the seed as well (Thompson and Egli, 1973). Herbicides stored in soybean seed can decrease germination and can be injurious on the developing seedling (Wax et al., 1969). Solomon and Bradley (2014) examined the influence of application timings of several synthetic auxin herbicides on soybeans and determined that following a V3 application of dicamba at sub-lethal rates, the number of pods per plant was similar to that of the non-treated control. In contrast, following a R2 application, the number of pods per plant was highly influenced by herbicide rate. In general, applications of synthetic auxin herbicides made during reproductive growth stages would be expected to result in residue carryover in the seed more than applications made at earlier growth stages (Barber et al., 2015). The objective of this experiment was to determine if similar results are observed in soybean progeny; however, the seed will be collected from the top, middle, and bottom of the plant.

PROCEDURES

In 2014, field trials were conducted at the University of Arkansas System Division of Agriculture's Lonn Mann Cotton Research Station to evaluate the response of soybean to low rates of dicamba. The DGA salt formulation of dicamba (Clarity® herbicide, BASF Corporation, Research Triangle Park, N.C.) was applied at two vegetative growth stages and six reproductive growth stages to evaluate the response of application timing on soybean injury and yield loss. The two low rates evaluated included: 1/64× (0.25 fl oz/ac or 0.0078 lb ae/ac) and 1/256× (0.0625 fl oz/ac or 0.00195 lb ae/ac) of a presumed labeled rate (16 fl oz/ac or 0.5 lb ae/ac). This study was conducted using a HBK 4950 (indeterminate) and a Halo 5.45 (determinate) cultivar. A meter row of plants from each plot were collected for further analysis and seed were planted in the greenhouse in 2015 to evaluate the effects of potential dicamba carryover into the progeny.

At the Althemier Laboratory in Fayetteville, Ark. a greenhouse study was conducted to evaluate if soybean progeny response to low rates of dicamba differed depending on the location the seed were collected from the parent plant. While

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hand harvesting, seed from soybean data were also collected on pod malformation. The design of this experiment in the greenhouse was similar to that in the field, organized as a randomized complete block design with an additional factor. Factors included: application timing, dicamba rate, and pod position. Fifteen seeds from each section of the plant were planted in individual pots to evaluate progeny emergence and vigor. Each plant was divided into thirds based on node count. At the second trifoliate stage, data were collected on soybean emergence, dicamba symptomology, and overall plant vigor. Average heights were measured using three randomly selected plants from each pot and above ground wet and dry biomass were recorded. Data were analyzed using JMP 12.1 (SAS Institute, Inc., Cary, N.C.) and means were separated using Fisher's protected least significant difference test ($\alpha = 0.05$).

RESULTS AND DISSCUSSION

Once progeny reached the second trifoliate stage, significant differences in progeny vigor and emergence were observed depending upon the growth stage when dicamba was applied and where the seed were harvested from the plant. A significant decrease in progeny emergence was observed in seed collected from the bottom of the plant. On average, 85% of the seeds germinated and seedlings emerged when collected from the top of the plant, whereas 71% emergence was observed when seed were collected from the bottom of the plant (Fig. 1). Furthermore, the lowest percentage of emergence was observed following a R4 and R5 dicamba application, resulting in 56% and 38%, respectively (Fig. 2). Similarly, visual estimates of injury to soybean progeny were greater in seed collected from the bottom of the plant (Fig. 3), and severity of injury increased as dicamba was applied to parent plants later into the reproductive stages. Furthermore, injury expressed in progeny following reproductive applications varied depending on the rate of dicamba applied. Seed collected from plants treated during R5-R6 growth stages with 1/64× rate dicamba had seedlings that expressed 53% to 57% visual injury, whereas when treated with 1/256× rate, progeny expressed 32% to 37% injury (Fig. 4). Injury symptoms included dicamba-like symptomology, such as petiole epinasty and severe leaf cupping. These finding are similar to that of the finding of Thompson and Egli (1973) when they investigated the carryover of 2,4-D, a similar auxin herbicide, into soybean progeny.

When progeny seed were collected, information was also recorded on the number of malformed pods at each location. The greatest percentage of pod malformation was observed following a 1/64× rate of dicamba applied at R4, resulting in 13% of the total pods being malformed (Fig. 5). As we investigate further, results indicate the largest percentages of malformed pods were collected from the middle of the plant when dicamba was applied at any growth stage; however, greater differentiation of pod malformation between locations was observed as dicamba was applied later in the reproductive growth stages. For example, when dicamba was applied at R4 growth stage, 43% of the malformed pods were collected from the middle of the plant, 27% from the top, and 30% from the bottom. Conversely, when dicamba was applied at V4 growth stage, 37% of the malformed pods were collected from the middle, 29% from the top, and 34% from the bottom (Fig. 6). From these results, we conclude that pod location does have an influence on dicamba-like symptoms observed on progeny; however, there does not appear to be a strong correlation between pod malformation and injury to progeny. Future analysis will need to examine if pod malformation is directly correlated with injury to progeny.

PRACTICAL APPLICATIONS

With the release of new technology providing dicamba tolerance to soybean, the potential for off-target movement or tank contamination to sensitive cultivars is high. The implication that dicamba can be transported to the seed of susceptible cultivars could have significant impacts on producers who grow seed of conventional or other transgenic lines that are not tolerant to the dicamba herbicide. As the adoption of dicamba technology increases, it will be important for growers to follow a stringent application program to decrease the potential of off-target movement of this herbicide.

ACKNOWLEDGEMENTS

The authors of this research would like to thank the University of Arkansas System Division of Agriculture and the Arkansas Soybean Promotion Board for the funding of this project.

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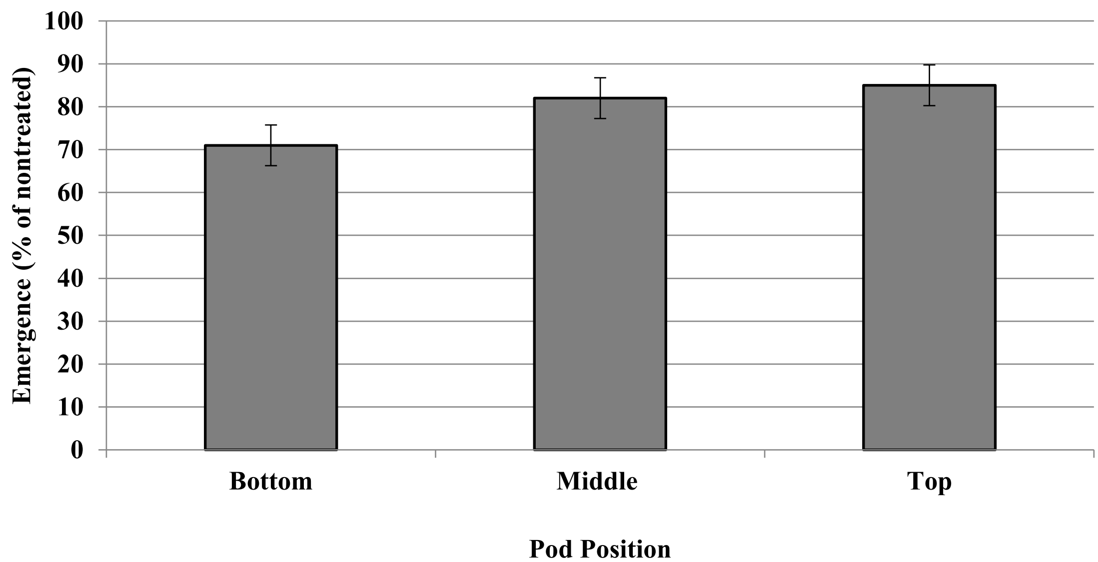

Fig. 1. The main effect of pod location on progeny emergence (%). Seeds were collected from field trials conducted at the University of Arkansas System Division of Agriculture's Lonn Mann Cotton Research Station in Marianna, Arkansas in 2014. Means were averaged across all application timings (V4, V6, R1-R6) and two dicamba rates (1/64×, 1/256×). Progeny was evaluated from a HBK 4950 (indeterminate) and a Halo 5.45 (determinate) soybean cultivar. Where error bars overlap, no statistical difference exists (α = 0.05).

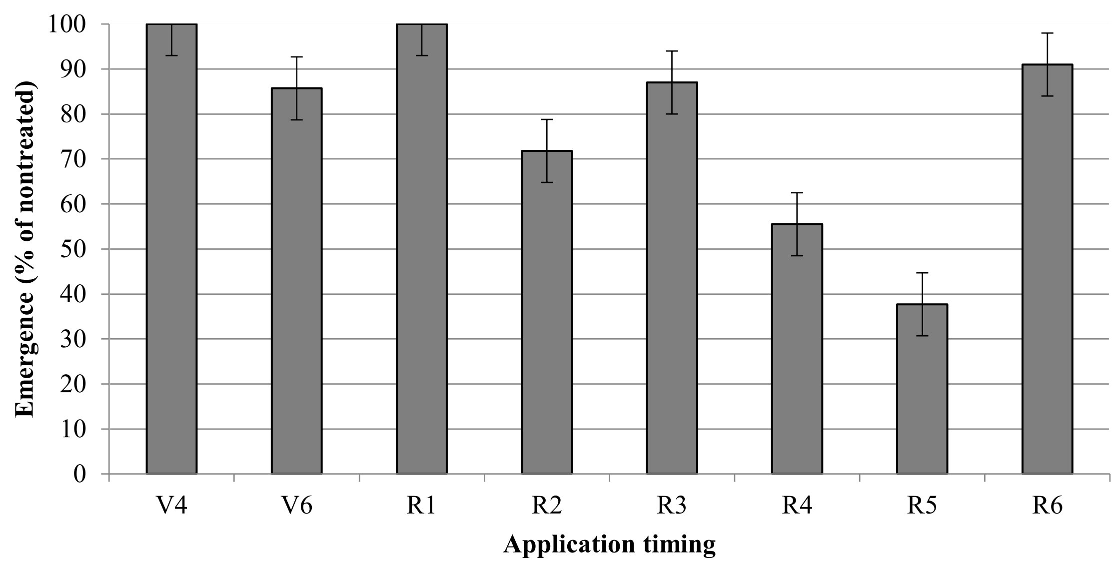

Fig. 2. The main effect of application timing on progeny emergence (%). Seeds were collected from field trials at the University of Arkansas System Division of Agriculture's Lonn Mann Cotton Research Station in Marianna, Arkansas in 2014. Means were averaged across two low dicamba rates (1/256×, 1/64×) and across all pod locations. Progeny was evaluated from a HBK 4950 (indeterminate) and a Halo 5.45 (determinate) soybean cultivar. Where error bars overlap, no statistical difference exists (α = 0.05).

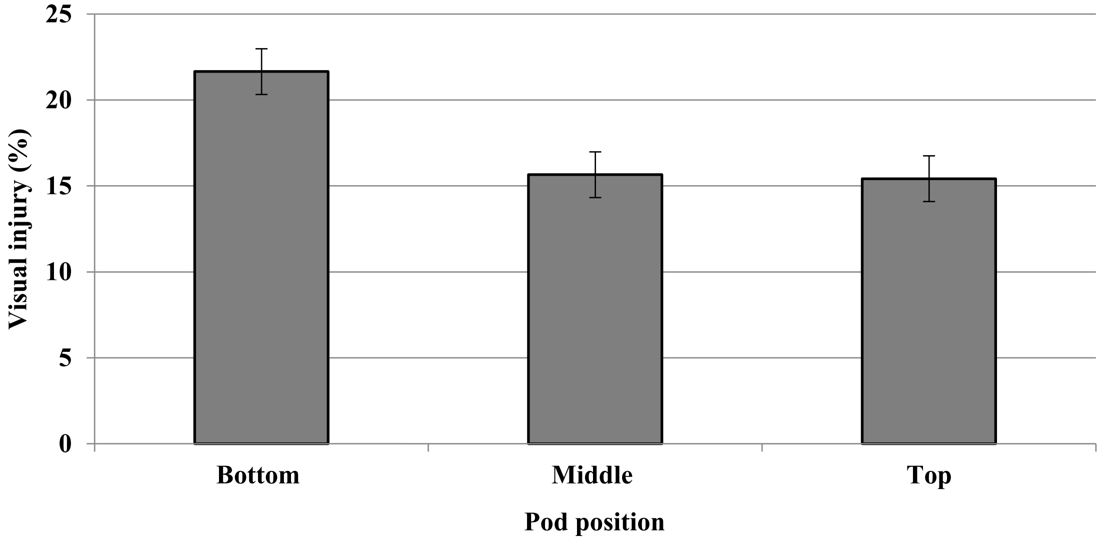

Fig. 3. The main effect of pod location on visual injury (%) observed in soybean progeny at the second trifoliate stage. Seeds were collected from field trials conducted at the University of Arkansas System Division of Agriculture's Lonn Mann Cotton Research Station in Marianna, Arkansas in 2014. Means were averaged across all application timings (V4, V6, R1-R6) and two dicamba rates (1/64×, 1/256×). Progeny was evaluated from a HBK 4950 (indeterminate) and a Halo 5.45 (determinate) soybean cultivar. Where error bars overlap, no statistical difference exists (α = 0.05).

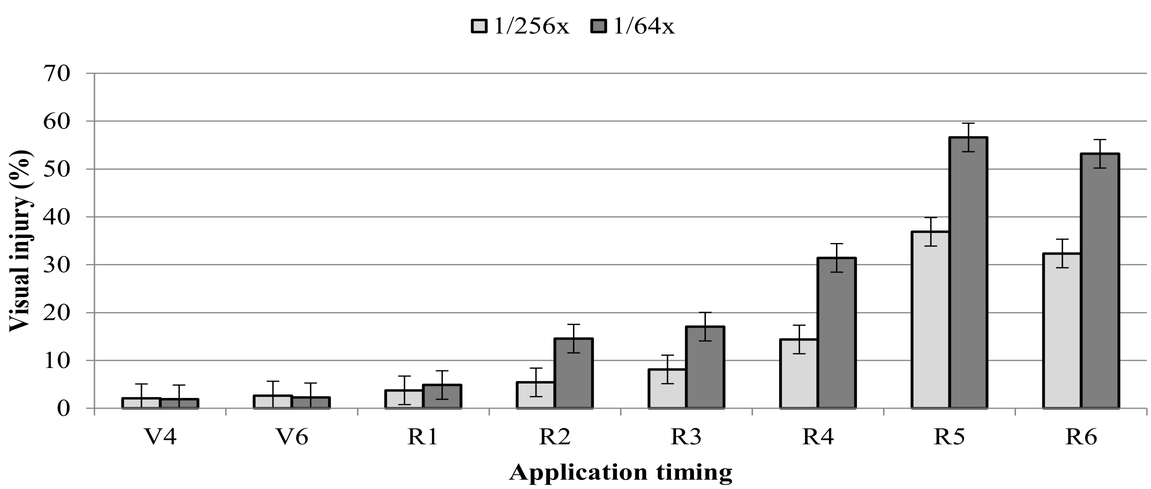

Fig. 4. The interaction of application timing × dicamba rate effect on visual injury (%) in soybean progeny observed at the second trifoliate growth stage. Seeds were collected from field trials at the University of Arkansas System Division of Agriculture's Lonn Mann Cotton Research Station in Marianna, Arkansas in 2014. Means were averaged across pod location on the plant of where the seeds were hand harvested. Progeny was evaluated from a HBK 4950 (indeterminate) and a Halo 5.45 (determinate) soybean cultivar. Where error bars overlap, no statistical difference exists (α = 0.05).

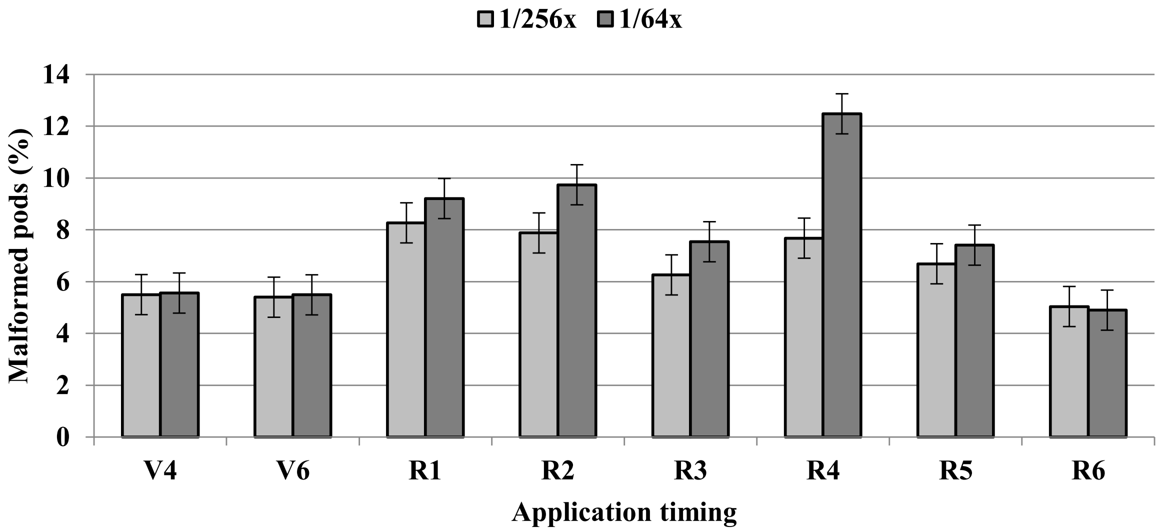

Fig. 5. The interaction of application timing × dicamba rate effect on the percentage of malformed pods observed. The y-axis represents the total amount of malformed pods divided by the total amount of pods on the plant (%). Soybean pods were collected from field trials at the University of Arkansas System Division of Agriculture's Lonn Mann Cotton Research Station in Marianna, Arkansas in 2014. Progeny was evaluated from a HBK 4950 (indeterminate) and a Halo 5.45 (determinate) soybean cultivar. Where error bars overlap, no statistical difference exists (α = 0.05).

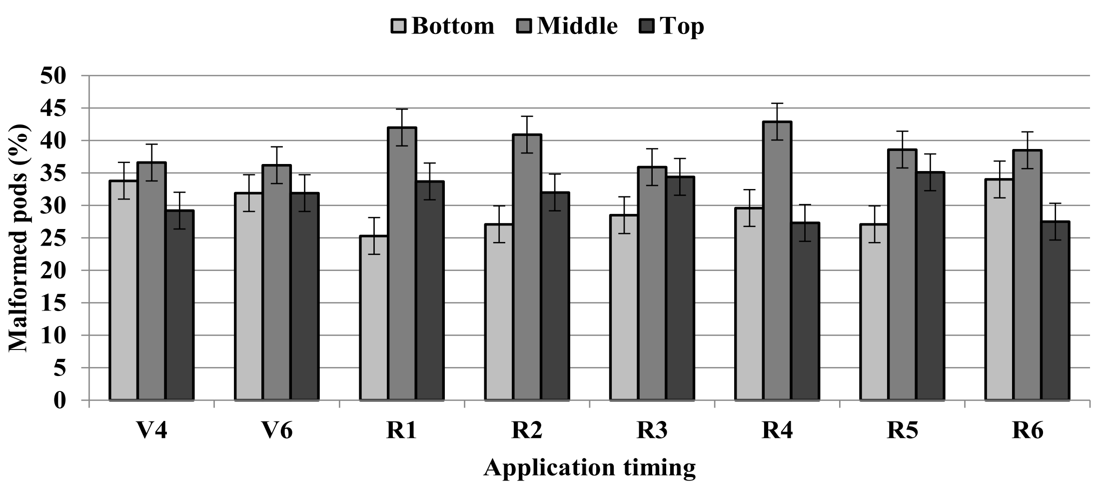

Fig. 6. The interaction of application timing × pod position effect on percentage of malformed pods collected from each location on the plant. The y-axis represents the total number of malformed pods in each section divided by the total number of pods on the plant (%). Soybean pods were collected from field trials at the University of Arkansas System Division of Agriculture's Lonn Mann Cotton Research Station in Marianna, Arkansas in 2014. Means were averaged across two low dicamba rates (1/256×, 1/64×) at each application timing. Progeny was evaluated from a HBK 4950 (indeterminate) and a Halo 5.45 (determinate) soybean cultivar. Where error bars overlap, no statistical difference exists (α = 0.05).

Soybean Response to Low Rates of Dicamba Applied at Vegetative and Reproductive Growth Stages

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

ABSTRACT

The introduction of the new Roundup Ready® Xtend Crop System will provide an alternative weed management option, but the risk of dicamba injury to sensitive crops, particularly soybean [*Glycine max.* (L) Merr.], from off-target movement and tank contamination is of concern. Experiments were conducted to determine the response of soybean yield to low rates of dicamba over a wide range of application timings. Two glufosinate-resistant cultivars (HBK 4950LL and Halo 5.45 LL) commonly grown in Arkansas were chosen for these studies. Two low rates of dicamba (1/64× and 256×) were applied at two vegetative (V4, V6) and six reproductive (R1-R6) growth stages. A negative effect of dicamba on soybean yield was observed following the R1 application, when the soybean begins to flower. When averaged across rates, dicamba applied at R1, reduced soybean yield 11%-17% in each cultivar and applications made during vegetative growth stages resulted in yield reductions of 13% to16%. Dicamba applied at the later reproductive stages resulted in insignificant yield loss. From these results, we conclude that the greatest yield loss can be expected when soybean is exposed to dicamba during the early reproductive growth stages.

INTRODUCTION

In response to herbicide-resistant weeds, advances in genetic engineering have led companies to develop crop cultivars with resistance to additional herbicide modes of action. Monsanto is developing the Roundup Ready® Xtend Crop System (Monsanto Company, St. Louis, Mo.), which is a new technology that will allow the use of both dicamba and glyphosate in soybean and dicamba, glyphosate, and glufosinate in cotton (*Gossypium hirsutum* L.) (Seifert-Higgins and Arnevik, 2012). This new technology will offer management options for glyphosate-resistant weeds; however, as was experienced with the release of glyphosate-resistant crops and the extensive use of glyphosate (Banks and Shroeder, 2002), problems are expected due to off-target movement of dicamba. In dicamba-resistant soybean, dicamba applications will be made pre-plant, at planting (PRE), and post-emergence (POST) (Seifert-Higgins and Arnevik, 2012). With a wide range of applications during the growing season and considering a wide range of planting dates, there is an expected increase in the opportunity for off-target movement (Barber et al., 2015; Norsworthy et al., 2015). Although with auxin herbicides symptomology is easily recognized, subsequent yield loss is dependent on the herbicide rate, specific crop, and weather conditions prior to and following application (Scholtes and Reynolds, 2014).

PROCEDURES

Several field experiments were conducted in 2014 and 2015 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station in Marianna, Arkansas and the Southeast Research and Extension Center near Rohwer, Arkansas to determine the effect of dicamba on soybean yield. Experiments were organized as a two-factor factorial, randomized complete block design, with four replications. The two factors included soybean growth stage at application and dicamba rate. Two cultivars commonly grown in Arkansas were evaluated in separate studies: HBK 4950 and HALO 5.45. Soybean was planted on 38-in. wide beds at 150,000 seeds/acre. The DGA salt formulation of dicamba (Clarity® herbicide, BASF Corporation, Research Triangle Park, N.C.) was applied at several growth stages. Two low rates of dicamba were evaluated: 1/64× (0.25 fl oz/ac) and 1/256× (0.0625 fl oz/ac) of a normal rate (16 fl oz/ac), as well as an untreated check. Applications were made at the V4 and V6 stages and at each reproductive stage starting with R1 and ending with R6. Dicamba treatments were applied using an air-pressurized tractor-mounted sprayer calibrated to deliver 15 gal/ac spray volume. Nontreated border areas between plots were 152-in. wide. Cross contamination between adjacent treated plots based on visible injury was not apparent. Visual estimates of percent crop injury were recorded 2 and 4 weeks after treatment (WAT) and grain yield was taken at plant maturity. To avoid bias results from overall differences in yield between site years, grain yield was converted to a percentage of the nontreated plots (relative grain yield). Data were subjected to analysis of variance (ANOVA) using JMP V. 11.0.0 (SAS Institute Inc., Cary, N.C.) to test for the significant effects of dicamba rate, treatment timing, and the interaction of the two factors of interest. Location and year combinations were considered an environment sampled at random, as suggested by Carmer et al. (1989) and Blouin et al. (2011). Analyses were

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performed on the means and standard error of the means are reported at $\alpha = 0.05$. Based on ANOVA, significant herbicide rate and application timing effects ($P < 0.05$) were observed for all parameters measured in all experiments.

RESULTS AND DISCUSSION

Symptomology observed for dicamba consisted of chlorosis of terminals, cupping and crinkling of uppermost leaves, swollen petiole bases, and stem and leaf epinasty. Auch and Arnold (1978) state that the severity of leaf injury was influenced by application rate, not growth stage; however, observations from this study differed. This may be because in their studies a smaller range of application timings were evaluated. At 14 days after treatment (DAT), significantly greater visual injury was observed following late vegetative/early reproductive applications compared to applications made later in the growing season for each cultivar.

HBK 4950 Soybean Cultivar. Averaged across rates, dicamba applied to HBK 4950 at V4 resulted in visual injury of 34% 14 DAT and a yield loss of 13%, whereas less than 2% injury and a yield loss of 3% was observed following a R5 application (Figs. 1 and 2). This indeterminate cultivar was found to be most sensitive to dicamba when that plant begins to flower, or also known as the R1 growth stage. Dicamba applied to soybean at R1 resulted in 27% injury 14 DAT and a yield reduction of 17% when compared to the nontreated. Yield reductions were reduced when dicamba was applied after R1. A yield loss of 9%-11% was observed when soybean was treated during full flower (R2) and pod filling (R3, R4). Dicamba applied at later reproductive stages (R5, R6) resulted in insignificant yield loss (3%-4%) in each cultivar.

HALO 5.45 Soybean Cultivar. Visual injury observed following dicamba applied to Halo 5.45 cultivar followed a similar trend to that of the HBK 4950 cultivar; however, more severe injury was observed following the applications made during the vegetative growth stages (Fig. 3). Although, the most sensitive growth stage was also determined to be R1, statistically similar yield loss resulted following the vegetative applications. When dicamba was applied to this determinate cultivar at V4, V6, R1, and R2 growth stages, yield reductions ranged from 15%-17% (Fig. 4). Even though cultivars cannot be directly compared statistically, in general, greater recovery was seen in this cultivar, resulting in 1% yield loss when dicamba was applied at R3. Yield results similar to that of the HBK 4950 cultivar resulted from applications made later in the growing season.

From these results, we conclude that soybean is very sensitive to dicamba during the late vegetative/early reproductive growth stages and visual injury is a moderate indicator of yield loss. Auch and Arnold (1978) stated that much of the unpredictable yield loss has been attributed to application timing and environment, but we feel the variable growth and development rate of soybean and variability between cultivars makes it difficult to simplify the effects of dicamba to soybean.

PRACTICAL APPLICATIONS

With the release of this new technology it will be important to inform growers of the detrimental yield loss that dicamba can have on soybean. As the adoption of this new technology increases, it will be mandatory to follow a strict stewardship program to decrease the potential of off-target movement of this herbicide.

ACKNOWLEDGEMENTS

The authors of this research would like to thank the University of Arkansas System Division of Agriculture and the Arkansas Soybean Promotional Board for funding this project.

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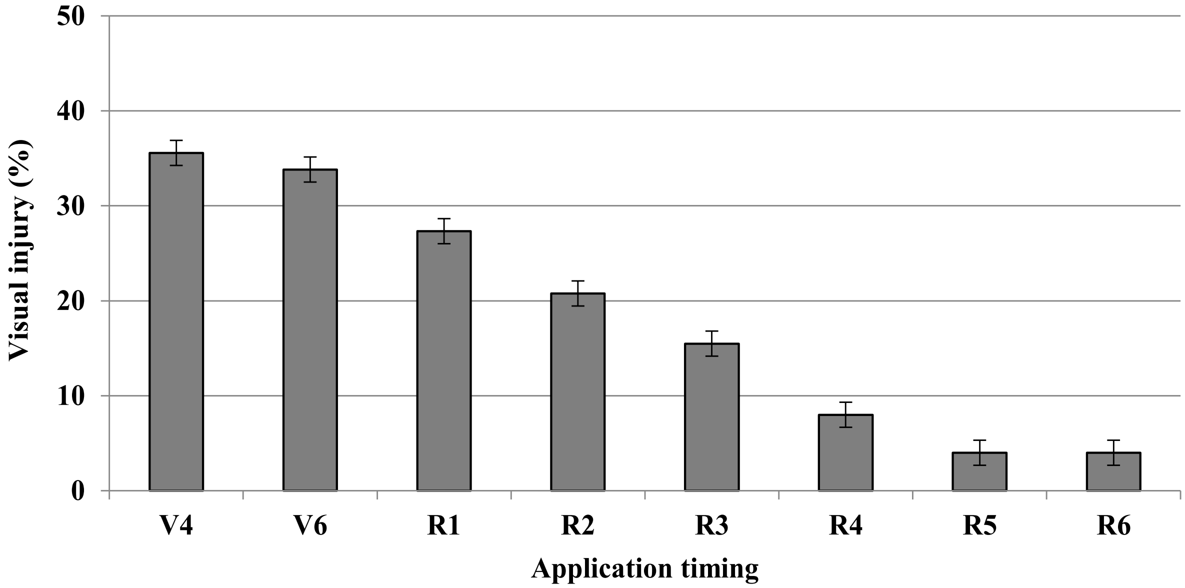

Fig. 1. The main effect of application timing of dicamba on visual injury of a HBK 4950 soybean cultivar 14 days after treatment. Visual injury was averaged across two low dicamba rates. Means are averaged across five site years for trials at the Lonn Mann Cotton Research Station at Marianna and the Southeast Research and Extension Center near Rohwer, Arkansas in 2014 and 2015. Where error bars overlap no statistical difference exists (α = 0.05).

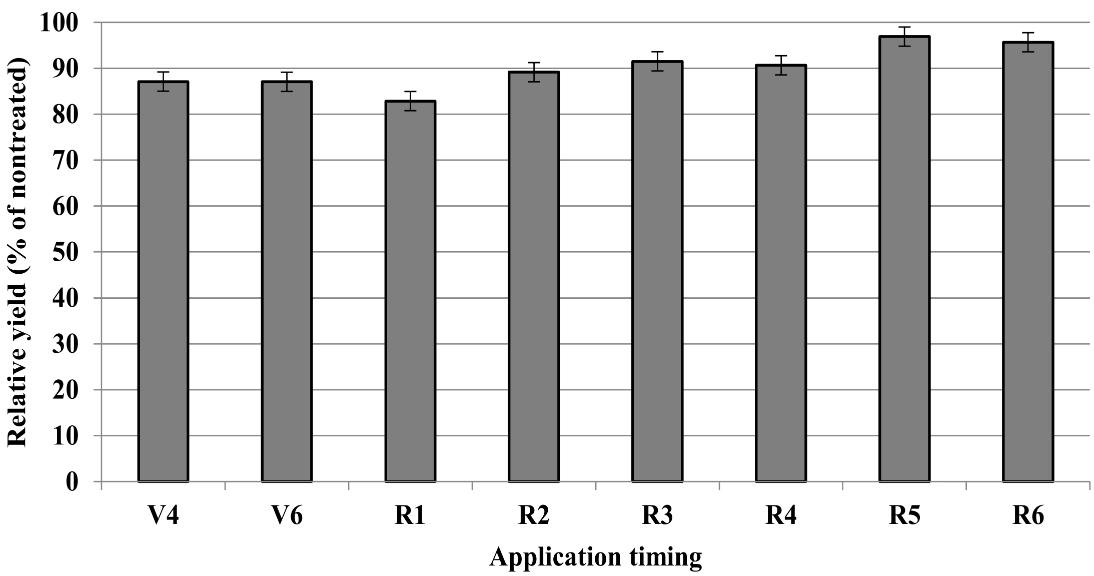

Fig. 2. The main effect of dicamba application timing on the relative yield of a HBK 4950 soybean cultivar. Yield was averaged across both dicamba rates. Means are averaged across five site years for trials at the Lonn Mann Cotton Research Station at Marianna and the Southeast Research and Extension Center near Rohwer, Arkansas in 2014 and 2015. Where error bars overlap no statistical difference exists (α = 0.05).

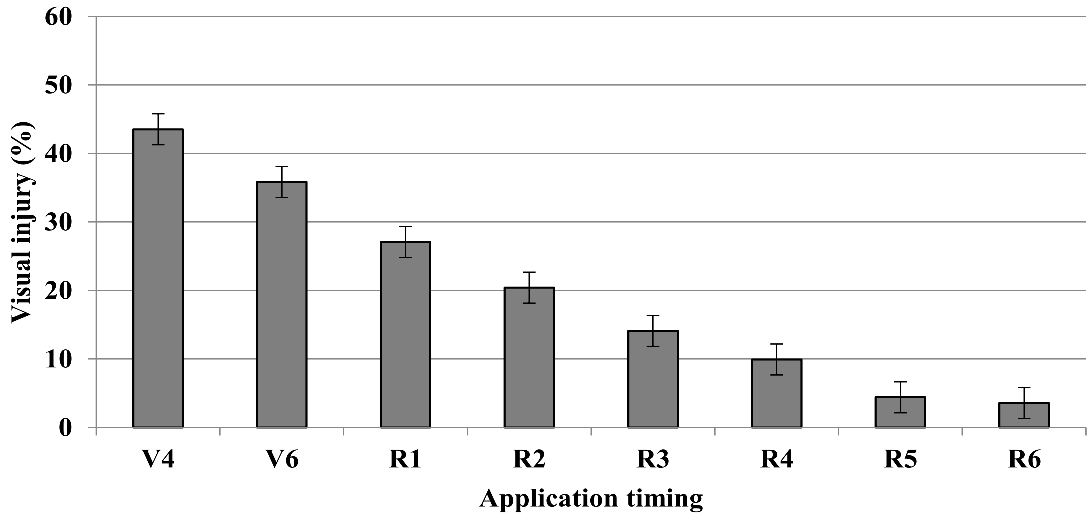

Fig. 3. The main effect of application timing of dicamba on visual injury of a Halo 5.45 soybean cultivar 14 days after treatment. Visual injury was averaged across two low dicamba rates. Means are averaged across three site years for trials at the Lonn Mann Cotton Research Station at Marianna and the Southeast Research and Extension Center near Rohwer, Arkansas in 2014 and 2015. Where error bars overlap no statistical difference exists (α = 0.05).

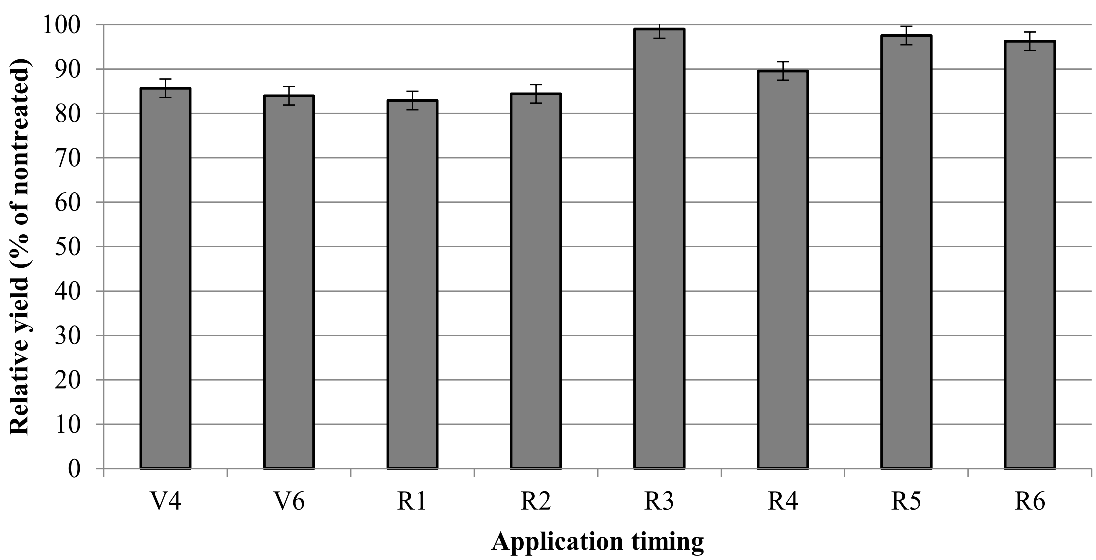

Fig. 4. The main effect of application timing of dicamba on the relative yield of a Halo 5.45 soybean cultivar. Yield was averaged across both dicamba rates. Means are averaged across three site years for trials at the Lonn Mann Cotton Research Station at Marianna and the Southeast Research and Extension Center near Rohwer, Arkansas in 2014 and 2015. Means with same letter are not significantly different (α = 0.05). Where error bars overlap no statistical difference exists (α = 0.05).

Palmer amaranth and Barnyardgrass Seed Retention in Soybean

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

ABSTRACT

Protecting herbicides against resistance is of the utmost importance when determining the future of weed control programs. Harvest weed seed control (HWSC) strategies, such as the ones currently adopted in Australia, can potentially have a major impact on lowering the amount of weed seed returned to the soil seedbank and thus lower the amount of resistance selection pressure placed on current herbicides here in the United States. An experiment was conducted in 2015 at the University of Arkansas System Division of Agriculture's Arkansas Agricultural Research and Extension Center in Fayetteville, Ark. to assess the seed retention of Palmer amaranth (*Amaranthus palmeri* S. Wats.) and barnyardgrass (*Echinichloa crus-galli* P. Beauv.) in soybean. The experiment consisted of two separate sampling methods with one sampling method used to determine the amount of weed seed shed over time and the second method allowing estimation of the number of seed produced per plant. Palmer amaranth and barnyardgrass each retained 98% and 43%, respectively, of the total yearly seed production at soybean maturity. Additionally, it was determined that Palmer amaranth seed production increases throughout the season and beyond crop maturity. Barnyardgrass began to shed seed much earlier in the growing season and continued seed shed beyond soybean maturity. Given the high retention rate of Palmer amaranth, it is believed that HWSC strategies that reduce weed seed additions to the soil seedbank could likely have a tremendous impact on improving herbicide performance and reducing the risk for future cases of resistance. The early seed shed and low retention rate of barnyardgrass at soybean maturity indicates that HWSC strategies would likely not be as impactful on the soil seedbank when dealing with this weed; however, some seed could be captured and destroyed. Based on this experiment, it would be beneficial to consider an optimum soybean maturity group, as this factor would influence the amount of weed seed available for capture and destruction.

INTRODUCTION

Herbicide-resistant weeds continue to be problematic in crop production systems throughout the world. Currently, U.S. agriculture depends on herbicides as the major method of weed control; however, due to the increase in herbicide resistance, growers must diversify weed management practices to prolong the use of current herbicides (Norsworthy et al., 2012). In Australia, where problematic weeds such as annual ryegrass, wild radish, brome grass, and wild oat exist, strategies including narrow-windrow burning, chaff cart collection systems, bale-direct systems, and the Harrington Seed Destructor have been developed to help in combating herbicide-resistant weeds at harvest (Walsh et al., 2013). The success of these strategies is highly dependent on the retention of weed seed at crop harvest. Prior research in Australia has shown that annual ryegrass, brome grass, wild radish, and wild oat retain 84% to 99% of seed at wheat maturity, allowing successful capture and destruction of these seed at crop harvest (Walsh and Powles, 2014).

For successful adoption of harvest weed seed control (HWSC) strategies in the U.S., investigation of seed retention on weeds such as Palmer amaranth (*Amaranthus palmeri* S. Wats.) and barnyardgrass (*Echinochloa crus-galli* (L.) P. Beauv.) is necessary. If high retention rates, such as the ones documented in Australia, are achieved in a field setting then it is possible that HWSC tactics could be very beneficial to growers in the U.S. and lower weed populations over time. If successful, this type of diversification would help to slow the evolution of herbicide resistance.

PROCEDURES

Field experiments were conducted at the University of Arkansas System Division of Agriculture's Arkansas Agricultural Research and Extension Center in Fayetteville, Ark. in 2015. Two experiments, one consisting of Palmer amaranth and one of barnyardgrass, were conducted to determine the seed retention of each species throughout the growing season and beyond soybean maturity. Both experiments were planted with Pioneer 95L01 soybean (maturity group IV variety) adjacent to one another to have similar environmental conditions. Each experiment consisted of two separate sampling methods. One sampling method was achieved by placing four greenhouse trays (F1721 Tray, T.O. Plastics, Inc. Clearwater, Minn), measuring 319-in.^{2} each and 1276-in.^{2} total, around the bottom of sixteen randomly chosen plants that would be sampled throughout the growing season to determine percentages of seed shed over time. The greenhouse trays were emptied weekly using a Dirt Devil Gator 9.6V cordless portable vacuum (TTI Floor Care North America, Glenwillow, Ohio) and samples were returned to the laboratory for counting. At the conclusion of the experiment, the sixteen plants that were sampled weekly

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throughout the growing season were harvested to determine a percentage of seed shed over time. This sampling method allowed for consistency of sampling the same plant throughout the entire experiment. The second sampling method consisted of collecting ten Palmer amaranth plants and eight barnyardgrass plants each week in an effort to quantify seed production throughout the growing season by counting the average number of seed per plant.

Both experiments were conducted following the same procedures in regard to sampling and collection. However, establishment of the weed populations to be sampled differed. For the Palmer amaranth experiment, Palmer amaranth seedlings were allowed to emerge naturally with the soybean crop, whereas the barnyardgrass experiment was initiated by sowing barnyardgrass seeds in the greenhouse on the day of soybean planting and transplanting the seedlings to the field at 3-4 weeks after planting. In each experiment, the sampled plants were either thinned or transplanted to one plant every 4-ft of row. After all data had been collected for the season, the data were averaged and standard errors calculated for each sampling method. In addition to averaging and calculating standard errors, the data for the second sampling method were fit to a non-linear regression model in Excel (Microsoft Corporation, Redmond, Wash.).

RESULTS AND DISCUSSION

Placing four trays around the bottom of Palmer amaranth and barnyardgrass allowed for the collection of weed seed shed from the plants each week. Over the course of the growing season, it was found that Palmer amaranth shed only 2% of the yearly total seed production at soybean maturity on 1 October 2015. Furthermore, it was found that at 28 days after soybean maturity, Palmer amaranth had only shed an additional 7% of the total seed production. This finding demonstrates that even if crop harvest were delayed, Palmer amaranth would still retain 91% of the yearly total seed production (Fig. 1). Barnyardgrass assessments showed that seed shed started on 18 August 2015. At soybean maturity, 57% of the yearly total seed production had been shed. As with Palmer amaranth, weekly collections of barnyardgrass continued until 28 days after crop maturity. At 28 days after crop maturity, barnyardgrass was determined to have shed an additional 8% of the yearly total seed production, demonstrating that barnyardgrass would only retain 35% of the total seed production if harvest were delayed for about one month (Fig. 2).

The second assessment procedure allowed for random sampling of plants from the same field for the determination of seed production for Palmer amaranth and barnyardgrass throughout the growing season. Palmer amaranth continued to develop seed throughout the growing season, and after soybean maturity, before starting to decrease in seed production (shatter seed) at approximately one month after soybean maturity (Fig. 3). Barnyardgrass, as expected from the results in part one of the experiment, continually shed seed throughout the growing season (Fig. 4). The effectiveness of HWSC is dependent on weed seed entering the combine at harvest; this date is ultimately determined by soybean maturity group and planting date, and thus, these would have an impact on its success with barnyardgrass and to a lesser degree Palmer amaranth.

PRACTICAL APPLICATIONS

Studies on weed seed retention have allowed for the determination of the ability to capture and destroy weed seed that enter and exit the combine. Based on the high retention rate of Palmer amaranth, it is very likely that capture and destruction of this seed is possible at harvest and would be successful if utilized in a commercial soybean production system. Additionally, while barnyardgrass seed shed started much earlier than that of Palmer amaranth, there is still the possibility of capture and destruction of a portion of barnyardgrass seed. However, given the low seed retention rate of barnyardgrass, HWSC tactics would be less impactful in comparison to Palmer amaranth on lowering the soil seedbank of barnyardgrass seed.

Given the success of narrow-windrow burning (Norsworthy et al., 2016), coupled with the high retention rate, a farmer that is battling Palmer amaranth in soybean should seek to implement HWSC strategies such as narrow-windrow burning as a way of reducing the weed seed return to the soil seedbank, thereby, reducing the resistance selection pressure that is currently being placed on herbicides. In the near future, it is expected that the Harrington Seed Destructor will be available as an integrated unit on commercial combines which will give greater capability for destroying weed seed prior to their return to the soil seedbank.

ACKNOWLEDGEMENTS

The authors would like to thank Bayer CropScience and the Arkansas Soybean Promotion Board for their funding of this research. Support was also provided by the University of Arkansas System Division of Agriculture.

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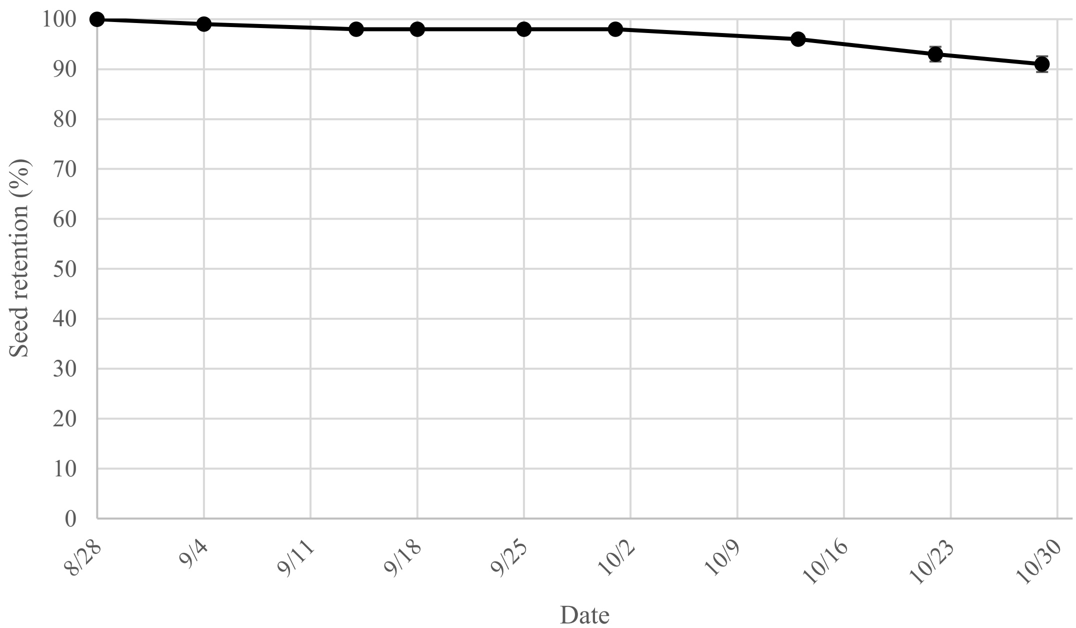

Fig. 1. Percentage ± standard error of seed retained on Palmer amaranth at each collection date.

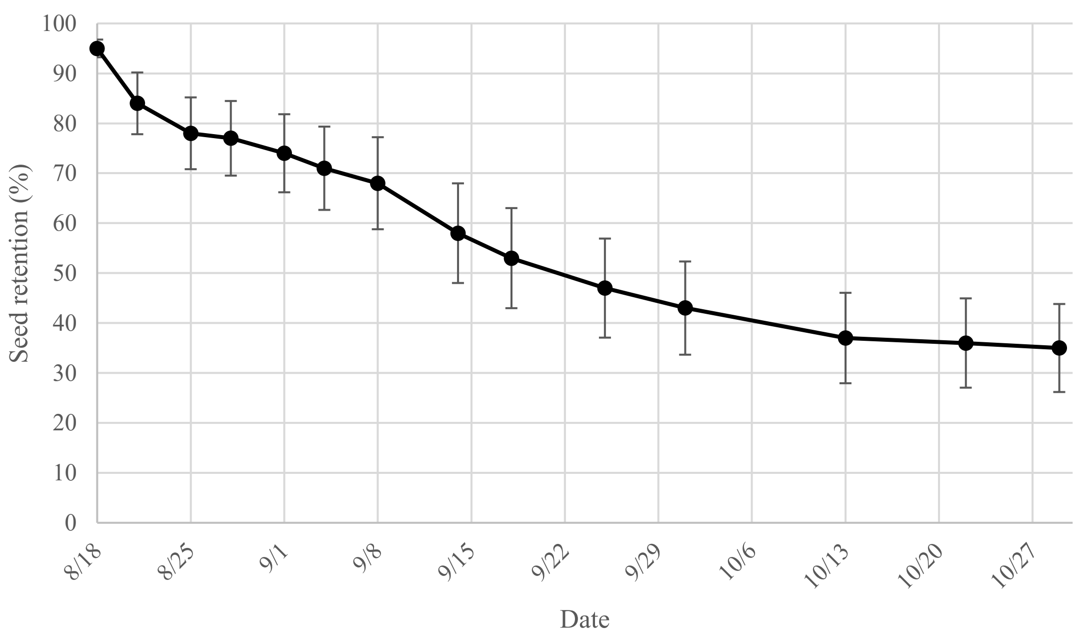

Fig. 2. Percentage ± standard error of barnyardgrass seed retained on plants at each collection date.

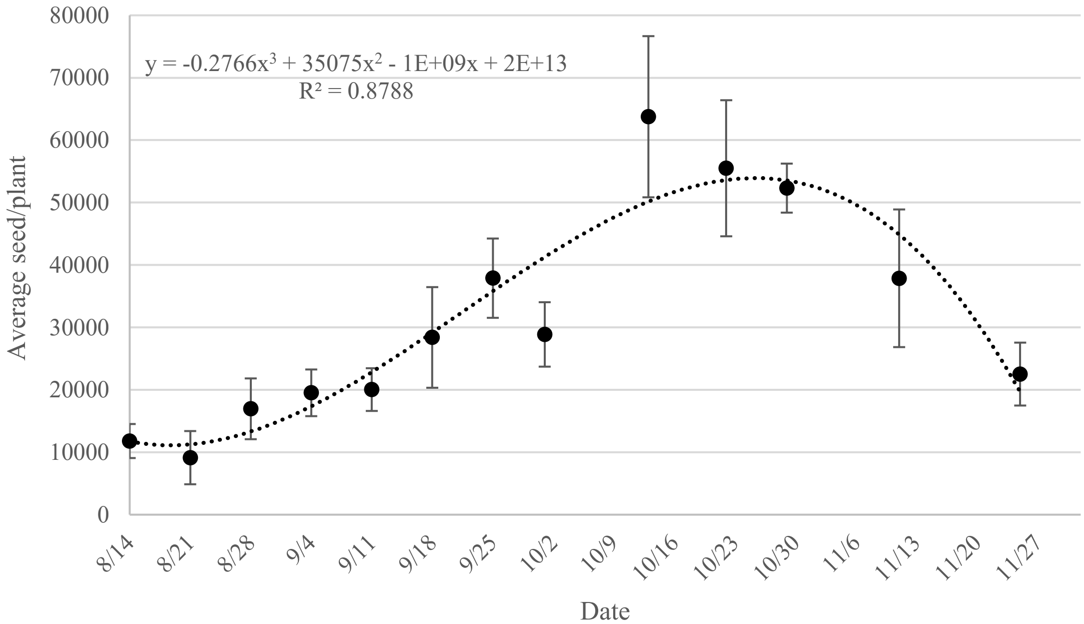

Fig. 3. Average number of seed/plant ± standard error at each collection date for Palmer amaranth.

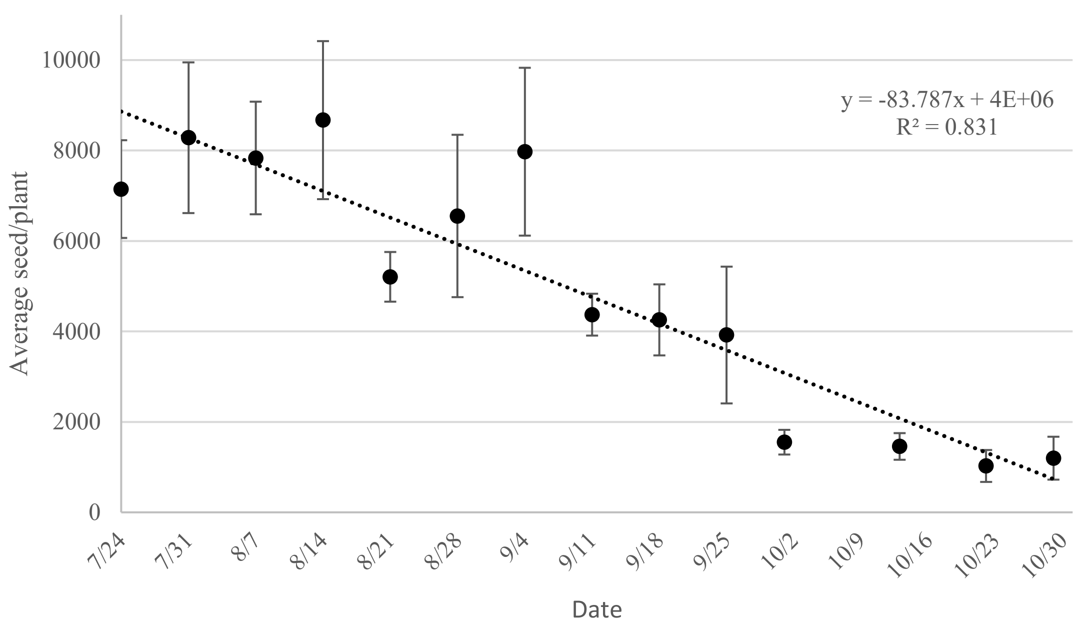

Fig. 4. Average number of seed/plant ± standard error at each collection date for barnyardgrass.

Use of Plant Elicitor Peptides as Signaling Molecules to Induce Nematode Resistance in Soybean

M.W. Lee[1], A.Huffaker[2], and F. Goggin[1]

ABSTRACT

Plant elicitor peptides (PEPs) are signaling molecules that trigger induced plant defenses against insects and pathogens, and that are found in a broad diversity of plant species. The objective of this study was to determine if applying synthetic PEPs to soybean (*Glycine max*) would trigger plant defenses against the root-knot nematode (*Meloidogyne incognita*), a major pest of numerous vegetable and field crops worldwide. In our current study, we demonstrate that seed treatments with 3 different synthetic PEPs derived from soybean (GmPEP1, GmPEP2, and GmPEP3) can enhance nematode resistance in soybean, reducing nematode egg mass production. In addition, gene expression studies with GmPEP-treated seeds have shown that GmPEPs trigger induced expression of several defense genes and in some cases activate expression of genes encoding PEP precursors (i.e., PROPEP genes). Treating soybean seeds with GmPEP1 induced expression of 3 genes associated with plant defenses against nematodes: *NBS LRR* (nucleotide binding site, leucine rich repeat), *RBOHD* (respiratory burst oxidase protein D), and *PMEI* (pectin methylesterase inhibitor) genes. Expression of *RBOHD* was highly induced by GmPEP1, GmPEP2, and GmPEP3. These results together suggest that soybean PEPs appear to have important roles in inducing defense signaling pathways that suppress nematodes.

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 as a tool to confer broad-spectrum nematode resistance in soybean.

Plant elicitor peptides (PEPs) 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). Six elicitor peptides have also been discovered in soybean (*G. max*). Each of the *G. max* peptides (GmPEPs) characterized contains a conserved core motif in the carboxyl region (Fig. 1). The study presented here suggests potential roles for GmPEPs to induce defense response against nematode in their exogenous application in seeds.

PROCEDURES

Peptide Synthesis and Treatment. In vitro synthesis of the 23 amino acid peptides GmPEP1 (Amino acid sequence: ASLMATRGSRGSKISDGSGPQHN), GmPEP2 (ASSMARRGNRGSRISHGSGPQHN), and GmPEP3 (PSHGSVGGKRGSPISQGKGGQHN) was performed by the Biomatik Corporation (Cambridge, Ontario) and their purities were verified by C18 HPLC and mass spectrometry. Soybean seeds (var. Williams82) were imbibed in petri dishes at room temperature (24 °C) overnight in a solution of 0.05% Tween 20 and 1uM GmPEP1, GmPEP2, or GmPEP3. Control seeds were treated with water and Tween 20 only. The next day, treated seeds were transferred to wet paper towels and kept at 23 °C for 3 days.

Evaluation of Response to Root-Knot Nematode. After seeds germinated on paper, they were planted in coarse sand under greenhouse conditions (16:8 L: D photoperiod, 21-27 °C). When plants had two true leaves, they were inoculated with ~8000 root knot nematode eggs. Eight weeks after inoculation, roots were detached, washed, and stained with Phloxine B to observe egg masses under a dissecting microscope. Root systems were then dried and weighed to calculate the average number of egg masses per unit of dry root mass. For statistical analysis, analysis of variance and Students *t* test were performed in JMP V. pro 11 (SAS Institute, Inc., Cary, N.C.).

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qRT-PCR Analysis of Relative Gene Expression. RNA extraction from root tissue was performed as previously described (Das et al., 2013). cDNA was generated with Superscript III reverse transcriptase and oligo-dT primers, and quantitative polymerase chain reaction (PCR) was performed with an Applied Biosystems (Foster City, Calif.) StepOnePlus thermal cycler using a QuantiTect SYBR Green PCR kit (Life Technologies Corp., Carlsbad, Calif.).

RESULTS AND DISCUSSION

Soybean PEPs Reduce Root-Knot Nematode Reproduction. Soybean plants that had received seed treatments GmPEP1, GmPEP2, or GmPEP3 showed lower numbers of root-knot nematode egg masses per unit of root weight than water-treated controls (Fig. 2). These results suggest that exogenous PEP treatment can enhance plant defenses against nematodes in soybean. Therefore, PEP seed treatments may be a useful tool for pest management because other methods using chemicals such as methyl bromide and other soil fumigants or genetic modification of the plant do not provide a safe environment.

GmPEPs Regulate Differentially Expression of Soybean PROPEP genes. The expression of three soybean ProPEP genes were analyzed in roots grown in seeds treated with each GmPEP. GmPEP1 peptide treatment strongly induced the expression of *ProPEP1*. However, *ProPEP2* and *ProPEP3* were not induced by either GmPEP2 or GmPEP3, respectively (Fig. 3). In other plant species, PEPs are known to interact with specific receptors (PEPRs); therefore, potential differences among GmPEPs in their effects on plant gene expression could be due to differences among the PEPs in their interactions with PEPR receptors.

GmPEPs Induce Several Defense Genes Regulating Soybean Resistance to Nematodes. Many defense related genes including *NBS LRR, RBOHD* and *PMEI* were previously reported to be upregulated by either the soybean cyst nematode or the root-knot nematode in nematode-resistant soybean cultivars (Wan et al., 2015; Xu et al., 2013). To determine if *NBS LRR, RBOHD* and *PMEI* were also involved in signaling events regulated by GmPEPs, the expression of these genes was analyzed in root tissues grown in seeds treated with each GmPEP.

Seed treatment with GmPEP1 strongly induced expression of all three defense genes studied (Fig. 4). Seed treatment with GmPEP2 or GmPEP3 also induced strong expression of RBOHD. The expression of RBOHD in response to all GmPEPs suggest that GmPEPs might stimulate production of reactive oxygen species (ROS) as a resistance response against nematodes. This is consistent with prior reports that PEPs in the model plant *Arabidopsis thaliana* trigger a ROS burst that activates further defense signaling pathways against herbivores and pathogens (Huffaker, 2015). Also, ROS abundance increases in a resistant soybean cultivar when inoculated with nematodes, compared to a mock-inoculated control (Beneventi et al., 2013). These results suggest that ROS may contribute to the nematode resistance conferred by PEPs.

PRACTICAL APPLICATIONS

Our results suggest that PEPs could be used to effectively induce defenses against nematodes in young plants, and to suppress root-knot nematode infestations on soybean. The fact that PEPs induce genes associated with soybean cyst nematode resistance suggests that PEPs might also be effective against this other highly damaging pest. 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 might be possible to protect plants from pests using PEPs as seed treatments, which would give growers a flexible, non-genetically modified management tool that would be compatible with a wide variety of cultivars.

ACKNOWLEDGEMENTS

This work was supported by the Arkansas Soybean Board (year 2 grant) and the University of Arkansas System Division of Agriculture's Arkansas Agricultural Experiment Station.

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Fig. 1. Alignment of soybean plant elicitor peptides (PEP) sequences. The N-terminal amino acids of GmPeps are highly variable, but the C-terminal regions of GmPeps show conserved motifs (in red). Two encoded peptides are generated from each GmProPEP4 and GmProPEP5 precursors.

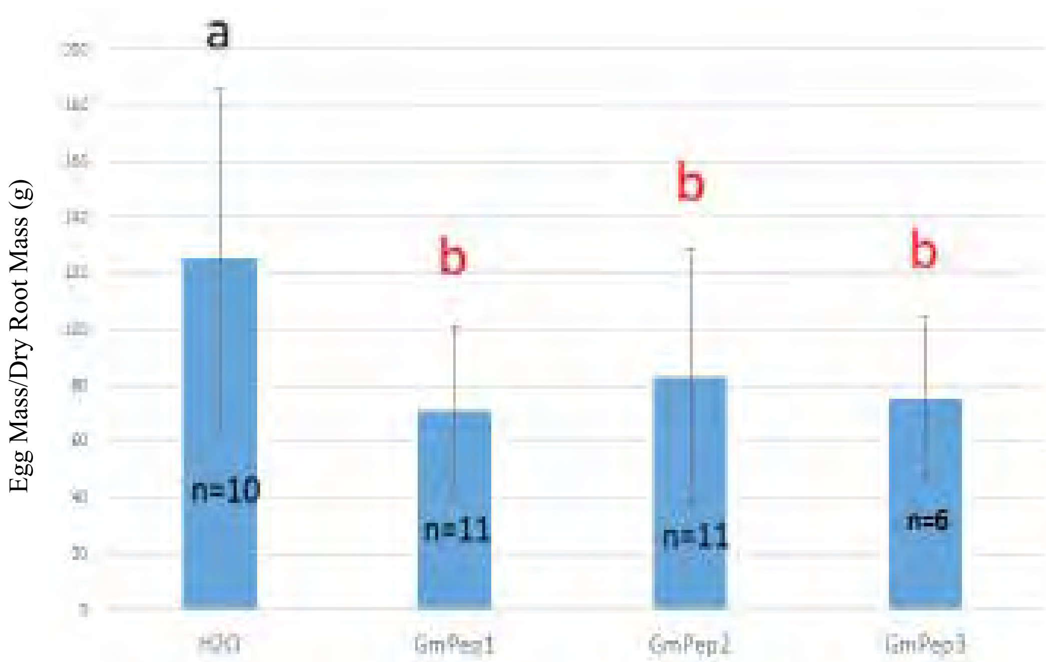

Fig. 2. Egg massas from soybean plants treated with water or soybean plant elicitor peptides (PEP). Nematode egg mass production was reduced on GmPEP-treated soybean plants compared to water-treated plants. In this experiment, peptides were used at 1 uM. Treatments labeled with diffferent letters are significantly different according to Student's *t* test ($P < 0.05$). The number of replicates per treatment are reported on each bar (n), and error bars represent the standard deviations (STD). The experiment was repeated 2 additional times with similar results (data not shown).

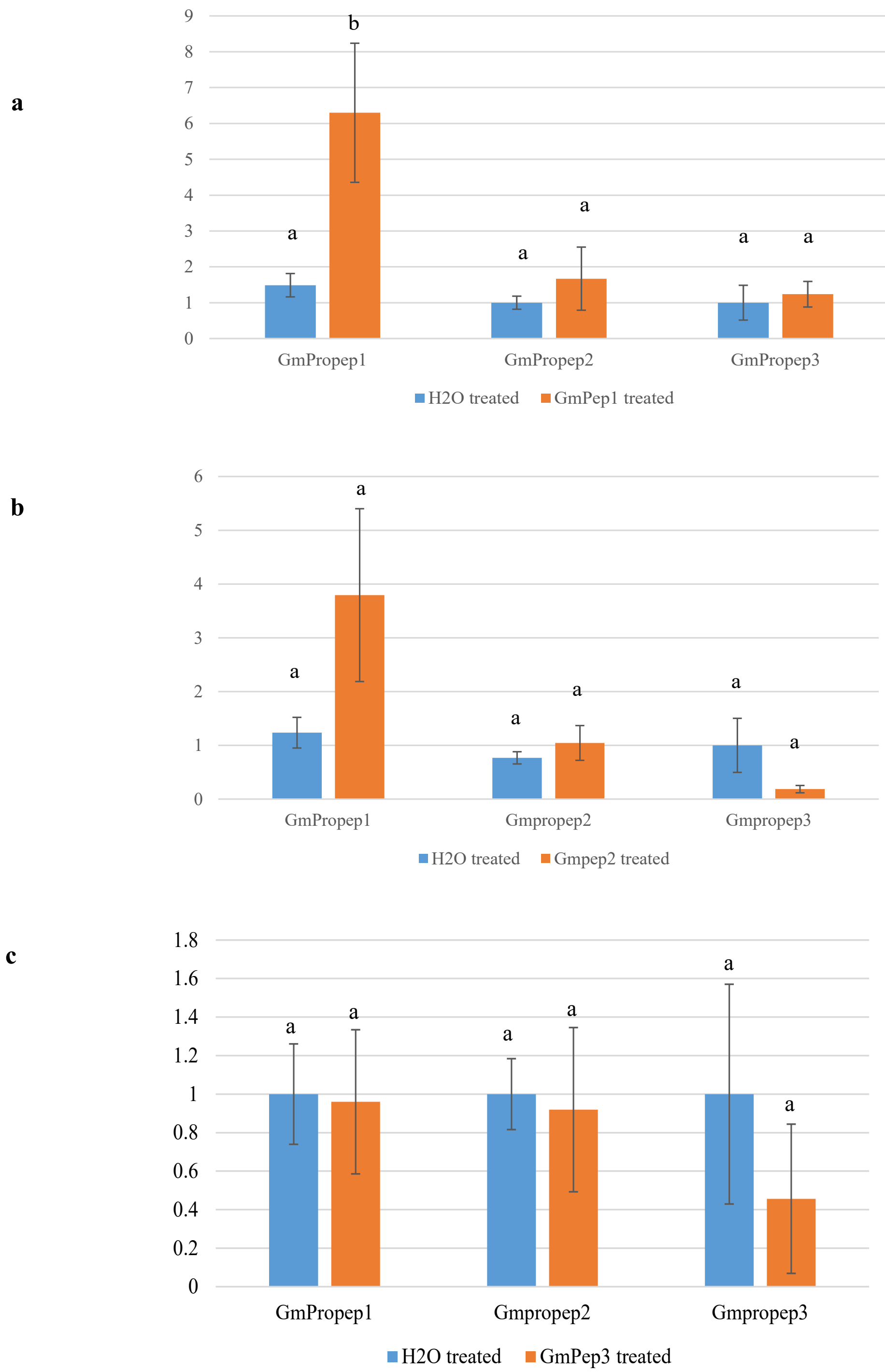

Fig. 3. Expression of soybean PROPEP precursor genes by seed treatments with GmPEPs. Soybean seeds were treated with 1 uM synthetic peptides (GmPEP1, 2, or 3) or with water (a negative control). Expression of each *GmProPEP* precursor gene was analyzed by qRT-PCR and normalized to expression of the housekeeping gene ELF1b (GLyma02g44460) expression (A, B, and C). Each measurement is an average of six replicates. Bars labelled with different letters are significantly different according to Student's *t* test ($P < 0.05$). GmPEP1 and GmPEP2 strongly induced expression of *GmProPEP1* (Glyma 10g36290). GmProPEP2 (Glyma20g31306) and GmProPEP3 (Glyma13g34221) were not induced by either GmPep2 or GmPep3, respectively.

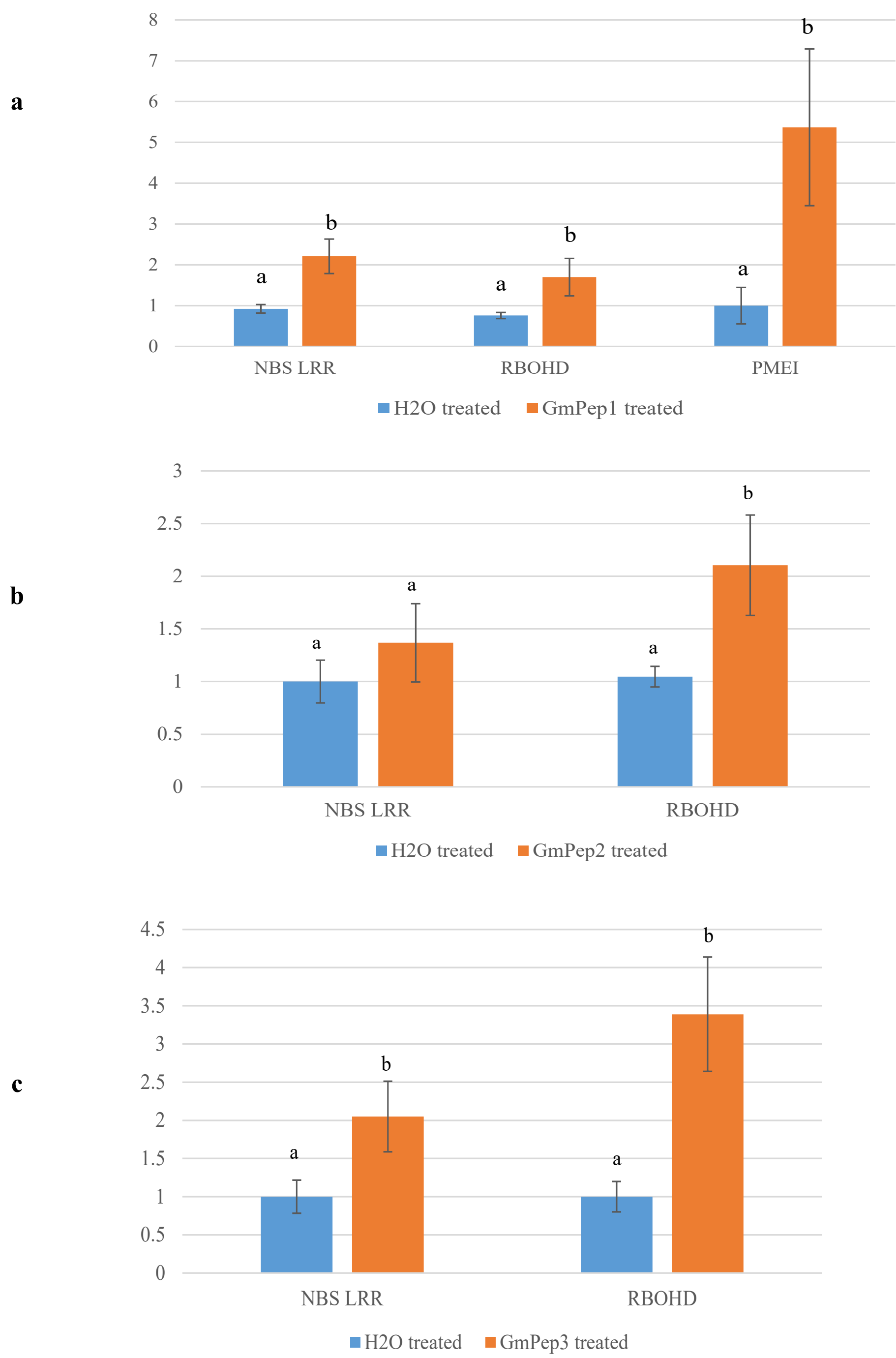

Fig. 4. Induction of several defense components by soybean seed treatments with plant elicitor peptides (PEPs). Transcripts levels od NBS LRR (Glyma06g26800), RBOHD (Glyma15g26790) and PMEI (Glyma10g02150) as indicators of plant defense responses were analyzed by a qRT-PCR after treating soybean seeds with 1 uM synthetic peptides (GMPep1, 2, or 3) or with water (a negative control) (A, B, C). The induction of NBS LRR is stronger in response to GmPep1 and GmPep3 but RBOHD transcripts were induced in response to all GmPeps. However, only GmPep1 strongly induced expression of PMEI. Label with different letter indicates a different expression level according to Student's *t* test ($P < 0.05$).

Evaluation of Defoliation on Soybeans with Insecticide Seed Treatments

N. Taillon[1], G. Lorenz[1], B. Thrash[2], A. Plummer[1], M. Chaney[1], and J. Black[1]

ABSTRACT

A study was conducted during the 2015 growing season to evaluate if plants treated with an insecticide seed treatment would recover faster and suffer less yield loss than non-treated plants. Plants in plots with 100% defoliation with and without seed treatments were compared to the same treatments with no defoliation. Results indicated no differences in the effect of seed treatment on recovery, although severe yield loss and loss of growth were observed due to defoliation at the V4 growth stage on late-planted soybean.

INTRODUCTION

Neonicotinoid seed treatments are commonly used to protect row crops from both above ground and below ground insect pests. These products are commonly used on most of the major row crops grown in Arkansas including soybeans. In some cases these compounds have also been reported to enhance plant vigor and biotic or abiotic stress tolerance independent of their insecticidal activity (Ford et al., 2010). While this mode of action has not been well defined, it has been associated with inducing the salicylate-associated plant defense responses of the plant. This phenomenon has been well documented in rice in Arkansas (Wilf et al., 2010a, 2009b, Taillon et al., 2015). The purpose of this study was to determine if a seed treatment of thiamethoxam (Cruiser®) had any impact on the ability of plants to recover from severe defoliation at the V4 growth stage.

PROCEDURES

In 2015, a trial was conducted at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Ark. Plot size was 12.5-ft. wide, 15-ft long, replicated 6 times. AG4632 cultivar was used in this study. Seed treatments included: an untreated control; a fungicide-only treatment, Apron Maxx® RTA 5 oz; an insecticide seed treatment, Cruiser 5FS 1.28 oz; and a combination of the fungicide and the insecticide seed treatment. Seed treatments were arranged in a randomized complete block design. At V6, two rows of each plot were completely defoliated and two rows were not. Stand count, plant height, and vigor ratings were taken two weeks after planting; plant height and vigor ratings were taken again at 21 days after defoliation; yield was also taken.

RESULTS AND DISCUSSION

Prior to defoliation, there were no differences among all treatments compared to the untreated check. Three weeks after defoliation, there was a significant difference in plant height and vigor between defoliated and non-defoliated plots but not among seed treatments or the untreated check (Figs. 1 and 2). Yield results indicated that all defoliated plots were lower than the non-defoliated plots; Cruiser alone had better yield than Apron Max RTA alone (Fig. 3).

Although there were no differences among the defoliated treatments, there was a noticeable trend for Cruiser treated plots, with and without a fungicide, to do better across all assessments. In the field, these differences were visually observed as well.

PRACTICAL APPLICATIONS

Yield increases associated with neonicotinoid seed treatments are well documented for all major row crops in the mid-South. These yield increases are often seen even though detectable insect levels are well below threshold. If neonicotinoid seed treatments provide the plant with the ability to overcome stress factors, they provide more value to the grower. Understanding those mechanisms could help enhance and quantify their value to soybean producers.

ACKNOWLEDGEMENTS

The authors would like to thank the Arkansas Soybean Promotion Board for their support of this research. Support was also provided by the University of Arkansas System Division of Agriculture.

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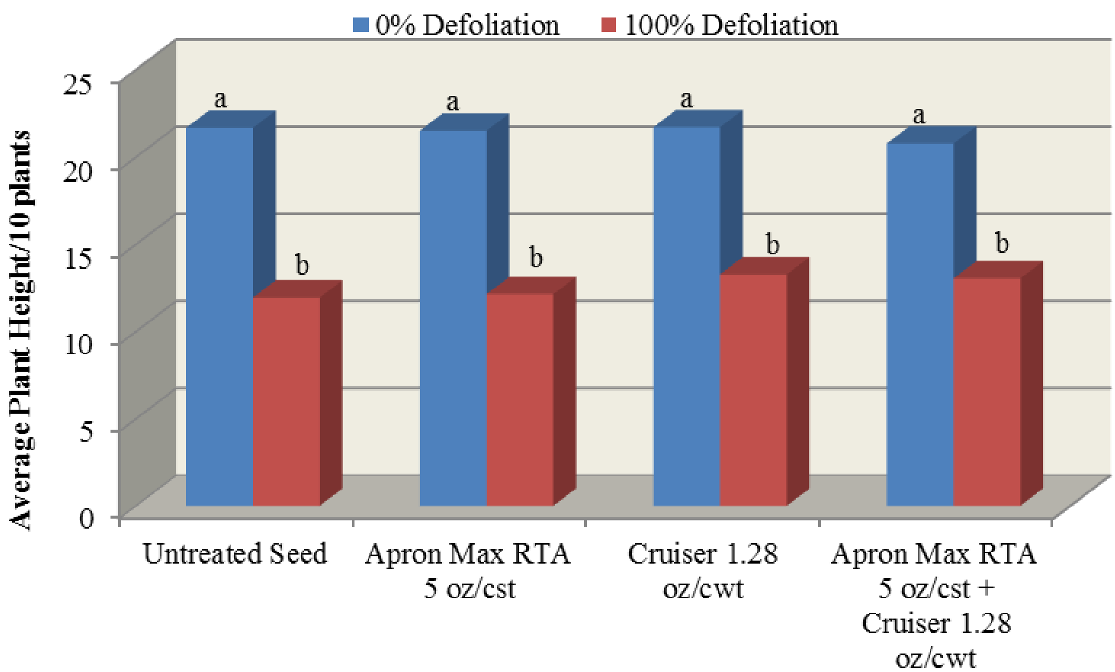

Fig. 1. Average plant height per 10 plants as measured on 27 July 2015, 21 days after defoliation. Means followed by the same letter are not statistically different.

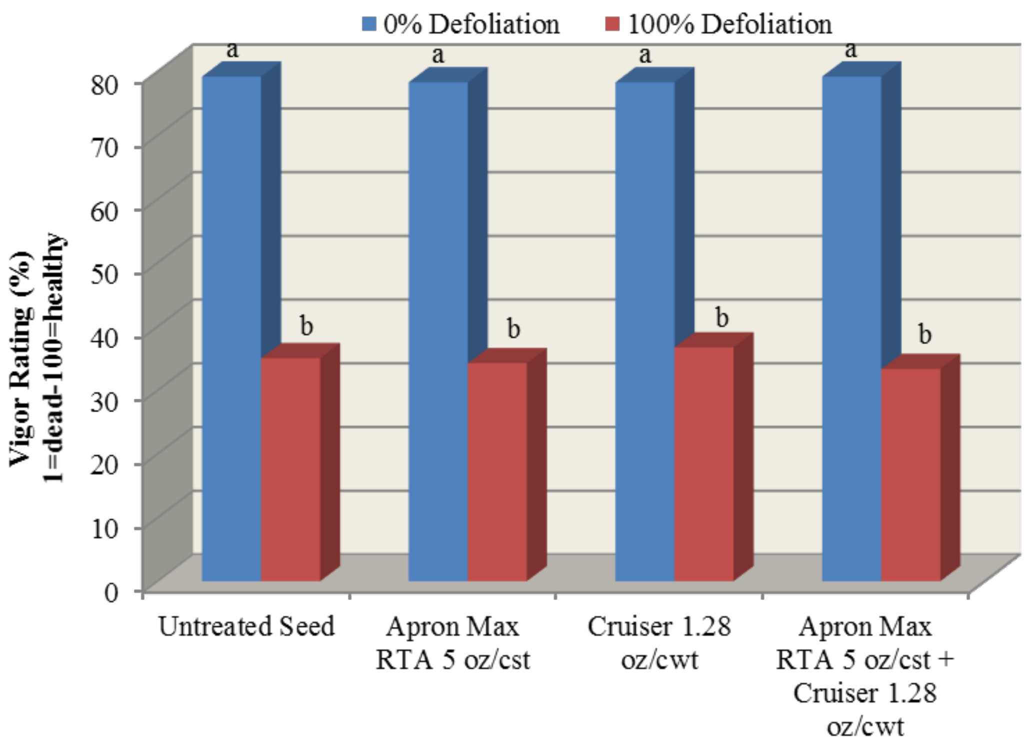

Fig 2. Vigor rating taken on 27 July 2015, 21 days after defoliation. Means followed by the same letter are not statistically different.

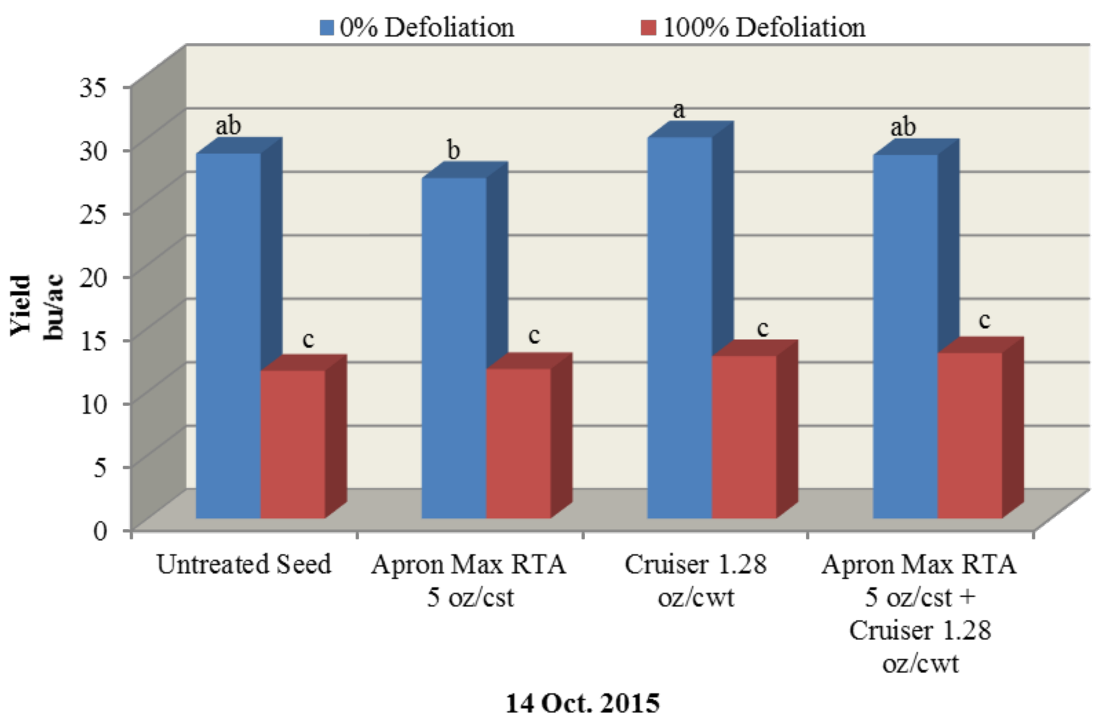

Fig. 3. Soybean yield. Means followed by the same letter are not statistically different.

Evaluation of Insecticide Seed Treatments for the Control of Thrips in Soybeans, 2015

N. Taillon[1], G. Lorenz[1], A. Plummer[1], M. Chaney[1], and J. Black[1]

ABSTRACT

A test was conducted during the 2015 growing season to evaluate the efficacy of insecticide seed treatments for control of thrips. Seed treatments significantly increased stand compared to the untreated check at 14 days after emergence. Most products controlled thrips compared to the untreated check and yields were increased compared to the check for Inovate®, Trilex® + Poncho®, Trilex and Cruiser Maxx Avicta®.

INTRODUCTION

Several species of thrips are an early-season pest of soybeans, the most common species being the soybean thrips, *Sericothrips variabilis*. Usually thrips are not a problem in soybeans. However, when they occur in large numbers they can cause stunting, delayed maturity, and yield loss. Use of neonicotinoid insecticide seed treatments has shown an increase in soybean yield and economic returns for growers in the mid-South (Gore, et al., 2014).

PROCEDURES

In 2015, a trial was conducted at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas. Plot size was 12.5-ft wide, 30-ft long, replicated 4 times. AG4632 cultivar was used in this study. Seed treatments included an untreated control; a fungicide only treatment, Trilex® 2000 1 oz; fungicide plus Poncho Votivo® 2 oz; CruiserMaxx® 3 oz; Cruiser Maxx 3 oz plus Avicta® 2.5 oz; Inovate® 4.78 oz; Accerleron® (Imidacloprid (I)) 2 oz.; and Acceleron (I) plus Poncho Votivo® 2 oz. Plots were arranged in a randomized complete block design. Stand counts were taken 7 and 14 days after emergence by measuring 10 plants per plot and averaging the heights; thrips samples were taken at 7 days after emergence by placing 5 plants per plot in 70/30 alcohol solution. Plants were washed and filtered in the lab at the Lonoke Extension Center, Lonoke, Ark., and thrips were counted using a dissecting scope (Burris, et al., 1990). Yield was also assessed.

RESULTS AND DISCUSSION

No differences in stand counts were observed at 7 days after emergence. At 14 days after emergence, Inovate, Cruiser Max, Trilex and Cruiser + Avicta had a higher stand count than the untreated check and Inovate had a higher stand count than both Acceleron (I) and Trilex Poncho/ Votivo treatments (Fig. 1).

Vigor observations at 7 days after emergence indicated all treatments were significantly better than the untreated check. However, no difference between treatments was observed at 14 days after emergence.

Thrips samples taken at 7 days after emergence indicated that all treatments except for Trilex + Poncho Votivo and Trilex alone reduced thrips compared to the untreated check. Acceleron (I) + Poncho Votivo reduced thrips below all other treatments except for Acceleron (I), CruiserMaxx + Avicta, and CruiserMaxx alone (Fig. 2).

Inovate, CruiserMaxx + Avicta, Trilex + Poncho Votivo, and Trilex alone all had better yield than the untreated check; Inovate had higher yield than Acceleron (I), CruiserMaxx, and Acceleron (I) + Poncho Votivo (Fig. 3).

PRACTICAL APPLICATIONS

These types of trials are conducted to evaluate efficacy of current and potential treatments for thrips to help us make sound recommendations for soybean producers that will help them protect their crop and get the most return on their investment. These products continue to be scrutinized for impact on non-target organisms and there are those that indicate they have little value to the producer, so it is important to document benefit to the producer.

ACKNOWLEDGEMENTS

The authors would like to thank the Arkansas Soybean Promotion Board for support of this research. Support was also provided by the University of Arkansas System Division of Agriculture.

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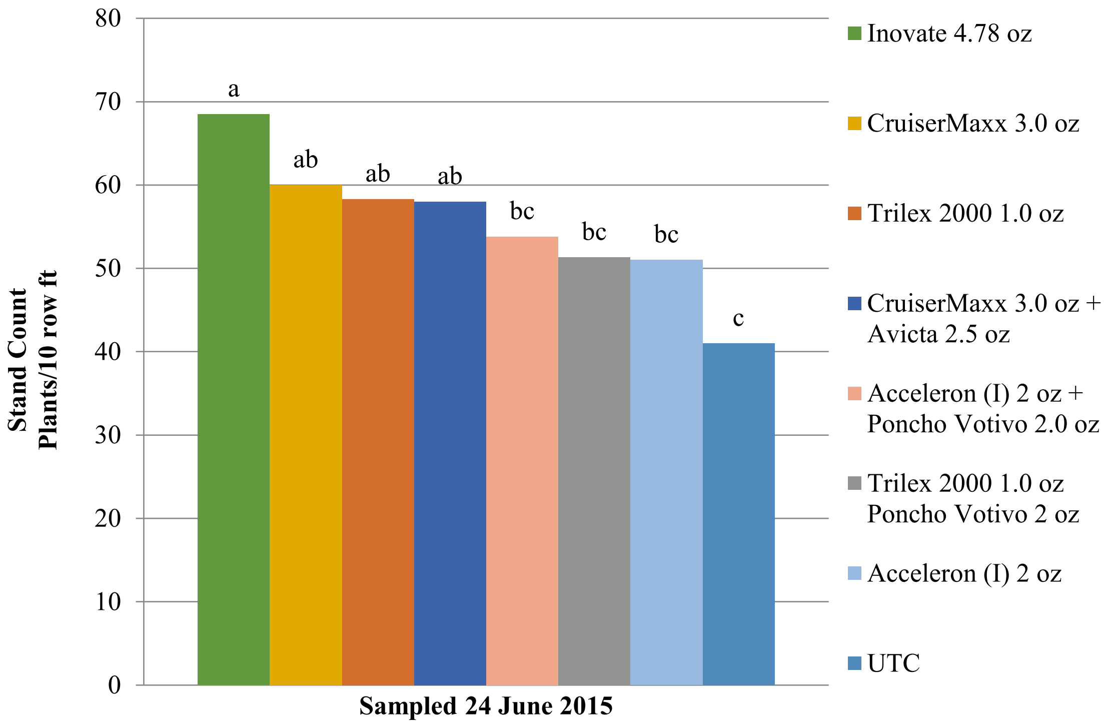

Fig. 1. Average stand count per 10 row-ft, 14 days after emergence. Means followed by the same letter are not statistically different.

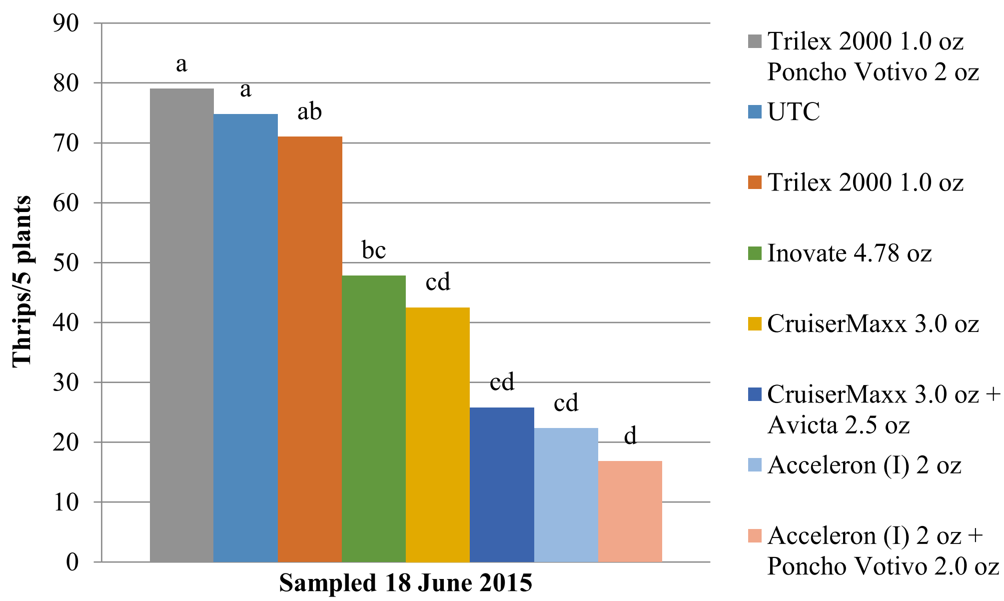

Fig. 2. Number of thrips per 5 plants, 7 days after emergence. Means followed by the same letter are not statistically different.

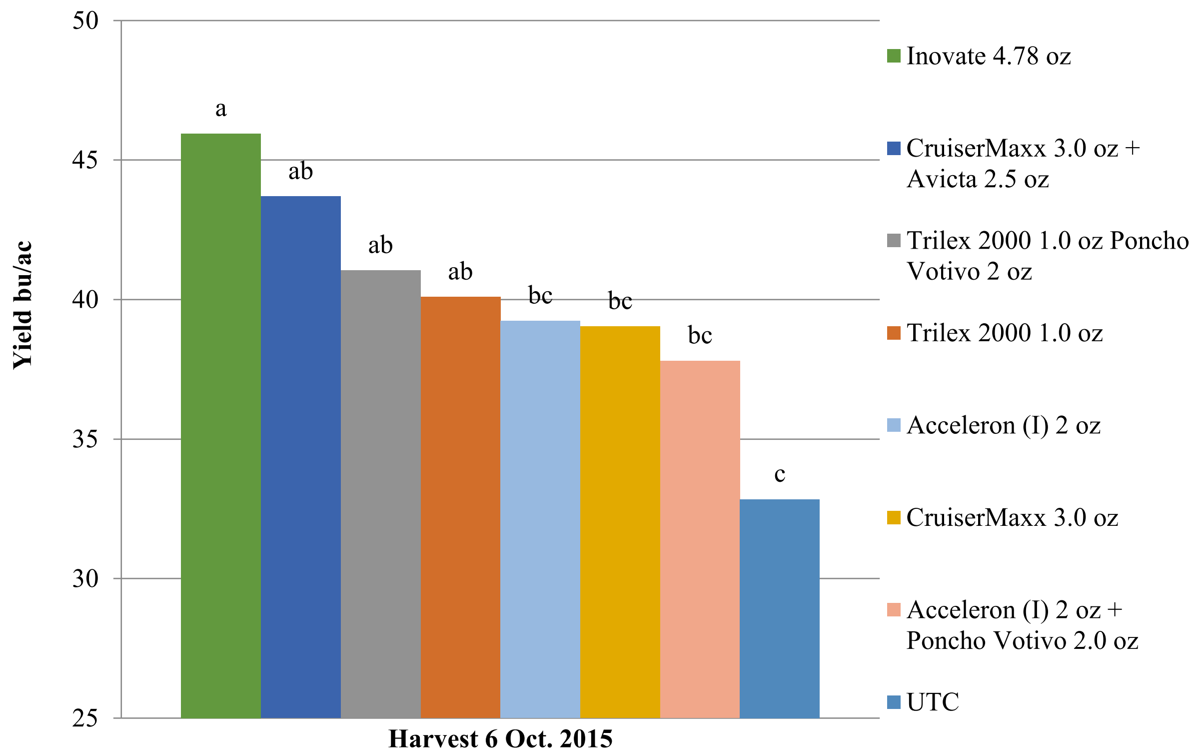

Fig. 3. Yield of selected insecticide treatments in soybean. Means followed by the same letter are not statistically different.

Evaluation of Automatic Applications on Profitability of Soybean Production

G. Lorenz[1], N. Seiter[2], G. Studebaker[3] T. Faske[4], T. Spurlock[5], B. Stark[6]
A. Plummer[1], and N. Taillon[1]

ABSTRACT

During the 2014 season, six large block field studies were conducted to determine the need and profitability of automatic applications for insect and disease control compared to treating as needed based on the University of Arkansas System Division of Agriculture's Cooperative Extension Service thresholds. At three locations no value was seen to either an automatic application of fungicide or insecticide. At one location, only the fungicide application provided an increase in yield. At two locations, the insecticide and fungicide increased yields independently of each other and the combination of both increased yields over all other treatments. The "Treat-Only-As-Needed" approach generated highest net returns for Farr and Miles locations. The Fortner location had highest net return from the insecticide plus fungicide treatment. The Griffin location had highest net return with the combination R3 and R5 fungicide only strategy, The Crow location had highest net return with fungicide only, and the Lost Cane trial's highest net return was for insecticide only. These yield and net return results for one year suggest that multiple years of study will be required to obtain a true picture of the strategy relationships based on economic net returns.

INTRODUCTION

Arkansas soybean producers spend more money today producing a crop than ever before and soybean insect pests can increase the cost of production and cause yield loss every year (Musser et al., 2011, 2012, 2013). With the current decline in commodity prices, it is important to evaluate the inputs of production so that profitability can be maintained for soybean production (Flanders, 2015). If automatic applications don't provide an economic return, growers need to understand that this approach can be costly and reduce profitability as well as reduce the long term benefits of these products for maintaining pest control. Resistance to pesticides from these types of applications can be more costly to the grower than they realize. If we show that automatic applications don't provide profit to the bottom line it may help growers to realize they can save money and increase profitability by spraying only as needed. On the other hand, if the "one and done" application is effective it will help us to evaluate our recommendations. The objectives of this study were: 1) Initiate studies comparing automatic applications of insecticides and fungicides to treating as needed based on the University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) thresholds. 2) Determine the profitability of the two programs to look at cost, yield increase, and profitability for Arkansas soybean producers. Can automatic applications be justified to maintain maximum profit for soybean producers? 3) Share results of studies with producers at grower meeting venues.

PROCEDURES

Large block trials were conducted on key growers from Southeast to Northeast Arkansas. Treatments included: 1) Fungicide plus insecticide automatic application at R3; 2) Insecticide only at R3; 3) Fungicide only at R3; 4) Treatment for disease or insect only if threshold is reached for plant disease or insect; 5) Automatic application of fungicide and insecticide at R3 followed by an automatic application of fungicide at R5. Fungicide applications were Priaxor at 4 oz/ac only for Nelson Crowe, Matt Miles, and Lost Cane locations; Crawfordsville location used Approach Prima at 6.8 oz/ac. At the Marianna and Lonoke locations, the R3 fungicide application included Topaz at 6 oz/ac with the Priaxor. For the insecticide application, Prevathon at 14 oz/ac was used for all locations. Plots were maintained and scouted working with growers and consultants. Automatic applications on plots were made based on crop phenology and suggested timing for insecticides and fungicides based on timings recommended by manufacturers and consultants. Plot design was randomized complete strip plot with four replications. Threshold plots were scouted for insects and diseases and applications were to be made based on thresholds. All plots were scouted weekly. To determine profitability of the two approaches for soybean producers, a partial budget approach was used to generate an economic analysis comparing the treatments. Product prices were determined from a survey of industry retail input providers. Application costs were estimated by modifying the 2015 UACES interactive

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enterprise budget for a Roundup Ready soybean/furrow irrigation system (Flanders, 2015). The market price utilized in the economic analysis was the 2015 Arkansas soybean statewide average price. Price quotes from National Agricultural Statistics Service LRGR-111, Arkansas Daily Grain Report, were compiled for 2 January-30 December 2015, to generate a simple, statewide average. All treatments were assumed to be custom, ground applications for economic analysis. Net returns were calculated by plot.

RESULTS AND DISCUSSION

No applications were made on any location based on established CES thresholds. Treatment 5 which was two applications of fungicide was only conducted at three of the six locations (Marianna, Miles and Crow). At the Marianna location, applications of fungicide alone, insecticide alone and the combined treatment increased yield over the untreated check; and the combined treatment with an additional fungicide application increased yield over the single and combination treatment (Table 1). At the Lonoke location, all treatments resulted in an increased yield over the untreated check, and the combination treatment resulted in increased yield over single treatment applications. At the Crow location, treatments with fungicide increased yield over the untreated and insecticide-only treatments, with no difference between untreated and insecticide-only. No differences were observed at three of the locations (Crawfordsville, Miles and Lost Cane).

The addition of the applications' and products' cost factors to the yields enabled net return estimates by treatment (Table 2). The "Treat-Only-As-Needed" approach generated highest net returns for Farr and Miles. Fortner had highest net return from the insecticide plus fungicide treatment. Griffin had highest net return with the combination R3 and R5 fungicide-only strategy, Crow had highest net return with fungicide only, and the Lost Cane highest net return was for insecticide only. These yield and net return results for one year suggest that multiple years of study will be required to obtain a true picture of the strategy relationships based on economic net returns (Stark et al., 2016).

PRACTICAL APPLICATIONS

With the current situation in agriculture of low commodity prices and increased costs of production, we have to find ways to reduce inputs for growers to be profitable. If automatic applications don't provide an economic return, growers need to understand that this approach can be costly and reduce profitability as well as reduce the long-term benefits of these products for maintaining pest control. If we show that automatic applications don't provide profit to the bottom line, it may help growers to realize they can save money and increase profitability by spraying only as needed. On the other hand, if the "one and done" application is effective it will help us to evaluate our recommendations.

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Table 1. Evaluation of automatic applications. Yields for each treatment.

Treatment	**Timing**	**Crawfordsville† Chuck Farr Armor 55R22**	**Marianna† Bobby Griffin Asgrow 4232**	**Lonoke † Jason Fortner Asgrow 4632**	**Nelson Crowe Asgrow 4642**	**Matt Miles Pioneer 47T36**	**Lost Cane Asgrow 4710**
		-------------------------------------Yield bu/ac---------------------------------------					
Prevathon 14 oz + fungicide	Automatic @ R3	76.03 a	48.08 b	67.18 a	73.98 a	77.76 a	85.8 a
Prevathon 14 oz		74.87 a	48.86 b	60.35 b	63.74 b	74.52 a	88.1 a
Fungicide Only		75.16 a	48.06 b	59.96 b	72.65 a	68.57 a	84.1 a
treat only as needed		76.71 a	41.44 c	54.72 c	63.12 b	73.55 a	84.2 a
Prevathon 14 oz‡ + fungicide fb fungicide only	@R3 & R5		54.09 a		75.18 a	66.82 a	

† Crawfordsville = Approach Prima 6.8 oz; Marianna = Topaz 6 oz + Priaxor 4 oz followed by Priaxor 4 oz; Lonoke = Topaz 6 oz + Priaxor 4 oz;

‡ Nelson Crowe = Priaxor 4oz at R3 & R5; no Prevathon.

Table 2. Economic evaluation of automatic applications. Net returns for each treatment.

Treatment	**Grower Brand Variety**	**Crawfordsville Chuck Farr Armor 55R22**	**Marianna Bobby Griffin Asgrow 4232**	**Lonoke Jason Fortner Asgrow 4632**	**Nelson Crow Asgrow 4642**	**Matt Miles Pioneer 47T36**	**Lost Cane Asgrow 4710**
		---$/ac---					
Insecticide + Fungicide	Automatic @ R3	292.71 a	35.81 b	208.15 a	275.53 a	309.82 a	382.01 a
Insecticide Only		299.49 a	64.88 a	168.65 b	198.43 b	295.88 a	418.60 a
Fungicide Only		302.97 a	53.29 b	160.67 b	281.29 a	244.29 a	384.15 a
Treat Only as Needed		339.36 a	20.83 c	140.85 c	216.64 b	311.03 a	407.04 a
Insecticide + Fungicide at R3 followed by Fungicide Only at R5			67.97 a		279.82 a	204.02 a	

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

J.L. Chlapecka[1] , N.R. Benson[2], M.L. Reba[3], and T.G. Teague[4]

ABSTRACT

Irrigation termination timing was evaluated on Mississippi County commercial farms in 2014 and 2015 in furrow-irrigated fields with Sharkey clay soils. A major objective was to validate and expand irrigation timing recommendations that pair plant growth measures with weather cues including use of local weather station data and atmometers to estimate evapotranspiration (ET). Four termination timing treatments were evaluated: early, standard, and late termination, along with a rainfed check. Even with above average rainfall in 2014 and 2015, there were yield differences among treatments with significant penalties for terminating irrigation prior to R6.5. These results validate current Arkansas recommendations.

INTRODUCTION

Expanded on-farm use of irrigation management tools is needed to improve water use efficiency in Arkansas soybean production. Decision guides developed by the University of Arkansas System Division of Agriculture's Cooperative Extension Service recommend irrigation timing using a suggested ET_0 deficit based on predominant soil type as well as plant growth stage (Henry et al., 2014). For clay soils, a 2-inch deficit is recommended as a trigger threshold to apply furrow irrigation. These recommendations also suggest irrigation termination timing at R6.5 (when half of the pods have seeds that are touching within the pod) if adequate soil moisture is present (Tacker and Vories, 1998). In 2014 and 2015 field trials, we evaluated termination timing using a combination of three irrigation cues based on plant growth stage, soil moisture, and evapotranspiration measurements.

PROCEDURES

The research sites were commercial farms in Mississippi County, Arkansas, in fields with Sharkey clay soils (Sharkey-Steele complex in 2014 and Sharkey-Crevasse complex in 2015). Cultivar, dates of planting, and irrigation timing for the 2014 and 2015 seasons are summarized in Table 1. Irrigation was applied using 18 in. × 10 mm poly irrigation tubing, and a computerized hole selection program (PHAUCET, Delta F.A.R.M., Stoneville, Miss.) was used to maximize the uniformity of irrigation sets. Soil moisture measurements were monitored using Watermark sensors (Irrometer; Riverside, Calif.) installed at different depths (6 in., 12 in., and 24 in.) in the top of the bed. The reference evapotranspiration (ET_0) was estimated using both the Penman-Monteith equation (Batchelor, 1984) and an atmometer (ET Gauge Company, Loveland, Colo.). Meteorological data was collected at the on-farm weather station (Campbell Scientific, Inc., Logan, Utah) located approximately one-half mile from the field site (http://weather.astate.edu/Main.asp). The cooperating producers performed all standard field operations, and only irrigation termination timing was altered. Plots extended the length of the fields, and width was the equivalent of two harvest swaths with the producer's combine. Harvest was made in the center portion of plots. Treatments were arranged in a randomized complete block with 4 replications in 2014 and 3 replications in 2015. Yield monitors were used for yield evaluations. Data were analyzed using PROC GLM with mean separation using protected least significant difference (SAS Institute, Cary, N.C.). Spatial analysis of yield monitoring data was completed using ArcGIS©10.1 (ESRI; Redlands, Calif.).

RESULTS AND DISCUSSION

Precipitation was ~50% above average for the April through August growing season in 2014 (Table 2); however there were periods when ET levels exceeded the 2-in. deficit (Fig. 1). Rainfall was on par in 2015, but was unevenly distributed early in crop development (Table 2). Calculated and measured ET levels exceeded the 2-in. deficit in late season for all treatments except the recommended timing treatment (Fig. 2). Plant height was taken weekly and the standard and late termination treatments were significantly taller than the rainfed treatment; and by harvest, average height of plants within the standard and late termination treatments was ~2 in. taller than rainfed (data not shown). Soil moisture sensors provided positive feedback on irrigation infiltration

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and effectiveness (data not shown). Insect pest abundance was also measured across the treatments, and no differences among treatments related to pest numbers or feeding injury were observed. Yield response indicated that the recommended standard and late irrigation termination timing in 2014 resulted in higher yields compared to the rainfed and early termination treatment (Fig. 3). There was no positive yield response to the late irrigation at R7. In 2015, the standard termination treatment produced 6 to 9 more bu/ac as compared to early and very early terminated irrigation treatments. Water deficit stress prior to pod development (R3) was detrimental to yield.

PRACTICAL APPLICATIONS

Irrigation termination scheduling based on a combination of ET, monitoring growth stage and soil moisture is a practical approach for improving water use efficiency in soybean production. Using proper irrigation scheduling techniques can improve water use efficiency, which will have a positive effect on water savings and overall soybean production efficiency.

ACKNOWLEDGEMENTS

We extend special thanks to soybean producers, Mike and Ryan Sullivan and Jeff Lammers, for their exceptional cooperation and support for on-farm research. The project was supported by the Arkansas Soybean Promotion Board, University of Arkansas System Division of Agriculture, Arkansas State University, and USDA National Institute of Food and Agriculture (project ARK02355).

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Table 1. Description and timing including plant growth stage, dates, and number of days after planting when irrigation was terminated in soybean; 2014, 2015 Mississippi County, Ark.

Year Cultivar Date of planting/harvest	Treatment description	Final irrigation[a] application Growth stage	 Date	 Days after planting
2014 Asgrow 4633MG IV 22 April / 23 Sept	Rainfed	-	-	-
	Early Termination	R5	28 Jul	97
	Standard Termination	R6.5	14 Aug	114
	Late Termination	R7	28 Aug	128
2015 Asgrow 4632 MG IV 25 June / 22 October	Rainfed	-	-	-
	Very Early Termination	R1	3 Aug	39
	Early Termination	R5	1 Sep	68
	Standard Termination	R6.5	17 Sep	84

[a] Dates of irrigation (days after planting) in 2014 were 11 July (80), 28 July (97) 14 Aug (114), and 28 Aug (128), and in 2015 irrigation was applied 3 Aug (39), 1 Sept (68), and 17 Sep (84).

Table 2. Monthly precipitation and average temperature for 2014 and 2015 near Manila, Ark. compared to 30-year (1981-2010) averages from nearby Keiser, Ark.

Variable and year	May	June	July	Aug.	Sep.	Season
	---------------------------------------°F---------------------------------------					
Mean air temperature						
2014	71.1	77.5	75.1	78.4	-	75.5
2015	-	79.6	81.7	76.1	72.7	77.5
1981-2010	71.0	79.3	82.0	80.5	73.1	-
	---------------------------------------in.---------------------------------------					
Total precipitation						
2014	4.53	6.38	4.69	5.73	-	21.33
2015	-	2.51	5.81	4.36	0.88	13.56
1981-2010	5.37	3.99	4.04	2.36	3.24	-

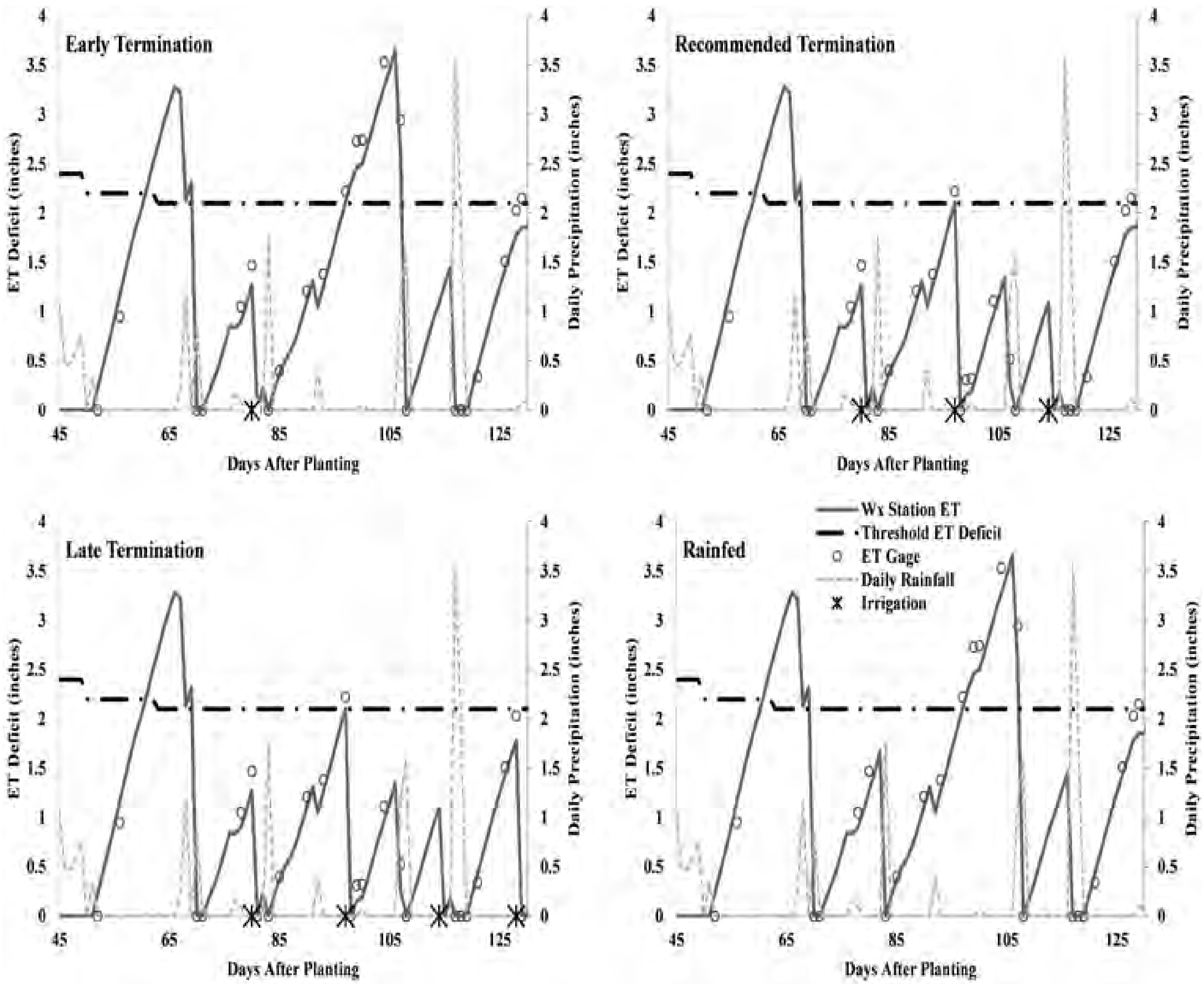

Fig. 1. Calculated evapotranspiration (ET) values from weather station measurements, a field atmometer (ET Gage), as well as daily precipitation and irrigation timing for the 2014 irrigation termination timing trial, Mississippi, County, Ark.

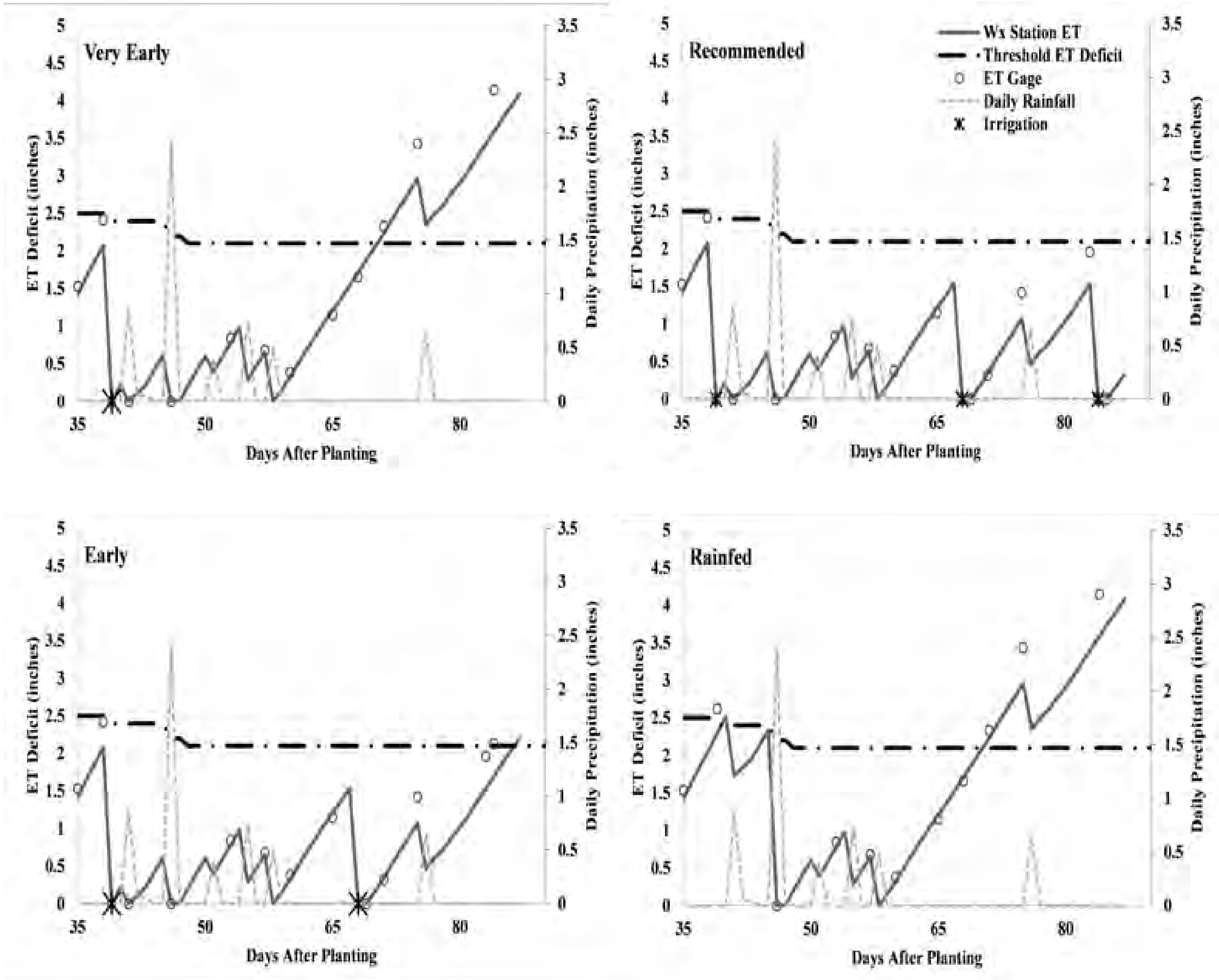

Fig. 2. Calculated evapotranspiration (ET) values from weather station measurements, a field atmometer (ET Gage), as well as daily precipitation and irrigation timing for the 2015 irrigation termination timing trial, Mississippi, County, Ark.

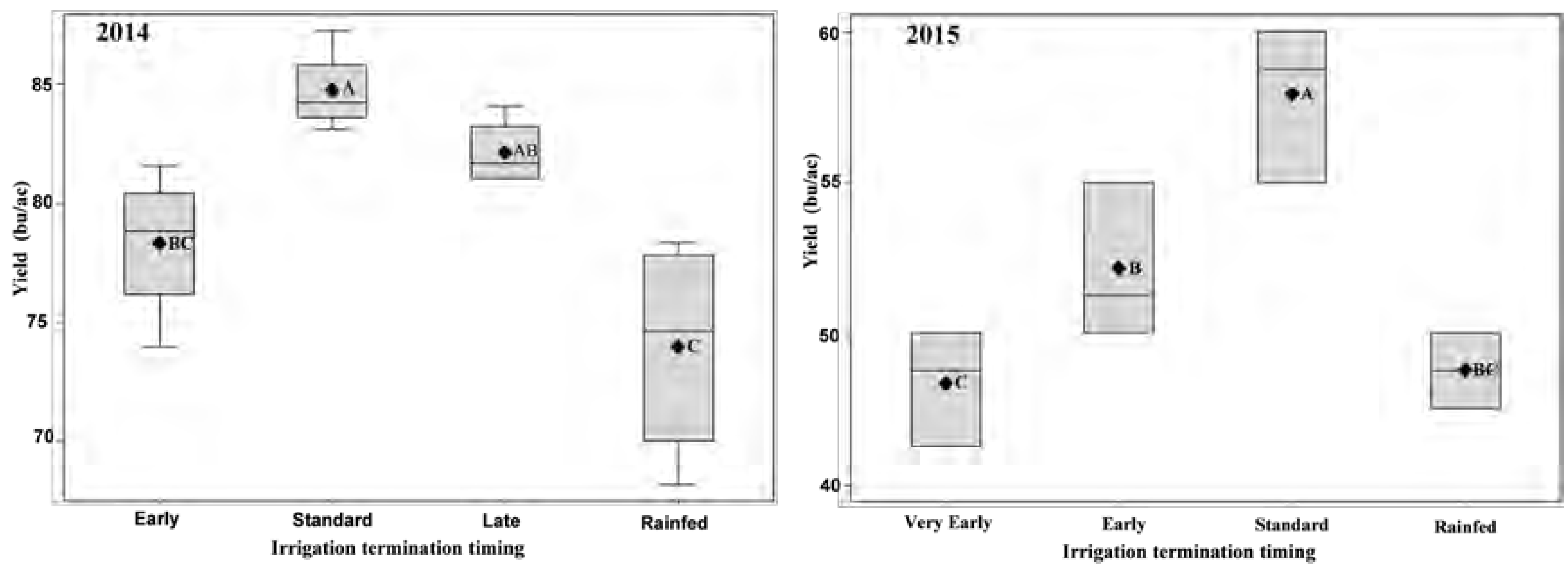

Fig. 3. Mean soybean yield (bu/ac) for 2014 and 2015 calculated from yield monitor data for each irrigation timing treatment. Boxes represent 50% quartile; diamonds within the box depict means and the line is the median value. Means within each year followed by similar letters do not differ (*P* = 0.05; least significant difference = 0.05).

Irrigation Initiation Timing in Soybean Grown on Sandy Soils in Northeast Arkansas

J.L. Chlapecka[1], A.M. Mann[2], N.R. Benson[3], M.L. Reba[4], and T.G. Teague[2]

ABSTRACT

Irrigation initiation timing was evaluated in a furrow-irrigated soybean field with sandy soils in Mississippi County, Ark. A major objective of this 2015 study was to validate and expand irrigation timing recommendations that pair plant growth measures with weather cues including use of local weather station data and atmometers to estimate evapotranspiration (ET) and use of Watermark sensors to measure soil moisture. Four initiation treatments were evaluated with irrigation starting when ET deficits reached 1 inch (early), 2 inches (standard), and 3 inches (late); there also was a rainfed check. Treatments were arranged in a strip-plot, randomized complete block design with 3 replications. Plot size was 24 rows wide and 1250-ft long, extending the length of the 35 acre field. Despite above average rainfall amounts in 2015, there were periods during crop reproductive development when measured ET and soil moisture values exceeded deficit thresholds. Yield response to irrigation timing depended on soil texture in the spatially variable field. There were two soil textures—coarse sand and sandy loam—classified using measures of soil electroconductivity (EC). Soil water deficits in both the rainfed and late initiation treatments reduced yield of plants in coarse sand, which encompassed approximately 12% of the field. In sandy loam portions of the field, the non-irrigated rainfed plants produced lowest yields, but plants receiving early irrigation also produced lower yields compared to standard and late initiation timing. There was increased lodging with the early irrigation initiation, and this likely contributed to the yield penalty. Current University of Arkansas System Division of Agriculture guidelines suggest a conservative irrigation regime, and results from this trial validate those recommendations.

INTRODUCTION

Expanded on-farm use of irrigation management tools is needed to improve water use efficiency in Arkansas soybean production. Decision guides developed by the University of Arkansas System Division of Agriculture's Cooperative Extension Service recommend irrigation timing using a suggested evapotranspiration (ET) deficit based on predominant soil texture as well as plant growth stage (Henry et al., 2014; Tacker and Vories, 1998). For sandy soils, guidelines suggest initiating irrigation after the R1 stage at a 2-inch ET deficit. This 2015 field trial was designed to validate current recommendations including plant response across different soil textures in a spatially variable field.

PROCEDURES

The research site was a commercial farm located near Manila, Ark., in a 35 acre field with soils mapped as a Routon-Dundee-Crevasse complex (fine-silty, mixed, active, thermic typic epiaqalfs-udipsamments) (Soil Survey Staff, 2015). Within-field variability of soil texture ranged from coarse sand (sand blows) (approximately 12% of the total field) to sandy loam. Treatment descriptions and production details are summarized in Table 1. Plots extended the length of the field (1250 ft), and plot width was the equivalent of two harvest swaths with the producer's combine. The four irrigation treatments were arranged in a strip-plot, randomized complete block design with 3 replications. Irrigation was applied using 18-in. × 10-mm poly irrigation tubing and a computerized hole selection program (PHAUCET, Delta F.A.R.M., Stoneville, Miss.) was used to improve uniformity of irrigation sets. A surge valve was used to control irrigation and to maintain equal applications on both sides of the riser. The cooperating producer performed all standard field operations, and only irrigation initiation timing was altered among treatments. Soil moisture measurements were monitored using Watermark sensors (Irrometer; Riverside, Calif.) installed at three different depths (6-in., 12-in., and 24-in.) and positioned in the top of the bed at two sites near the center of each irrigation plot. The reference evapotranspiration was estimated using both the Penman-Monteith equation (Batchelor, 1984) and an atmometer (ET Gage Company, Loveland, Colo.). Meteorological data were collected at the on-farm weather station (Campbell Scientific, Inc., Logan, Utah) located approximately one quarter mile from the field site. The accumulated ET deficit was calculated each day by adding the recorded daily ET and subtracting the daily rainfall from the accumulated ET deficit of the previous day (Irmak et al., 2005). We followed the practice suggested by Pryor (2015) and adjusted ET deficits to zero following irrigation only if readings from Watermark sensors at the 6-in. depth rose above -30 kPa. If there was poor irrigation water infiltration, the irrigation event was considered only 50%

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effective, and the ET deficit was reduced only 50% compared to the previous day. On the day of harvest, lodging scores were assigned in each treatment plot ranging from 0 (no lodging) to 5 (all plants down). Yield evaluations were made using a grain cart catch weight as well as yield monitor with measurements taken from a harvest swath (12 rows) in the center of each plot running the length of the field. Yield was adjusted to 13% moisture. A two-way factorial treatment structure was used for analysis of the yield monitor measured yield with irrigation treatment and block effect and soil electroconductivity (EC) classifications included as a co-variate. Soil EC measurements were collected in spring 2015 using a Veris® 3150 dual depth Soil Surveyor (Veris Technologies, Salina, Kan.) in every row within the field. For the analysis, soil EC values were stratified into two classes—coarse sand (deep <3.3 mS/m) and sandy loam (> 3.3) mS/m). Data were analyzed using PROC GLM and MIXED (SAS Institute; Cary, N.C.). Spatial analysis was completed using ArcGIS©10.1 (ESRI; Redlands, Calif.).

RESULTS AND DISCUSSION

Precipitation was approximately 20% above average for the growing season of May through August; however, deficit thresholds were reached in treatments for both ET and soil moisture (Fig. 1, Table 2). Significantly greater levels of lodging were associated with the early and recommended irrigation initiation treatments compared to the late initiation treatment; no lodging was apparent in the rainfed treatment plots (Table 3). There were no statistical differences among treatments in mean total yields as measured by catch weight for the length of field plots (data not shown); however, when yield monitor data were evaluated with yield segregated by soil texture, there were irrigation timing ($P = 0.09$), soil texture ($P < 0.001$), and irrigation * soil texture interactions ($P < 0.001$) (Fig. 2). Lowest yields were associated with plants in the coarse sand soil EC class compared to plants in sandy loam soil EC class. In coarse sand, water-deficit stress reduced yield in the rainfed and delayed irrigation initiation treatments. Yield from plants in the sandy loam soil EC class was highest with standard and late initiation timing. Significantly lower yields were observed in the rainfed treatment and with early initiation.

PRACTICAL APPLICATIONS

Irrigation initiation scheduling based on a combination of ET, monitoring growth stage and soil moisture is a practical approach for improving water use efficiency in soybean production. Using proper irrigation scheduling techniques can improve water use efficiency, which will have a positive effect on water savings, overall production efficiency and farm profitability.

ACKNOWLEDGMENTS

We extend special thanks to producers, David, Justin and Tab Wildy and Paul Harris and the staff at Wildy Family Farms for their exceptional cooperation and support for on-farm research. We thank D.K. Morris, ASU, for assistance with soil EC measurements, and J.L. Willers, USDA-ARS, Starkville, Miss. for assistance with statistical analysis. Funding and support for the project was provided by the Arkansas Soybean Promotion Board, University of Arkansas System Division of Agriculture, Arkansas State University, and USDA National Institute of Food and Agriculture (project ARK02355).

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Table 1. Description and irrigation initiation timing including plant growth stage, dates, and number of days after planting for soybean irrigation initiation trial, 2015, Manila, Ark.

Treatment (planned ET deficit for irrigation initiation)	Irrigation[a] initiation timing			
	Actual ET (in.) at irrigation	Growth stage	Date	Days after planting
Rainfed	-	-	-	-
Late initiation (3 inch)	3.3	R3	24-Jun	62
Recommended initiation (2 inch)	2.7	R2.5	17-Jun	55
Early initiation (1 inch)	1.8	R2	10-Jun	48

[a] Dates of irrigation (days after planting) were 10 June (48), 17 June (55), 24 June (62), 29 June (67), 13 July (81), 17 July (85), 29 July (97), 3 Aug (102), and 17 Aug (116).
ET = evapotranspiration.

Table 2. Days above the recommended accumulated evapotranspiration deficit for each irrigation timing treatment in 2015 during bloom (R1-R2), pod (R3-R4), pod fill (R5-R6), and the entire season for soybean irrigation initiation trial, 2015, Manila, Ark.

Treatment	Bloom	Pod	Pod Fill	Total
	---------------------------days---------------------------			
Rainfed	11	8	4	23
Late Initiation	11	1	0	12
Recommended Initiation	4	0	0	4
Early Initiation	0	0	0	0

Table 3. Mean soybean plant height of plants in sandy loam soils texture from V1-R2 stage and from R2.5-R6 stage; lodging ratings at harvest included; irrigation initiation trial, 2015, Manila, Ark.

Irrigation Treatment	Height V1-R2	Height R2.5-R6	Lodging rating
	------------------in.------------------		
Rainfed	5.1	17.7	0.0
Late	5.4	19.7	1.0
Recommended	5.4	21.1	2.3
Early	5.2	21.6	2.7
LSD_{05}	0.4	3.3	0.7
P > F	0.49	0.17	<0.01

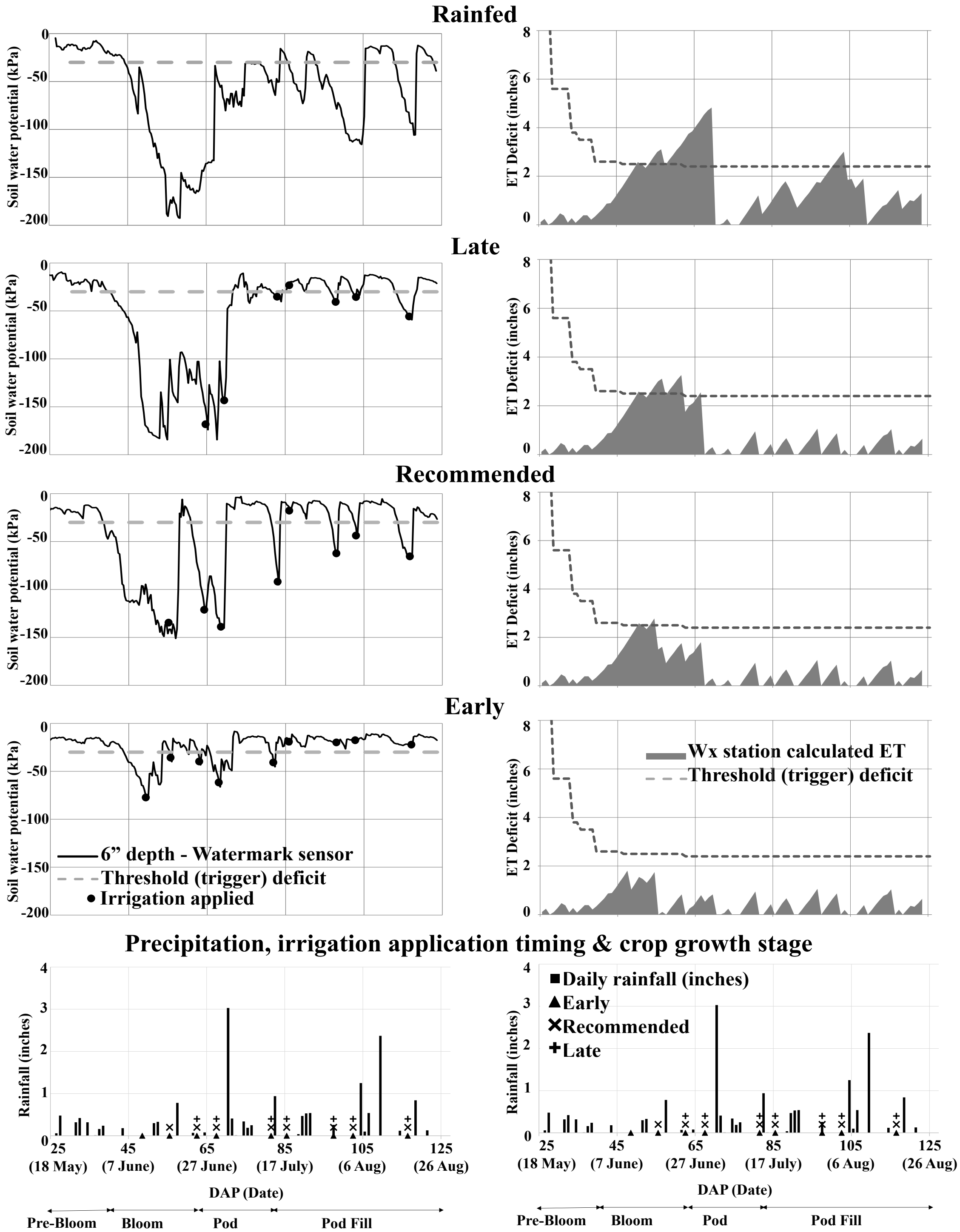

Fig. 1. Mean soil water potential (kPa) at a 6-in. depth in sandy loam soil (left) and accumulated evapotranspiration (ET) deficit (right) with rainfall and irrigation events plotted beneath with days after planting (DAP) and date on the x-axis along with crop growth stage for 2015 soybean irrigation initiation trial, Manila, Ark.

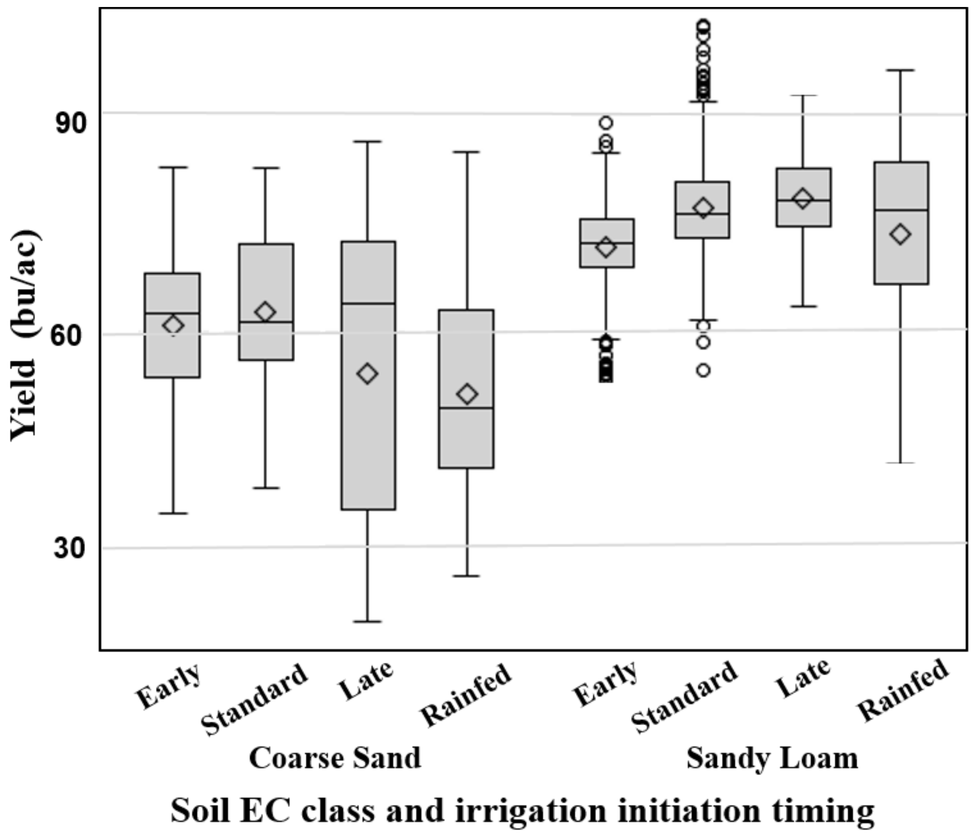

Fig. 2. Mean soybean yield (bu/ac) for each irrigation timing treatment determined from yield monitor data and segregated by soil texture classed using soil electroconductivity (EC) for soybean irrigation initiation trial, 2015, Manila, Ark. Boxes represent 50% quartile; diamonds within the box depict means, and the line is the median value.

Optimal Investment in Reservoirs and Tail-Water Recovery for Economic Returns and Groundwater Conservation

K. Kovacs[1] *and M. Mancini*[1]

ABSTRACT

We examine the economic effectiveness of conjunctive water management with on-farm reservoirs and tail-water recovery to address groundwater scarcity in the Mississippi River Delta region of Arkansas. We find that reservoirs should be built when the depth to the aquifer exceeds 60 feet, and the average share of productive land in a reservoir should be about 2%. Soybean intensive areas use reservoirs sparingly to support shallow groundwater pumping depths, but groundwater remains the primary source of irrigation. Rice intensive areas use reservoirs to supplant groundwater with reservoir surface water when the depth to groundwater increases.

INTRODUCTION

The region for the application of our model is the Lower Mississippi River Basin in Arkansas (referred to as the Arkansas Delta) which has long relied on groundwater from the Mississippi River Valley Alluvial Aquifer. Producers choose among multiple crops that require varying intensities of irrigation along with whether to convert farm land to reservoirs. Reservoirs increase the surface water available for irrigation, and this may replace irrigation from wells. Most economic studies of conjunctive water management have been done at the individual farm level, however this ignores that withdrawal by one user lowers the water table and increases the pumping cost for all users. This pumping effect on others means the appropriate water management for a farm depends on the pumping done by surrounding farms and the agricultural region as whole. A regional depression in an aquifer emerges when many farms above the aquifer are growing irrigation intensive crops (ANRC, 2012).

PROCEDURES

Greater detail on the methods and data can be found in Kovacs and Mancini (2016). The farm production choices are likely to differ across regions that predominantly grow irrigation intensive rice and those that grow predominantly less irrigation intensive crops such as soybeans. These regions are different in terms of the relative yield of rice and soybean and in terms of their initial groundwater scarcity. There is a greater urgency to use reservoirs in the rice-intensive region than in the soybean-intensive region. To examine the differences across the two regions, a rice-intensive area is defined as the subset of all sites where the percentage rice land in 2033 is equal to or greater than 35% of the site area (539 sites or 254 thousand acres), and an irrigated soybean-intensive area is defined as the subset of all sites where the percentage soybean land in 2033 is equal to or greater than 35% of the site area (1219 sites or 532 thousand acres).

The cost and water storage capacity of reservoirs are key factors affecting whether reservoirs are built, how much land is made into reservoirs, and the return on investment (ROI) in reservoirs. There is uncertainty in the cost and water storage capacity of reservoirs because the cost of a reservoir depends on the unknown size of the reservoir and the water storage capacity depends on access to unknown amounts of surface water such as streams and ditches that fill the reservoirs. High cost/low water storage reservoirs function as a lower bound of the potential reservoirs on the landscape, and low cost/high water storage reservoirs act as an upper bound of the potential reservoirs on the landscape.

RESULTS AND DISCUSSION

Tables 1 and 2 show the economic, land, and irrigation results for the rice intensive land and the irrigated soybean intensive land. Both show that reservoirs lead to a reduction in the acreage of the non-irrigated sorghum and Conservation Reserve Program (CRP) land. There is an increase in rice for the rice intensive area while there is an increase in irrigated soybeans for the soybean intensive area. Reservoirs increase thirty-year farm net returns for all scenarios, and the magnitude of the profit increase depends on the reservoir costs more than the crop mix across the reservoir scenarios. Both Tables 1 and 2 indicate the baseline and the low cost/high water storage reservoir scenarios decrease groundwater use and increase the volume of the aquifer compared to the landscape without reservoirs. However, the groundwater use in the high cost/low water storage scenario is actually greater because a small number of reservoirs are built that store a limited amount of water. This leads to more groundwater use coupled with the reservoir water to support a greater acreage of high value crops like rice and soybeans.

The return on investment (ROI) of reservoirs is higher for the rice intensive area than for the soybean intensive area. The baseline reservoir scenario has a 14.6% ROI in the rice intensive area and a 2.2% ROI in soybean intensive area.

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More land is converted to reservoirs in the rice intensive area than in the soybean intensive area. A positive, low ROI in the high cost/low water storage scenario suggests reservoirs are worthwhile to producers even when their costs are at the high end and the water storage capacity is low. However, while ROI is still positive, the aquifer is more depleted than in the no reservoir scenario, indicating the high cost/low storage reservoirs do little for conservation. This suggests that lowering reservoir costs and/or increasing reservoir water storage would increase ROI and preserve the aquifer.

The results of the regression for explaining ROI in reservoirs for the baseline cost/water storage scenario are shown in Table 3 using explanatory site characteristics such as the initial volume of the aquifer, the initial depth of the aquifer, and the net returns per acre excluding irrigation costs for the crops grown on the landscape. There is a positive relationship between ROI and the initial depth to the aquifer for the rice area. At depths greater than 60 feet, the ROI increases at a rate of about 2% for every increase in depth of 10 feet. The coefficient for natural recharge is positive and significant for the soybean area and for the entire landscape. On the soybean intensive land, a limited number of reservoirs are built to maintain ample reserves of cheap groundwater, and this approach is especially effective with large natural recharge.

PRACTICAL APPLICATIONS

Reservoirs are most likely to be built when the depth to groundwater is more than 60 feet, and the average share of productive land in a reservoir is likely to be about 2% with an ROI of the reservoirs of about 11%. Rice intensive sites favor reservoirs when the depth to the aquifer, the net returns to rice, and the net returns to double-crop soybean are large because those site characteristics are associated with higher groundwater pumping costs. Reservoirs at soybean-intensive sites are built for their potential to increase the aquifer and thereby lower groundwater pumping costs rather than replace groundwater as the primary source of irrigation. Without the possibility to increase the aquifer, the soybean intensive sites avoid reservoirs and focus on mining the relatively shallow groundwater.

ACKNOWLEDGEMENTS

The authors would like to thank the Arkansas Soybean Promotion Board and the U.S. Geologic Survey of the 104b research grant program, U.S. Department of the Interior, Grant #: G11AP20066 for their funding of this research. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Farm production and aquifer conditions in 2033 with and without reservoirs for rice intensive landscape.

Land, water, and economic conditions in 2033	No reservoirs	Reservoirs		
		Baseline	High cost and low water storage	Low cost and high water storage
Rice (thousand acres)	103	126	121	126
Soybeans (thousand acres)	18	20	18	20
Double crop soybeans (thousand acres)	74	68	70	66
Non-irrigated sorghum (thousand acres)	41	26	34	25
CRP land (thousand acres)	18	1	8	0
Reservoirs (thousand acres)	--	13	3	17
Annual reservoir water use (thousand acre-feet)	--	152	42	194
Annual groundwater use (thousand acre-feet)	330	233	332	189
Aquifer (thousand acre-feet)	11520	13473	11468	14323
30 year farm net returns (millions $)	658	738	684	765
Return on investment in reservoirs	--	14.6%	4.3%	20.9%

Note: 539 sites in the rice intensive landscape.

Table 2. Farm production and aquifer conditions in 2033 with and without reservoirs for soybean intensive landscape.

Land, water, and economic conditions in 2033	No reservoirs	Reservoirs		
		Baseline	High cost and low water storage	Low cost and high water storage
Rice (thousand acres)	45	47	47	47
Soybeans (thousand acres)	470	481	473	480
Double crop soybeans (thousand acres)	0	0	0	0
Non-irrigated sorghum (thousand acres)	6	2	2	2
CRP land (thousand acres)	11	0	9	0
Reservoirs (thousand acres)	--	2	1	3
Annual reservoir water use (thousand acre-feet)	--	20	6	32
Annual groundwater use (thousand acre-feet)	583	578	585	566
Aquifer (thousand acre-feet)	32835	32998	32813	33275
30 year farm net returns (millions $)	1775	1787	1779	1791
Return on investment in reservoirs	--	2.2%	0.7%	2.9%

Note: 1219 sites in the soybean intensive landscape.

Table 3. Parameter estimates for regressions of the return on investment in reservoirs.

	Rice intensive sites	Irrigated soybean intensive sites	All sites
Intercept	-1.37** (-4.01)	1.27 (1.24)	-0.60** (-2.69)
Aquifer	-3.33E-4 (-0.20)	0.02** (3.22)	-6.05E-3** (-4.82)
Depth	4.87E-3** (5.95)	1.69E-3 (0.51)	1.26E-2** (17.29)
Natural recharge	6.89E-3 (0.82)	0.19`** (4.38)	0.02** (3.05)
Net returns rice	3.07E-3** (3.16)	-9.09E-3** (-2.98)	-2.26E-3** (-3.31)
Net returns irrigated soybean	-1.53E-3 (-1.74)	-4.24E-3 (-1.52)	1.59E-3* (2.29)
Net return double crop soybean	2.16E-3* (2.42)	-5.40E-3 (-0.83)	5.09E-3** (5.20)
Net return sorghum	-1.01E-3 (-1.87)	-3.11E-3 (-1.08)	-4.66E-3** (-7.06)
Number of observations	539	1219	2724
Number of observations with ROI > 0	411	211	1249

Note: t-values in parentheses.
* $P < 0.05$.
** $P < 0.01$.

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

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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 done through improving irrigation efficiency and timing. The expected decline on current water resources makes it more important to develop and improve management practices that improve water use efficiency. Research has shown that delays in irrigation initiation, scheduling, and termination can limit yields. Furthermore, these limiting effects can vary among maturity groups, soil textures, 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 in different soil textures 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 current irrigation scheduling recommendations for furrow-irrigated soybeans.

INTRODUCTION

Research has shown the positive effects of irrigation on soybean yields. It has been reported that 80% of the soybean acreage is irrigated in Arkansas (USDA-NASS, 2013). Irrigated soybean yield averages were 20 bu/ac (1342 kg ha^{-1}) higher than unirrigated average from data obtained in 2011 and 2012 (USDA-NASS, 2013). However, ground water available for irrigation is declining in the main row-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, 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 of the global population may be under water stress conditions by 2025 (FAO, 2013). Soybean production systems will face the dilemma of maintaining or increasing yields with less water available for irrigation. Additionally high irrigation costs will demand that Arkansas growers produce consistently high yields to remain competitive.

Research has shown that 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 textures, and growing seasons (Garcia et al., 2010). A major factor effecting 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 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. Research has shown that high soil compaction can result in yield losses up to 45% (Kirnak et al., 2013). Deep tillage fractures the hard pan or compacted zones of the soil 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 very low organic matter (OM) content 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 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) report-

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ing 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 on aluminum concentrations with sequential applications of Flue Gas Desulfurized (FSD) gypsum to an Alfisol with a fragipan horizon located 16 inches deep.

The first objective of this study was to verify existing irrigation trigger thresholds while testing less conservative triggers. Less conservative triggers could result in less irrigation used in Arkansas row-crop production. Second, the study examined two practices for furrow-irrigated soybeans 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.

PROCEDURES

Field trials were conducted in 2015 at two different locations with varying soil textures: University of Arkansas System Division of Agriculture's Rohwer Research Station (RRS), Rohwer, Ark. (clay); Rice Research and Extension Center (RREC) Stuttgart, Ark. (silt-loam with a pan). The yield effects of deep tillage and gypsum amendment were assessed for four different irrigation treatments. Water use was monitored using flowmeters (www.Mccrometer.com) and soil moisture was monitored using Watermark™ soil matric potential sensors (www.irrometer.com) over the course of the study and reported in order to quantitatively assess the different water use and soil moisture in irrigation treatment across soil treatments. Irrigation treatments were developed for each site based on the soil texture and current scheduling recommendations. A modified Benelli plate atmometer (etgage.com) was used to schedule irrigations. The fully irrigated treatments were set at the current recommendations of 1.75 in. for silt loam with a pan and 2.0 in for a clay soils. Deficit levels were established by adding 1 in. (2.54 cm) and 2 in. (5 cm) to the base deficit to create the reduced irrigation treatment levels, and crop coefficients were applied based on crop growth stage as outlined in Henry et al. (2012). A non-irrigated check was also included in the study. Other than specific irrigation and soil management treatments, other cultural practices were in accordance with current University of Arkansas System Division of Agriculture, Cooperative Extension Service recommendations.

Plot Design. The field was divided into four blocks and each block received a soil treatment: deep tillage (rip), deep tillage with gypsum application, gypsum application, and no treatment (conventional). These blocks were further divided into 6 row plots with 30-in. row spacing and 8 row plots with 38-in. row spacing, for RREC and RRS, respectively. Each set of rows were watered at four different irrigation deficits (fully irrigated, +1 in. deficit, +2 in. deficit, and non-irrigated) with each irrigation treatment having 3 replicates randomly assigned within each soil treatment block (except Stuttgart which had two replicates for the non-irrigated treatments within each soil treatment). The fully irrigated treatments were scheduled in accordance with Arkansas irrigation scheduling using atmometer (ET gauge) recommendations for each site's soil texture (Stuttgart silt-loam with a pan and Rohwer clay). All sites were planted to Progeny 4900 RY soybean variety. Deep tillage was performed with a John Deere 5 shank no-till soil management system implement. The implement is a low-surface disturbance tillage device, plots were tilled to 14-18 in. (36-46 cm) depth.

Stuttgart Site Specifics. The soil treatment blocks with deep tillage were ripped 18 in. (46 cm) deep with 30 in. (76 cm) spacing on 5 May 2014. Plots were planted on 6 June 2015 and soybeans emerged 16 June 2015 and gypsum was applied at one ton per ace (2472 kg ha^{-1}) on 6 June 2015 using a BBI 1039 Single Axle Fertilizer Lime Spreader (Katyas Corporation, Cornelia, Ga.). Cultural practices (fertilizer and pesticides) were in accordance with current Cooperative Extension Service recommendations. The middle 4 rows of each plot, 800 ft (180 m) lengths beginning 50 ft (15 m) from the irrigation pipe, were harvested on 13 and 14 October 2015.

Rohwer, Site Specifics. The blocks with deep tillage were treated at 18 in. (46 cm) deep and at 30 in. (76 cm) on 29 May 2013, although row spacing at this site is 38 in. (97 cm). All plots were planted on 5 May 2015. The gypsum was applied at one ton per acre using the same spreader previously mentioned. Cultural practices (fertilizers and pesticides) were in accordance with current Cooperative Extension Service recommendations. The field was harvested on 22 Sept. 2015, the middle 2 rows were harvested for each plot in 200 ft (60 m) lengths beginning 50 ft (15 m) from the irrigation pipe.

Statistical Analysis. In order to compare the yields for the different treatment combinations, general linear models were used in the form of a two way analysis of variance with a response variable of yield (bu/ac) with two-factor soil treatment and irrigation treatment with four-factor levels each (Soil treatment levels: Ripped, ripped with gypsum, gypsum, and no treatment. Irrigation treatments: fully irrigated, +1 in. deficit, +2 in. deficit, and non-irrigated).

RESULTS AND DISCUSSION

Water Use and Soil Moisture Data. A total of 6.25 in. (159 mm) of rainfall was experienced during the growing season in Stuttgart, and the amount of irrigation applied is 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). Irrigation volumes are shown in Table 1, during the season 18 in. (46 cm) of irrigation was applied to the fully irrigated treatment, 10.1 in. (25 cm for the +1 in. deficit and 7.9 in (20 cm) for the +2 in. deficit. The fully irrigated treatment required 7 irrigations, 4 irrigations for the +1 in deficit and 3 irrigations for the +2 in deficit (Table 1). Minimal differences were observed in overall average seasonal soil matric potentials between soil treatments (Table 2).

Interaction was detected between the soil and the irrigation treatments in relation to yield (Table 3). Similar to last year's findings (Gaspar, 2014) deep tillage and deep tillage + gypsum treatments produced higher yields. Within all irrigation treatments, the deep tillage treatment produced, 10%, 15%, 18% and 15% more yield than conventional in the fully irrigated, +1 in. deficit, +2 in. deficit and non-irrigated, treatments respectively (Table 3). The only clear difference in yield between the deep tillage + gypsum treatment and the conventional + gypsum was that within the +1 in. deficit plots, deep tillage + gypsum treatment yielded 17% more grain than the conventional + gypsum (Table 3). There were no differences for the other irrigation treatments and the gypsum amended plots in each irrigation treatment. Again no effect on yield was observed in any gypsum amended treatments. Within all irrigation treatments, no clear differences in yields were found between deep tillage and deep tillage + gypsum treatments or between conventional and conventional + gypsum treatments (Table 3).

Within all soil treatments, the fully irrigated treatment resulted in higher yields than all other irrigation treatments, and the non-irrigated treatment resulted in lower yields than all other irrigation treatments. Thus no change in the irrigation recommendations for silt loam soils with a pan appear appropriate (Table 3).

Rohwer (Clay Soil Type). The fully irrigated plots received 11.7 in. water from three irrigation events compared to 10.3 in. water and two events for the +1 in. deficit, and 3.0 in. water and one event for the +2 in. deficit treatment (Table 1). There was good soil moisture until late R2 growth and the first irrigation occurred on 23 June 2015. The field received 5.30 in. rain from 3-6 July 2015 that caused flooding ranging from 3 to 20 in. deep due to blocked field drainage. The water receded by 10 July 2015 but data from several soil moisture sensors was lost. The soil moisture data showed greater moisture levels in the fully irrigated compared to the dryland areas as expected (Table 2). Insufficient data was salvaged to determine if any soil treatment effects on soil moisture profiles were present. There were no soil treatment effects on yield in 2015 (Table 3). Generally, yields of the fully irrigated and + 1 in. deficit were not significantly different, but dropped off considerably at the +2 in. deficit. Two irrigations nearly doubled yields compared to the dryland plots in 2015. Although the +2 in. deficit treatment only received one irrigation, it resulted in an average increase of 5 bu/acre per inch of water applied compared to 2.1 bu/acre-in applied water average of the other two irrigated treatments. The one irrigation event of the +2 in. deficit irrigation occurred at R5 growth. There was no significant difference in yield between fully irrigated treatments and +1 in. deficit for all soil treatments, indicating that using this deficit results in the same yield as the fully irrigated deficit, thus the current recommendation for clay soils could be adjusted without reduction in yield.

PRACTICAL APPLICATIONS

The findings indicate that deep tillage has real potential to improve furrow-irrigated soybean yields and in silt loam soils with a pan and a clay soil. In clay soils it appears that the deficit can be increased by an additional 1 in. deficit above the current recommendation and result the same yield with less water required to maintain yields. In the silt loam, deep tillage resulted in a significant increase in yield. Gypsum amendment did not result a significant treatment effect for yield in this study. Additional studies with more resolution are needed to determine if changes to current deficit recommendations for the atmometer are needed. Additionally, further study is needed to explain the resulting yield increase in silt loam soils and increase deficit in clay soils, due to deep tillage, this may be due to improved water holding from compaction removal.

ACKNOWLEDGEMENTS

Funding for this project was provided 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. Water applied and number of irrigations for 2015 Stuttgart (top) and Rohwer (bottom) respectively.

Irrigation Trt	Number of irrigations	Total Water Applied (inches)
Fully irrigated	7	18.0
+1 in. Deficit	4	10.1
+2 in. Deficit	3	7.9
Non-irrigated	0	0.0

Irrigation Trt	Number of irrigations	Total Water Applied (inches)
Fully irrigated	3	11.7
+1 in. Deficit	2	10.3
+2 in. Deficit	1	3.0
Non-irrigated	0	0.0

Table 2. Season average soil moistures (centibars) for Stuttgart 2015 across three depths (6 in., 18 in., and 30 in.) for each soil treatment at each irrigation level, and Rohwer 2015 averaged for a 24 in. deep profile for each soil treatment at irrigated and non-irrigated irrigation levels, respectively.

	Stuttgart Seasonal Average Soil Tension Centibars				
	--------------------Soil Treatment---------------				
Irrigation trt	**Ripped**	**Rip/Gyp**	**Gypsum**	**No treatment**	**Average**
Fully Irrigated	67.4	64.3	62.4	78.7	68.2
+1 in. Deficit	76.5	89.1	91.9	61.6	79.8
+2 in. Deficit	96.9	128.1	114.7	73.0	103.2
Non-irrigated	148.0	X	118.7	143.1	136.6
Average	97.2	93.8	96.9	89.1	

	Rohwer Seasonal Average Soil Tension in Centibars				
	--------------------Soil Treatment---------------				
Irrigation trt	**Ripped**	**Rip/Gyp**	**Gypsum**	**No treatment**	**Average**
Fully Irrigated	85	nd	44	nd	65
Non-irrigated	80	116	101	105	101
Average	83	116	73	105	

Table 3. Interaction effect between irrigation treatment and soil treatment on yield (bu/ac) and mean comparison. 2015 season, Stuttgart and Rohwer, Ark.

	Stuttgart Yield			
	Irrigation Treatment			
	Fully irrigated	**+1 in. deficit**	**+2 in. deficit**	**Non-irrigated**
Soil treatment	**Yield (bu/ac†)**			
	---------------------------- 2015 season ----------------------------			
Deep tillage	57.9 Aa*	49.8 Ba	48.4 Ba	24.6 Ca
Deep tillage + Gypsum (G)	56.1 Aab	49.3 Ba	44.1 Cb	21.8 Dab
Conventional + G	56.1 Aab	40.9 Bb	43.4 Bbc	19.8 Cb
Conventional	52.3 Ab	42.4 Bb	39.7 Bc	20.9 Cab
Std Err of LS Mean	1.1			

	Rohwer Yield			
	Irrigation Treatment			
	Fully irrigated	**+1 in. deficit**	**+2 in. deficit**	**Non-irrigated**
Soil treatment	**Yield (bu/ac)**			
	---------------------------- 2015 season ----------------------------			
Deep tillage	48.0 Aa†	49.4 Aa	37.7 Ba	25.7 Ba
Deep tillage + Gypsum (G)	48.8 Aa	46.7 Aab	36.4 Ba	25.9 Ca
Conventional + G	47.8 Aa	43.3 Ab	42.1 Aa	22.5 Ba
Conventional	43.7 Aa	44.0 Aab	37.3 Ba	21.0 Ca
Std Err of LS Mean	1.4			

† means followed by the same lowercase letter in the column and the same uppercase letter in the row, does not differ by Tukey's test at 5% probability.

Soil Property Differences among High- and Average-Yielding Areas of Soybean Fields in Arkansas

T.C. Adams[1], K.R. Brye[1], L.C. Purcell[1], and J. Ross[2]

ABSTRACT

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 2013, the state was split into seven geographic divisions for contest purposes. The objective of this study was to evaluate the effects of soil physical and chemical property differences on yield between high- and average-yielding areas in select soybean fields across Arkansas. Immediately prior to or just after soybean harvest in 2014, two locations in each of the seven geographic divisions within Arkansas with a yield-contest area in close proximity to an average-yield area were soil sampled. Samples were collected from the 0- to 4-in. and 4- to 8-in. depth increments in each high- and average-yield area and soil texture, bulk density (BD), soil pH (pH), electrical conductivity (EC), soil organic matter, and Mehlich-3 extractable nutrient concentrations were measured. Multiple regression analyses were performed to evaluate the relationships between yield and measured soil properties, averaged across soil depths, in the average- and high-yielding areas separately and combined. No soil properties were shared between the average-, high-yielding, and combined regression equations; but BD, sand, clay, pH, EC and Mg, Fe, and Zn concentrations were significant in two of the three equations. All regression equations were highly significant ($P < 0.0001$) and R^2 values were 0.79, 0.62, and 0.59 for the average-, high-yielding, and combined datasets. With careful characterization of soil properties in high-yielding, contest fields compared with typical, average-yielding fields, it is possible to identify key differences that allow for an extra yield bump in lower-yielding fields.

INTRODUCTION

In 1999, the Arkansas Soybean Promotion Board (ASPB) together with the Arkansas Soybean Association (ASA) initiated a yearly soybean yield contest, “Grow for the Green”. In 2011, the ASPB and ASA divided the contest entries into early-season, full-season, and double-crop production systems. Furthermore, in 2013, another change occurred when the state was split into seven geographic regions (Fig. 1), and an eighth, statewide, non-genetically-modified-organism category.

From 1999 to 2015, the average soybean yield for Arkansas increased from 1881 to 3427 kg ha^{-1} (USDA-NASS, 2015), and currently, there is a lack of information examining a multitude of soil characteristics that contribute to high-yielding soybean growth and productivity in Arkansas and beyond. With careful characterization of soil properties in high-yielding areas within fields compared with average-yielding areas in the same or adjacent fields, key differences could be identified that may explain the greater yields in certain areas and offer opportunities to better manage average-yielding areas for greater yields. Therefore, the objective of this study was to evaluate the effects of soil physical and chemical property differences on yield between high- and average-yielding areas throughout Arkansas.

PROCEDURES

In late-summer to early fall 2014, two producers in each of the seven regions were identified as willing cooperators 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. The two areas (i.e., the high- and average-yielding areas) per producer within a region were used for subsequent soil sampling purposes. The high-yielding areas were specifically managed for the yield contest, while the average-yielding areas may have been managed similarly or differently.

In each high- and average-yielding area and immediately before or just after soybean had been harvested, five sample points were established in a diamond formation, with three points in the same row approximately 203 ft apart, and two points perpendicular to the middle row approximately 125 ft in the opposite direction from the middle point of the middle row. At each point, soil samples were collected from the 0- to 4-in. and 4- to 8-in. depth intervals using a 1.8-in. diame-

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ter, 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 to pass a 0.08-in. mesh sieve. Soil pH and electrical conductivity (EC) were determined potentiometrically using a 1:2 soil mass:water volume mixture. Mehlich-3 extractable nutrient concentrations (i.e., P, K, Ca, Mg, S, Na, Fe, Mn, Zn, B, and Cu) were determined using a 1:10 soil mass:extractant solution volume ratio (Tucker, 1992) and analyzed by inductively coupled argon-plasma spectrometry (ICAP, Spectro Analytical Instruments, Spectro Arcos ICP, Kleve, Germany). Soil organic matter (SOM) concentration was determined by weight-loss-on-ignition at 360 °C for 2 h (Schulte and Hopkins, 1996), and particle-size analyses was conducted using a modified 12-h hydrometer method (Gee and Or, 2002). Total carbon (C) and nitrogen (N) concentrations were determined by high-temperature combustion using a VarioMax CN analyzer (Elementar Americas Inc., Mt. Laurel, N.J.). Yields from high-yielding areas were verified by the Arkansas Soybean Association or reported by the producers, and yields from average-yielding areas were reported by the producers. All soil properties were then averaged across depth for each sampling point.

Multiple regression analyses were conducted using the JMP mixed, stepwise fit model platform V. 12 Pro (SAS Institute, Inc., Cary, N.C.) to evaluate the relationship among yield and measured soil properties separately for the average- and high-yielding-area datasets and combined across yield areas. Significance was judged at $P < 0.05$.

RESULTS AND DISCUSSION

Regression equations for the average- and high-yielding areas and both areas combined were all highly significant ($P < 0.001$). Equations also had R^2 values of 0.79, 0.62, and 0.59 for the average-, high-yielding, and combined equations, respectively, indicating a large proportion of the variation in soybean yield was explained by measured soil physical and chemical properties.

Although no soil properties were shared among the average-, high-yielding, and combined multiple regression equations, several properties were shared between two of the three equations (Table 1). Bulk density (BD) had a negative effect, as evidenced by the negative coefficient estimate, in both the average-yielding and combined equations. As BD increases, soil compaction increases, thus negatively affecting effective rooting depth, total porosity, and water infiltration (USDA-NRCS, 2015a). Percent sand had a slight positive effect, as evidenced by the positive coefficient estimate, on yield in both the average-yielding and combined regression equations. Similarly, percent clay had a slight positive effect on yield in both the high-yielding and combined equations. Percent silt was excluded from analysis, as sand and clay have a greater effect on water retention in soils. Excessively sandy or clayey soils will limit yields as a result of a low water-holding capacity and poor drainage, respectively. Soil pH had a negative effect in the high-yielding regression equation, but a positive effect when average- and high-yielding areas were combined. Particular elements become unavailable in too acidic or alkaline environments but soybean prefers a small range of soil pH for optimal growth (USDA-NRCS, 2015b). Electrical conductivity (EC) had a strong positive effect in both the average-yielding and combined regression equations. Although EC is a measure of soil salinity, it has been correlated to concentrations of nitrate, potassium, sodium, chloride, and sulfate (USDA-NRCS, 2015c). Extractable soil magnesium had a slight negative effect in both the high-yielding and combined equations. Excessive magnesium is most likely due to groundwater irrigation with high concentrations of $Mg(HCO_3)^2$, common to areas in eastern Arkansas (UACES, 2014). Extractable soil iron also had a slight negative effect on yield for both the average-yielding and combined regression equations. Extractable soil zinc, however, had a slight negative effect in the average-yielding equation, but a slight positive effect in the high-yielding equation.

While many soil properties were shared between two of the three multiple regression equations, there were some properties only belonging to one of the regression equations (Table 1). Extractable soil phosphorous had a slight positive effect in the average-yielding equation. Phosphorous is one of the nutrients most commonly limiting crop growth, and P in plants is used for storage and transfer of energy produced by photosynthesis (USDA-NRCS, 2015d). Extractable soil calcium had a slight negative effect in the combined regression equation. Excessive calcium is more than likely a result of groundwater irrigation with high concentrations of $Ca(HCO_3)^2$, common to fields in eastern Arkansas (UACES, 2014). Extractable soil sulfur had a negative effect in the combined regression equation. Recently, sulfur deficiency has been recognized as a factor limiting crop production, especially on deep sandy soils in Arkansas (UACES, 2014). Extractable soil sodium had a positive effect in the combined regression equation. Although excessive sodium in soils can result in poor internal drainage and weakened soil structure, each cultivar of each crop has a particular salt tolerance (USDA-NRCS, 2015c). Extractable soil manganese had a slight positive effect in the average-yielding regression equation. Manganese regulates ureide levels, in which increasing the soil Mn supply increases ureide degradation, thereby improving sensitivity to drought (Vadez and Sinclair, 2002). Extractable soil copper had a positive effect on the combined regression equation. Although copper is a micronutrient essential for not only plant growth, but for soil functioning as well (Maderova et al., 2011), copper deficiencies have not been recognized in Arkansas (UACES, 2014). Extractable soil boron had a negative effect on the high-yielding regression equation. Boron toxicity in Arkansas can occur, most likely with soybean grown on soils with a pH < 6.0 and soil test boron greater than 2.5 mg kg^{-1} (UACES, 2014). Total carbon had a strong positive effect and total nitrogen a negative effect in the combined regression equation. Soil C and N are dependent on the amount of plant residues deposited or removed, the C and N concentrations in plant residues, and the rate at which C and N mineralize in soil (Wang and Sainju, 2014). Previous crop type, which varied in this study as either corn (*Zea mays* L.), rice (*Oryza sativa* L.), soybean, and fallow, affects the quantity and quality (i.e., C:N ratio) of residues returned to the soil and, therefore, resulting soil C and N levels. Extractable soil K and SOM were not significant parameters for any of the three regression equations.

PRACTICAL APPLICATIONS

Attempts to improve and/or maximize yield have focused on either the plant itself, through breeding, or the environment in which a crop is produced (i.e., management practices such as tillage and crop rotation). Additionally, studying specific soil properties associated with exceptionally high yields may help to meet the global demand for food as nations are struggling with food shortages and hunger. There is still an enormous of amount of potential information that can be gleaned from the suite of soil properties that this study will aim to elucidate from in-field observations. Through an enhanced understanding of soil properties in their own fields, producers may be able to determine which fields have the potential for increased productivity given appropriate management and resources, and which fields are unlikely to respond to increased management and resources.

ACKNOWLEDGEMENTS

Research for this project is funded by the Arkansas Soybean Promotion Board. We would also like to thank Johan Desrochers and William Smartt for their field and laboratory assistance. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Summary of soil property regression equation coefficients and associated *P*-values for average-yielding and high-yielding areas, and all areas combined for fields sampled in fall 2014, including overall regression model significance.

	Average		High		Combined	
Soil Property	Coefficient Estimate	*P*	Coefficient Estimate	*P*	Coefficient Estimate	*P*
BD†	-1929	0.005	-	-	-1736	0.026
Sand	22.2	< 0.001	-	-	29.5	< 0.001
Clay	-	-	66.7	< 0.001	37.9	< 0.000
pH	-	-	-286	0.007	344	0.004
EC	7002	< 0.001	-	-	6937	0.004
P	9.6	0.001	-		-	-
Ca	-	-	-	-	-0.6	0.012
Mg	-	-	-2.9	< 0.001	-3.3	< 0.001
S	-	-	-	-	-70.0	0.001
Na	-	-	-	-	32.5	< 0.001
Fe	-3.6	< 0.001	-	-	-2.6	0.005
Mn	4.3	< 0.001	-	-	-	-
Zn	-5.0	< 0.001	5.5	0.004	-	-
Cu	-	-	-	-	187	< 0.001
B	-	-	-532	0.002	-	-
TC	-	-	-	-	40398	< 0.001
TN	-	-	-	-	-2164	0.016
Intercept	5734	< 0.001	7090	< 0.001	2469	0.070
Model P-value	< 0.001		< 0.001		< 0.0001	
R^2	0.79		0.62		0.586	

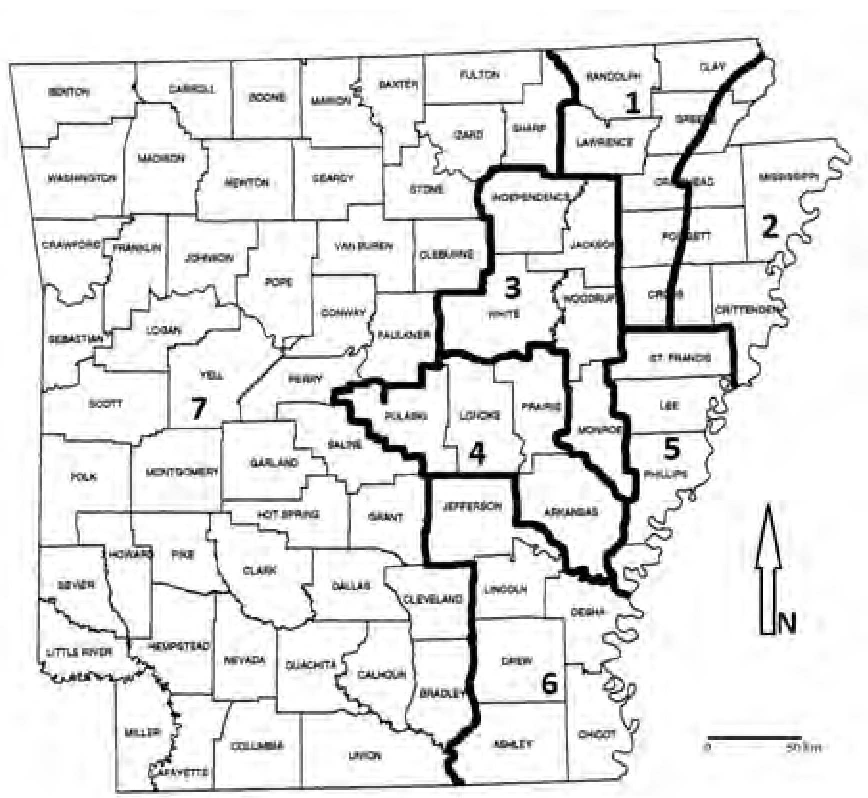

Fig. 1. Seven regions for the "Grow for the Green" contest sponsored by the Arkansas Soybean Promotion Board together with the Arkansas Soybean Association. Division 1: Northeast Delta; Division 2: Northeast; Division 3: White River Basin; Division 4: Central and Grand Prairie; Division 5: East Central Delta; Division 6: Southeast Delta; Division 7: Western.

Preliminary Evaluation of Long-Term Residue Management and Irrigation Practice Effects on Infiltration into a Loess Soil

K.R. Brye[1], J. Desrochers[1], M. Thompson[1], and R. Anderson[1]

ABSTRACT

A long history of intense row-crop agriculture in the Lower Mississippi River Delta region of eastern Arkansas has compromised the sustainability of groundwater resources throughout the region, in part due to the lack of significant groundwater recharge following substantial groundwater withdrawals for irrigated crop production. The objective of this field study was to evaluate the effects of long-term agricultural management practices (i.e., residue level, residue burning, irrigation, and tillage) on surface infiltration into a loess soil managed for 14 years in a wheat (*Triticum aestivum*)-soybean [*Glycine max* (L.) Merr.], double-crop production system in eastern Arkansas. Infiltration was measured over a 20-minute time period using a double-ring infiltrometer. Results indicate that, while infiltration was similar among most of the 16 management practice combinations, infiltration was 1.7 times greater ($P < 0.05$) in the irrigated-non-burned-no-tillage-high-residue-level treatment combination than in all other treatment combinations, with the exception of the irrigated-non-burned-no-tillage-low-residue-level treatment combination which was statistically similar. Adopting alternative agricultural management practices in a wheat-soybean, double-crop production system in eastern Arkansas, such as no-tillage and non-burning of crop residues, as compared to the traditional practices of conventional tillage following residue burning, can help reduce the dependency on irrigation and conserve water, while at the same time improve potential groundwater recharge so that soybean and other crop production enterprises can remain sustainable for future generations.

INTRODUCTION

Groundwater aquifer levels in the Lower Mississippi River Delta region of eastern Arkansas are declining due to extensive withdrawals for agricultural irrigation purposes (Scott et al., 1998). Some agricultural row crops, particularly rice (*Oryza sativa* L.), use a tremendous amount of water to produce optimum yields, where a large proportion of the water needed to maintain three to four months of flooded-soil conditions comes from groundwater along with surface water (i.e., from reservoirs). In the absence of sufficient and timely natural rainfall during the growing season, even non-flooded-soil-requiring crops, such as corn (*Zea mays* L.) and soybean require extensive irrigation to produce optimal yields. However, a compounding factor with extensive groundwater withdrawals for agricultural irrigation is the lack of regional groundwater recharge to replenish the water removed for irrigation.

The Lower Mississippi River Delta region of eastern Arkansas has a long history of intense row-crop agricultural production. One common management practice associated with intensive row-crop agriculture is tillage. Tillage is necessary to prepare a seedbed for planting and is often conducted to manage crop residues and as a cultural practice for weed control. However, tillage also is extremely disruptive to near-surface soil physical properties, such as structure, bulk density, water-stable aggregation, and the soil organic matter concentration. Through its effects on soil physical properties, repeated annual tillage tends to reduce porosity and water absorption capacity (Verkler et al., 2008), which leads to increased runoff and decreased infiltration (Harper et al., 2008). Repeated annual tillage also tends to create a plow pan, a relatively thin soil zone below the depth of mixing that tends to be compacted and limits vertical water movement and infiltration. Furthermore, fine-textured loessial and alluvial parent materials that comprise a large portion of the Lower Mississippi River Delta region of eastern Arkansas are prone to crusting and erosion if left bare, both of which further exacerbate the lack of recharge area to replenish groundwater withdrawn for agricultural irrigation.

The objective of this field study was to evaluate the effects of long-term agricultural management practices (i.e., residue level, residue burning, irrigation, and tillage) on surface infiltration into a loess soil managed for 14 years in a wheat-soybean, double-crop production system in eastern Arkansas. It was hypothesized that the combination of no-tillage and non-residue burning would result in greater surface infiltration rates than the combination of conventional tillage and residue burning, which is the common management practice combination throughout much of the Lower Mississippi River Delta region of eastern Arkansas.

PROCEDURES

On 7 November 2015, after several days of sufficient rainfall to uniformly wet the soil throughout the entire study area, double-ring infiltration measurements, with a 6-in. inside diameter inner ring, were conducted in triplicate in

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various soil management systems at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Branch Experiment Station near Marianna, Ark. Similar to the procedures used by Jacobs et al. (2015), infiltration measurements were conducted in 16 different soil management practice combinations (i.e., tillage and no-tillage, residue burning and non-burning, high and low residue level, and irrigated and dryland production) in a long-term wheat-soybean, double-crop production system that had been managed consistently since Spring 2002. Details of the annual plot management and treatment imposition were reported by Amuri et al. (2008) and Norman et al. (2016). In each of 48 plots, 10-ft. wide by 20-ft. long, a double-ring infiltrometer was inserted to a depth of approximately 1 in. After insertion, the volumetric soil water content in the top 2.4 in. was measured using a Theta Probe (Dynamax, Inc., Houston, Texas) in triplicate within the outer ring of the double-ring infiltrometer. The height of water inside the inner ring was recorded immediately after filling up the inner ring with tap water and then thereafter at 1, 2, 3, 4, 5, 8, 10, 12, 15, 18, and 20 minutes from the start of the each infiltration measurement. The total infiltration rate over the 20-minute time period was calculated and reported as in./h. An analysis of variance was conducted using SAS V. 9.3 (SAS Institute, Inc., Cary, N.C.), assuming a completely random design, to evaluate the effect of management practice combination (i.e., 16 different combinations replicated three times throughout the study area) on total infiltration rate. Means were separated by least significant difference at the $P < 0.05$ level.

RESULTS AND DISCUSSION

At the time of measurements, the soil water content in the top 2.4 in. ranged from 15% to 28% (v/v) and averaged 23% (v/v) throughout the entire study area. Thus, the soil at the site was relatively moist and reasonably water conductive due to the recent preceding rainfall. As a result, the total infiltration rate over the 20-minute measurement period ranged from <0.01 in./h (0.015 cm/h) in one replication of the non-irrigated-no-burn-conventional-tillage-low-residue-level treatment combination to 0.4 in./h (0.99 cm/h) in one replication of the irrigated-no-burn-no-tillage-high-residue-level treatment combination throughout the study area.

Based on formal statistical analyses, residue and water management practice combinations associated with a long-term wheat-soybean, double-crop system significantly affected ($P < 0.001$) infiltration into a loess-derived soil with a silt-loam surface texture in the Lower Mississippi River Delta region of eastern Arkansas. Total infiltration rate over the 20-minute measurement interval was more than 1.7 times greater in the irrigated-non-burned-no-tillage-high-residue-level treatment combination than in all other treatment combinations, with the exception of the irrigated-non-burned-no-tillage-low-residue-level treatment combination which was statistically similar (Fig. 1). Regardless of residue level, the residue covered soil surface left behind from the lack of burning coupled with the non-tilled plow layer resulted in a set of soil surface characteristics that facilitated more infiltration than when the soil surface was disturbed by burning and tillage. The irrigated nature of the non-burned/no-tillage combination, regardless of residue level, likely created a more well-structured, near-surface soil environment with more water-stable aggregates than did the dryland/non-irrigated counterpart treatment combination due to greater soil organic matter inputs as a result of greater biomass production (Norman et al., 2016). The results of the current study support those reported by Verkler et al. (2008), who documented reduced soil moisture loss under no-tillage and non-burning compared to conventional tillage and residue burning treatments in the same plots that were used for the current study.

PRACTICAL APPLICATIONS

Greater surface infiltration of water, either from natural rainfall or irrigation, into certain residue and irrigation management practice combinations will result in less off-site transport of sediment (i.e., soil erosion) and sediment-adsorbed nutrients and/or chemicals. However, equally important will be the concomitant increased soil water content and increased potential for groundwater recharge in areas of historically intense cultivated agricultural production that currently contribute very little to groundwater recharge in the Lower Mississippi River Delta region of eastern Arkansas. Adopting alternative agricultural management practices in a wheat-soybean, double-crop production system in eastern Arkansas, such as no-tillage and non-burning of crop residues, as compared to the traditional practices of conventional tillage following residue burning, can help reduce the dependency on irrigation and conserve water, while at the same time build up the groundwater reserves so that soybean and other crop production enterprises can remain sustainable for future generations.

ACKNOWLEDGEMENTS

This project was funded by the Arkansas Soybean Promotion Board and supported by the University of Arkansas System Division of Agriculture. Johan Desrochers, Matt Thompson, Rebecca Anderson, Marya McKee, and Casey Rector are gratefully acknowledged for their field assistance.

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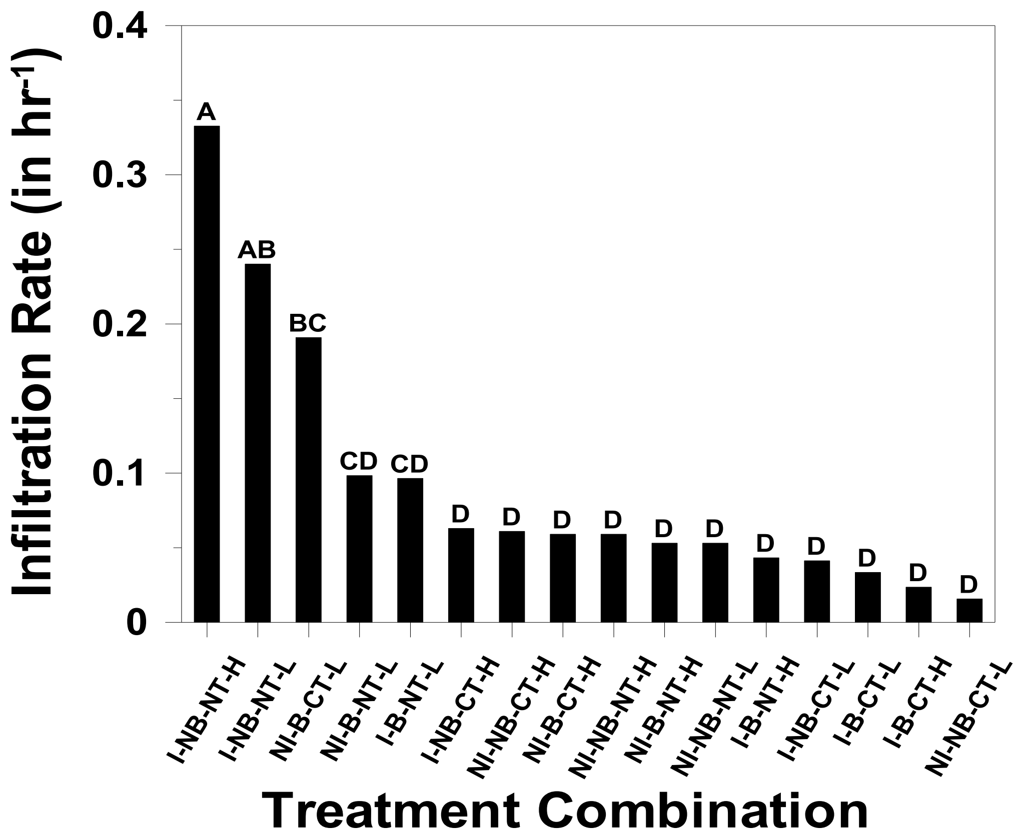

Fig. 1. Management practice combination effects on infiltration using a double-ring infiltrometer. Bars with different letters are significantly different at the *P* < 0.05 level. Treatment abbreviations are defined as follows: irrigated (I), non-irrigated (NI), burned residue (B), non-burned residue (NB), no-tillage (NT), conventional tillage (CT), high wheat residue level (H), and low wheat residue level (L).

Cover Crop Species and Planting Date Influence Soybean Yield

T. L. Roberts[1], W.J. Ross[2], K.L. Hoegenauer[1], J. Shafer[1], C. Greub[1], S. Williamson[1] and C. Scott[1]

ABSTRACT

Soybean [*Glycine max* (L.) Merr.] is an integral part of Arkansas' agricultural sector, both in terms of revenue and also for its rotational benefits. The influence of cover crop species and cover crop planting date on soybean yield was the primary focus of this research project. Single-seeded cover crops of tillage radish (*Raphanus sativus* L.), wheat (*Triticum aestivum* L.), cereal rye (*Secale cereale*), and Austrian Winter Pea (*Pisum sativum* subsp. arvense) were evaluated over a range of five planting dates from 15 Sept. through 15 Nov. at the University of Arkansas System Division of Agriculture's Pinetree Research Station (PTRS) and the Rohwer Research Station (RRS) during 2014-2015. The highest overall soybean yields within each cover crop species were seen for the earliest cover crop planting dates and soybean yield tended to decline as cover crop planting increased was delayed to 15 Nov. The magnitude of yield difference for the earliest and latest planting date tended to be approximately 20 bu/ac for all cover crops and locations. The data presented in this paper indicate that the earlier cover crops are established, the greater the benefit to soybean yield and performance. The high biomass production of cover crops such as wheat and cereal rye can have both positive and negative effects as the soil moisture retention in these cover crops were high enough at PTRS that soybean planting was delayed approximately 1 month past the planting of soybean following tillage radish or Austrian Winter Peas. Selection of cover crop species and establishment are two key components of successful cover crop implementation into soybean production systems in Arkansas.

INTRODUCTION

Soybean is a major component of all Arkansas crop rotations. Recent work in the upper Midwest on cover crops has sparked a renewed interest in their use for weed suppression, water retention and erosion control in Arkansas. Many of the major surface water impairments in Arkansas are related to sedimentation and turbidity, which are a direct result of erosion from land surfaces. If fall weather conditions are optimal, much of the field preparation for spring planting is done immediately following harvest in the fall. Seasonal rainfall accumulation during this fallow period from mid-October through mid-April for most fields is significant to promote >3 tons/ac of soil loss through erosional processes (Blanco and Lal, 2008). Cover crops can also increase soil organic matter, improve soil structure and prevent crusting, which all can play a major role in soybean establishment and yield potential (Karlen et al., 1994). Cover crops have not been used extensively in Arkansas within the last 30 years, and changes in crop rotations and production practices have also evolved greatly during this time. Developing cover crop management guidelines for Arkansas producers is a pivotal step in protecting our natural resources, while maintaining or increasing our soybean yields.

PROCEDURES

Trials were established at the University of Arkansas System Division of Agriculture's Pinetree Research Station (PTRS) and Rohwer Research Station (RRS) during fall of 2014. Cover crops were drill-seeded as close as possible to the proposed planting dates (within 7 days) of 15 Sept., 1 Oct., 15 Oct., 1 Nov., and 15 Nov. at each location. The cereal rye and wheat cover crops were drill-seeded at 45 lb seed/ac, and the tillage radish was seeded at 5 lb seed/ac with the addition of 4 nitrogen (N) rates at emergence to investigate the effects of planting date and fall N rate on cover crop establishment and soybean yield. Austrian Winter Pea, being a legume does not require N fertilization, so the effects of planting date and seeding rate were investigated for this cover crop with seeding rates being 20, 40, 60 and 80 lb seed/ac. All cover crops were established in 9 rows spaced 7-in. apart. All plots were 20-ft. in length. Cover crops were terminated in mid-March at the RRS and mid-April at the PTRS. The cover crop biomass had a profound effect on soil moisture conditions at each location and the unusually wet spring led to very different planting dates for soybean following each cover crop at PTRS, but had no effect on soybean planting date at RRS (Table 1).

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 and flood irrigation at PTRS. Soybean seeds were treated with Cruiser Maxx seed treatment prior to planting and were no-till, drill-seeded at 155,000 seed/ac in 20-ft. plots to match the cover crop treatment structure.

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Each experiment was a randomized complete block design with four blocks. The analysis of variance (ANOVA) model was analyzed as a factorial design with planting date and N rate for cereal rye, wheat and tillage radish and planting date and seeding rate for Austrian Winter Pea. 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 (LSD) method with an alpha level of 0.05.

RESULTS AND DISCUSSION

The ANOVA indicated that there were no statistically significant interactions of either planting date and N rate or planting date and seeding rate for all crops at both locations. The only significant factor that affected soybean yield was cover crop planting date for all crops at both locations except for cereal rye at PTRS, where there were no statistically significant factors that affected soybean yield (Table 2).

For the purposes of this study, soybean yield across cover crops species was not compared since at the PTRS location there were large differences in soybean planting date based on cover crops species (Table 1). For the tillage radish and Austrian Winter Pea cover crops at PTRS, the cover crop biomass matted and decayed quickly allowing for drier soil conditions and earlier planting of soybean. However, the large amounts of biomass produced by the wheat and cereal rye cover crops at PTRS and their slow decomposition were excellent at retaining soil moisture to the extent that it took roughly 1 month longer to establish the soybean in these cover crops. The large differences seen across cover crops at the PTRS location are most likely a combination of the cover crop species effect as well as the planting date effect.

Although we do not have the ability to predict rainfall frequency and quantity well in advance of soybean planting, it is important to note that the biomass production and breakdown differences amongst cover crops species can be a benefit as well as a hindrance. In years with above average rainfall, cover crops that produce large amounts of biomass may retain soil moisture to the extent that it limits planting opportunities. However, these large amounts of biomass can help retain soil moisture, prevent weed emergence and decrease irrigation rates in drier than normal springs.

For the PTRS location, soybean yield was primarily affected by cover crop planting date, with earlier cover crop planting dates tending to result in higher soybean yields (Table 2). Overall, the highest yields seen at the PTRS location were following Austrian Winter Pea planted 15 Sept and averaged 103 bushels/ac. These high yields are most likely due to the earlier planting date, residual N generated by the leguminous cover crop and ideal water management in the small plot trial. Although soybean yields were highest following Austrian Winter Pea, this may not be a viable crop rotation as they are both legumes and can harbor many of the same pests including nematodes. Similar to Austrian Winter Pea, soybean yields following tillage radish were maximized for the earliest planting date of tillage radish and declined as the planting dates of radishes increased to 15 Nov. Although there were some slight statistical differences in yield for soybean following wheat and some slight numerical differences for soybean following cereal rye, the yield differences across planting dates were not nearly as significant as for Austrian Winter Pea or tillage radish. For soybean following tillage radish and Austrian Winter Pea at the PTRS, the earlier planting date of the cover crop tended to result in higher soybean yields.

At the RRS, there was a significant cover crop planting date effect on soybean yield for all cover crop species. The highest soybean yields for following all cover crop species were seen at the earliest cover crop planting date of 15 Sept., and yields declined as the cover crop planting date increased was delayed to 15 Nov. (Table 3). The magnitude of soybean yield difference (~20 bushels/ac) between the earliest and latest cover crop planting dates was similar for all cover crop species planted at RRS as well as the tillage radish and Austrian Winter Pea planted at PTRS. Although the yields at RRS were significantly less than those reported at PTRS, the trends in cover crop planting date and its effect on soybean yield were quite similar. Earlier planting dates of cover crops tended to produce better stands and higher fall biomass regardless of N fertilizer rate or seeding rate. The later planting dates often times had less stand and biomass prior to winter dormancy and even resulted in less biomass production prior to termination in the spring. Fall growth and overall cover crop performance appears to affect soybean yield the following year, as earlier planted, more vigorous cover crops tended to result in higher soybean yields.

PRACTICAL APPLICATIONS

The data presented in this paper indicates that cover crop planting date regardless of species and location, affects soybean yield. The fall growth, establishment and performance of the cover crop directly impacts soybean yield. Cover crops can be a huge tool for Arkansas producers to help combat herbicide resistant weeds as well as increase water conservation efforts. Earlier planting dates of cover crops in the fall tended to lead to higher soybean yields the following year. Therefore, the more time and effort that is put into planning and establishing winter cover crops in the fall, the more positive benefits can be expected to soybean yields the following year.

ACKNOWLEDGEMENTS

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

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Table 1. Selected soil and agronomic management information for cover crop establishment trials conducted in 2015 in Arkansas.

Information or Event	Pinetree Research Station	Rohwer Research Station
Soil series	Calloway silt loam	Hebert silt loam
Previous crop	Soybean	Soybean
Row width (inches)	7	7
Seed rate (seed number/acre)	155,000	155,000
Soybean Seeding Date (Following Wheat)	13 July	14 May
Soybean Seeding Date (Following Cereal Rye)	13 July	14 May
Soybean Seeding Date (Following Austrian Winter Pea)	15 June	14 May
Soybean Seeding Date (Following Tillage Radish)	13 June	14 May

Table 2. Soybean yield as influenced by cover crop establishment date at the Pinetree Research Station (PTRS) in 2015.

Establishment date	Wheat	Cereal Rye	Tillage Radish	Austrian Winter Pea
	-----	-----	Yield (bu/ac)	-----
15 Sept	52	57	77	103
1 Oct	48	56	76	102
15 Oct	46	57	68	96
1 Nov	45	56	60	84
15 Nov	49	56	54	85
LSD $_{0.05}$	3.0	NS	5.3	8.5

Table 3. Soybean yield as influenced by cover crop establishment date at the Rohwer Research Station (RRS) in 2015.

Establishment date	Wheat	Cereal Rye	Tillage Radish	Austrian Winter Pea
	-----	-----	Yield (bu/ac)	-----
15 Sept	42	44	39	42
1 Oct	38	40	33	40
15 Oct	36	30	25	35
1 Nov	27	27	24	26
15 Nov	26	25	22	25
LSD $_{0.05}$	3.5	4.5	3.9	3.3

Validation of Soil-Test Based Fertilizer Recommendations for Soybean

M. Fryer[1], N.A. Slaton[1], T.L. Roberts[1], R.E. DeLong[1], T. Richmond[1], J. Hedge[2], and S. Hayes[2]

ABSTRACT

Soil-test interpretations need to be accurate to maximize crop yields and farm profits and justify the use of variable rate fertilizer applications. Our research objective was to validate the accuracy of the University of Arkansas System Division of Agriculture's soil-test based phosphorus (STP) and potassium (STK) fertilizer recommendations for irrigated soybean. The study included six treatments of various combinations of two phosphorous (P) rates (0 and 60 lb P_2O_5 /ac) and four potassium (K) rates (0, 60, 120, and 160 lb K_2O/ac) plus a no-fertilizer control. Comparisons were made to examine the STP and STK accuracy including P fertilizer alone compared to no fertilizer and K fertilizer alone compared to no fertilizer. The current interpretations of STP and STK were 33% and 83% accurate, respectively, in predicting soybean yield response to fertilization. All of the STP interpretation errors occurred in the suboptimal soil-test levels where a yield response to fertilization was expected but yield was not changed by fertilization suggesting that soil-test level definitions for P need to be lowered to improve recommendation accuracy.

INTRODUCTION

The adoption rate of precision agriculture technologies, specifically variable rate fertilizer applications, is increasing (Erickson and Widmar, 2015), but literature that quantifies the accuracy of the fertilizer recommendations is scarce. Factors such as spatial nutrient variability, time of sample collection, sample depth, and previous crop can all affect soil-test interpretations. Validating the accuracy of fertilizer recommendations is a crucial step in agronomic and environmental nutrient management.

A project examining the accuracy of the University of Arkansas System Division of Agriculture (UASDA) soil-test-based phosphorus (STP) and potassium (STK) interpretations for irrigated soybean was initiated in 2013 to pinpoint soil-test levels that contain the most interpretation errors and to test if the recommended fertilizer rate maximizes yield (Fryer, 2015). The overall objective of this report is to examine the frequency and magnitude of soybean yield responses to phosphorous (P) and potassium (K) fertilization within the existing framework of soil-test interpretations for trials established in 2015. For this report, the five UASDA soil-test levels (Very Low, Low, Medium, Optimum, and Above Optimum) were condensed into three levels [Suboptimal (SO), Medium (M), and Optimal (O)]. Suboptimal and Medium soil-test levels were considered to be responsive to fertilizer, while Optimal soil-test levels were not expected to benefit from fertilizer.

PROCEDURES

Two or three preliminary composite soil samples (0-4 in. depth) from the general research area in each of five selected fields were taken in March or early April. Research was located at the Lonn Man Cotton Research Station (LMCRS), the Pine Tree Research Station (PTRS) 2 locations, the Northeast Research and Extension Cener (NEREC), and the Rice Research Station (RRS). Preliminary soil sample pH (2:1 water:soil ratio) and Mehlich-3 analyses (analyzed by inductively coupled plasma spectroscopy) were performed to determine the average STP and STK levels, fertilizer recommendation, and treatment structure for each study. Selected soil and agronomic information as well as the name of each site is presented in Table 1.

Each study contained two fertilizer-P rates (0 and 60 lb P_2O_5/ac) and four fertilizer-K rates, making up six treatments: 1) the recommended P_2O_5 rate, and 0 lb K_2O/acre; 2) the recommended P_2O_5 rate, and 60 lb K_2O/ac; 3) the recommended P_2O_5 rate, and 120 lb K_2O/ac; 4) the recommended P_2O_5 rate, and 160 lb K_2O/ac; 5) the alternate P_2O_5 rate, and the recommended K_2O rate; and 6) no P_2O_5 or K_2O. Fertilizer was applied preplant or shortly after planting to individual soybean plots that encompassed 270 ft^2 to 300 ft^2. Four sites were furrow irrigated and planted on raised beds, except for the PTRS-F24 which was planted in narrow rows and flood irrigated (Table 2). At establishment, additional 0-4 in. deep soil samples consisting of five soil cores (1 in. diameter) were taken from each of the no-fertilizer control plots in each replicate (n = 6) in every study and processed as described by Fryer (2015). Selected soil chemical properties are presented in Table 2.

Each study was organized as a randomized complete block design with six blocks. Comparisons among treatments were made with single-degree-of-freedom contrast statements using the MIXED procedure in SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.) and evaluated at three levels of

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significance ($P \leq 0.05$, 0.10, and 0.25). Grain yield differences were evaluated using yields of soybean that received i) the recommended fertilizer-P and -K rates, ii) P fertilizer alone, and iii) the recommended fertilizer-K rate alone, all compared to soybean that received no fertilizer-P or -K. Yield responses to fertilization were categorized as an increase, no change, or a decrease. We hypothesized that yield increases to fertilization would be measured on Suboptimal (more frequent and greater response) and Medium (less frequent and smaller response) testing soils, but fertilization would result in no yield change on soil testing in the Optimal level. A yield decrease was never expected from fertilizer applications, but was included in our hypothesis testing.

RESULTS AND DISCUSSION

Three loamy soils (LMCRS, PTRS-F24, and PTRS-F4) and two clayey soils (NEREC and RRS) were included in the soybean fertility studies conducted in 2015. The sites that had Suboptimal STK and were expected to respond positively to P fertilization included LMCRS, PTRS-F4 and PTRS-F24 (Table 3). The NEREC had Medium STP but Optimal STK. The LMCRS, PTRS-F24, and PTRS-F4 each had a Suboptimal STK level and K fertilization was expected to result in a yield increase. The RRS and NEREC, both clayey soils, had Optimal STK and were not expected to respond to K. Soil at only the RRS had an Optimal STP level.

Regardless of the STP level and the significance level used to interpret the yield results, soybean yield was not affected by P fertilization at any of the five sites compared to the yield of soybean that received no fertilizer-P (P-only, Table 3). The yield of soybean grown at two (LMCRS and PTRS-F24; $P \leq 0.05$) of the three sites with a Suboptimal STK level was increased from K fertilization when compared to no fertilizer (K only, Table 3). No yield benefit from fertilizer-K was expected at the NEREC and RRS and yield was not affected by K fertilization indicating that the recommendation to not apply K on the clayey soils high in STK was correct. When evaluating the recommended P and K fertilizer rates compared to no fertilizer, the three sites where both P and K were recommended showed yield increases to fertilizer-P and -K (LMCRS, PTRS-F24, and PTRS-F4; $P \leq 0.05$) compared to no fertilizer.

PRACTICAL APPLICATIONS

The overall accuracy of the UASDA soil-test interpretations for the five research trials is presented in Table 4. The level of significance to interpret the yield responses had no effect on the accuracy of either STP, STK, or the overall recommendation indicating that there was a clear response to fertilization at each site. Trials completed in 2013 and 2014 showed that the significance level did play a role in the level of accuracy primarily for interpreting yield response to K fertilization (Fryer, 2015). In 2015, the STP interpretations were 33% accurate in predicting soybean response to fertilizer-P. All of the error occurred in the Suboptimal STP level where yield increases to P fertilization were expected but were not measured. The existing recommendations for STP were accurate only when yield increases from fertilizer were not expected. Soil-test K interpretations were 83% accurate, but none of the sites had a Medium STK level. Like STP, the lone error in interpreting STK occurred in the Suboptimal level where yield was expected to increase from K fertilization. The overall P and/or K recommendation was examined and showed to be 67% accurate. The recommendation was 100% accurate when both P and K, or no fertilizer was recommended. The error occurred only when P fertilizer was recommended. These results largely agree with results reported by Fryer (2015) indicating that soils with Optimal soil-test levels rarely benefit from fertilization and that the thresholds that define STP levels need to be redefined by lowering the critical STP value that triggers a P fertilizer recommendation. Reducing the critical STP from 35 ppm to 25 ppm could save growers money on P fertilizer without influencing soybean yield.

ACKNOWLEDGEMENTS

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

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Table 1. Selected soil and agronomic information for five soybean fertilization trials conducted at multiple sites during 2015.

Site [a]	Soil Series	Variety	Row Width	Planting date	----------Previous Crop and Fertilizer [b]--------		
			in.		Crop	lb P_2O_5/ac	lb K_2O/ac
LMCRS	Convent	Armor 55-R22	38	8 May	Grain Sorghum	0	0
PTRS-F24	Calhoun	Armor 47-R13	15	23 June	Grain Sorghum	0	0
PTRS-F4	Calloway	Armor 47-R13	30	10 June	Corn	0	0
NEREC	Sharkey	Delta Grow 4767 LL	38	6 May	Soybean	0	0
RRS	Sharkey & Desha	Armor 55-R22	38	8 May	Corn	0	0

[a] Abbreviations include: LMCRS, Lon Mann Cotton Research Station; NEREC, Northeast Research and Extension Center; PTRS, Pine Tree Research Station; RRS, Rohwer Research Station. The letters and numbers after the site abbreviation represent the field name.

[b] Crop grown and fertilizer applied during the 2014 growing season.

Table 2. Selected soil chemical property means (n = 6) from the 0-4 in. depth of five phosphorous (P) and potassium (K) soybean fertilization trials conducted during 2015.

Site [a]	Soil Chemical Properties, 4-in. sample depth							
	pH	P	K	Ca	Mg	Mn	Zn	SOM
		------------	------------	ppm	------------	------------		(%)
LMCRS	7.0	23 (2)	69 (5)	1085	232	233	2.4	2.0
PTRS-F24	8.0	8 (1)	51 (7)	2206	291	324	1.8	2.5
PTRS-F4	7.0	26 (3)	70 (9)	1641	241	358	1.7	2.3
NEREC	7.0	31 (4)	252 (24)	4155	884	34	4.0	4.0
RRS	7.1	46 (4)	247 (26)	3880	798	150	3.4	3.3

[a] Abbreviations include: LMCRS, Lon Mann Cotton Research Station; NEREC, Northeast Research and Extension Center; PTRS, Pine Tree Research Station; RRS, Rohwer Research Station. The letters and numbers after the site abbreviation represent the field name.

[b] The value in parentheses following each P and K mean represents the standard deviation.

Table 3. Expected soybean yield response to phosphorous (P), potassium (K), or P and K fertilization compared to a no P and K control at five research sites established during 2015.

Site [a]	Recommended Fertilizer P_2O_5	K_2O	Expected Yield Response [b] P	K	Check Yield [c]	Yield Response to [d] P only	K only	Recommended [e]
	-------- (lb/ac) --------				(bu/ac)	---------------Yield difference (*P-value*)-----------		
LMCRS	60	120	Yes	Yes	46	-1 (0.63)	5 (<0.01)	7 (<0.01)
PTRS-F24	60	160	Yes	Yes	50	-1 (0.45)	6 (<0.01)	6 (<0.01)
PTRS-F4	60	120	Yes	Yes	47	1 (0.72)	1 (0.47)	3 (0.05)
NEREC [f]	60	0	Yes	No	52	0 (0.86)	1 (0.33)	0 (0.86)
RRS	0	0	No	No	56	1 (0.50)	-1 (0.61)	NA

[a] Abbreviations include: LMCRS, Lon Mann Cotton Research Station; NEREC, Northeast Research and Extension Center; PTRS, Pine Tree Research Station; RRS, Rohwer Research Station. The letters and numbers after the site abbreviation represent the field name.

[b] Expected Response: Yes, soil-test level is Sub-Optimal (Very Low or Low), or Medium; and No, soil-test level is Optimal (Optimum or Above Optimum).

[c] Check yield, the mean yield of soybean that received no P or K.

[d] Yield response: P only, single-degree-of-freedom contrast comparing the yield with no P or K to P fertilizer; K only, single-degree-of-freedom contrast comparing the yield with no P or K to the recommended K fertilizer rate; and Recommended, single-degree-of-freedom contrast comparing the yield with no P or K to that of rice fertilized with the recommended rates of both P and K fertilizer.

[e] 'NA' indicates that the comparison was not possible.

[f] 'P only' and 'Recommended' comparisons are the same.

Table 4. Site responses and accuracy of the soil-test prediction of soybean yield response (see Table 3) to fertilization at five research sites in 2015 as defined by soil-test phosphorus (STP) and potassium (STK) level and the level of significance at which statistical comparisons were made.

Nutrient evaluation [a]	Soil-test level [b]	Soil-test Concentration	Total sites	Interpreted at *P*-value ≤0.05 [c]			Interpreted at *P*-value ≤0.10 [c]			Interpreted at *P*-value ≤0.25 [c]		
				I	NC	D	I	NC	D	I	NC	D
		(ppm)		---- Number of sites [d] ----			---- Number of sites [d] ----			--- Number of sites [d] ---		
P-only	SO	≤25	2	0	2	0	0	2	0	0	2	0
P-only	M	26-35	2	0	2	0	0	2	0	0	2	0
P-only	O	≥36	1	0	1	0	0	1	0	0	1	0
Overall STP Accuracy (%) [e]				------------ 33% ------------			------------ 33% ------------			----------- 33% -----------		
K-only	SO	≤90	3	2	1	0	2	1	0	2	1	0
K-only	M	91-130	0	--	--	--	--	--	--	--	--	--
K-only	O	≥176	2	0	2	0	0	2	0	0	2	0
Overall STK Accuracy (%) [e]				------------ 83% ------------			------------ 83% ------------			----------- 83% -----------		
P&K		Recommended [f]	3	3	0	0	3	0	0	3	0	0
P-only		Recommended [f]	1	0	1	0	0	1	0	0	1	0
None		Recommended [f]	1	0	1	0	0	1	0	0	1	0
Recommendation Accuracy (%) [e]				------------ 67% ------------			------------ 67% ------------			----------- 67% -----------		

[a] Evaluation of the response to fertilized with 'P-only', 'K-only', the Recommended 'P&K', and the Recommended 'P-only' all compared to no fertilizer. 'None' is compared to P-only and K-only.

[b] Soil-test level abbreviations: SO, Suboptimum; M, Medium; O, Optimum.

[c] Abbreviations: I, yield Increase; NC, No Change in yield; D, yield Decrease.

[d] Shaded cells represent the correct yield response to fertilizer applications. Note: small and less frequent yield increases were expected in the M soil-test levels compared to the SO soil-test levels.

[e] Accuracy calculated as the weighted average for the three soil-test levels where the number of sites with the correct outcome (see footnote 'd') is divided by the number of total sites. Overall STK Accuracy was calculated using only two soil-test levels because no site fell within the Medium soil-test level.

[f] The evaluation of the recommended P and K fertilizer rates interpreted from the soil-test nutrient concentration at each site.

Potential Nitrogen Fertilizer Savings when Grain Sorghum is Rotated with Soybean

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

ABSTRACT

The benefits of crop rotations over monocultures have been documented extensively. However, there is limited information on the potential fertilizer savings possible when grain sorghum [*Sorghum bicolor* (L.) Moench] is rotated with soybean [*Glycine max* (L.) Merr.] under an Arkansas production system. A series of studies were established to determine the nitrogen (N) credits possible to grain sorghum under such a rotation at two locations in Arkansas. Grain sorghum was grown in rotation with soybean or grain sorghum. Soil samples showed a residual nitrate-N level 3 times higher at a location where soybean was planted the preceding year, compared to the nitrate-N level at a site where grain sorghum had been grown the previous year. Treatments consisted of N rates equivalent to 0, 40, 80, 120, 160, and 200 lb N/ac. Under the conditions of these studies, the N rate needed to maximize yield was 120 lb N/ac for the monoculture, compared to 80 lb/ac when grain sorghum was rotated with soybean. These results, although preliminary, indicate that grain sorghum when planted following soybean can produce optimal yields with significantly less N fertilizer.

INTRODUCTION

Low commodity prices make the evaluation of practices that have the ability to reduce total production costs of utmost importance. Nitrogen (N) fixation by legumes can significantly contribute to the nutrition needs of a rotational crop such as grain sorghum or corn [*Zea mays* (L.)]. There are several factors that affect the ability of a plant to fix atmospheric N, including fertility status, soil pH, and proper inoculum among others. The amount of N returned to the soil for the subsequent crop can vary significantly. For instance, Varvel and Wilhelm (2003) reported an estimated contribution ranging between 50-70 lb N/ac per year in a long-term rotation experiment with soybean. Typical N rates for grain sorghum vary among soil texture, but they are in the range of 120-160 lb/ac, so a reduction of 50-70 lb N/ac can result in significant N fertilizer savings for a grain sorghum crop following soybean in rotation. The objective of this study was to evaluate the potential N fertilizer savings when grain sorghum is grown in rotation with soybean.

PROCEDURES

Research plots were established at the University of Arkansas System Division of Agriculture's Rohwer Research Station (RRS) near Rohwer, and the Lon Mann Cotton Research Station (LMCS), near Marianna during 2015. The soils are mapped as a Desha silt loam at RRS and as Memphis silt loam at LMCS. The preceding crops at RRS were soybean and grain sorghum, while at LMCS was soybean only.

Soil samples were collected during the spring of each year, from the shoulder of existing beds or before beds were formed. One composite soil sample from the 0-6 in. soil depth was collected from each location, each year. The soil was extracted for plant-available nutrients using the Mehlich-3 procedure (Table 1). Nitrate-N was determined with an ion-selective electrode, and pH was measured in a 1:2 soil: water (vol:vol) mixture. Soil fertility levels were optimum. During 2014, 0.5 lb Zn/ac, as zinc sulfate, was applied as a foliar spray using a backpack sprayer.

Nitrogen treatments were 0, 40, 80, 120, 160, and 200 lb N/ac. Each plot consisted of four 38-in. wide and 25-ft. long rows with treatments arranged in a randomized complete block design and replicated five times. Urea coated with Agrotain™ (an urease inhibitor) was the nitrogen form used and was applied in a 2-way split, with 40 lb N/ac surface-applied at planting and the remaining surface-applied 25-30 days after planting.

Grain sorghum variety Pioneer 84G62 was planted to achieve a population of 90,000 plants per acre. Furrow irrigation and weed and insect control was completed according to University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) recommendations. At maturity, the two middle rows of each plot were harvested with a plot combine equipped with a weigh-system and grain moisture meter. Yields were adjusted to 15.5% moisture content for statistical analysis. Mean separations were performed using SAS (SAS Institute, Inc., Cary, N.C.) software and, when appropriate, means were separated with the Fisher's Protected least significant difference method at a significance level of 0.10.

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[2] Program Technician, Department of Crop, Soil and Environmental Sciences, Lonn Mann Cotton Research Station, Marianna.

RESULTS AND DISCUSSION

Soil test results from the different locations and rotations show sufficient levels for potassium (K) and phosphorus (P), according to CES recommendations. Residual soil nitrate levels, however, varied significantly. For instance, the field at RRS where soybean had been grown in 2014 shows nitrate-N level of 46 ppm, compared to only 10 ppm for the field where grain sorghum was planted previously. The nitrate-N level at LMCS, where soybean was the preceding crop, was 24 ppm.

Table 2 shows average grain yield at the two locations, according to crop rotation. Under continuous grain sorghum (RRS, GS:GS), the yield response to N fertilizer was obvious, with yields maximizing at approximately 120 lb N/ac. The average yield from the control treatment (0 lb N/ac) was only 33 bu/ac. Such yield contrasts with the 87 bu/ac yield observed for the control treatment for the S:GS rotation at RRS. A very similar yield (88 bu/ac) was observed for the control plots (0 lb N/ac) at the LMCS location. The N rate required to maximize GS yields, when rotated with soybean, appears to be around 80 lb/ac. Such rate was 120 lb N/ac for the LMCS location. A simple "back of the envelope" calculation shows that the yield of the control treatment, when GS was rotated with soybean, was equivalent to the yield obtained when 80 lb N/ac was applied in the GS:GS rotation.

PRACTICAL APPLICATIONS

This preliminary evaluation shows the potential for significant N fertilizer savings when grain sorghum is rotated after soybean, probably due to the ability of soybean to fix atmospheric nitrogen. The information obtained under the conditions of these studies is not sufficient to provide clear guidelines on the magnitude of the N credits to consider when deciding on how much to reduce the typical N fertilizer rate for GS. At this moment, it is probably safe to assume that a reduction of 30 lb N/ac, when grain sorghum is rotated after soybean, should still be enough to maximize yield potentials. However, more research is needed to develop more precise guidelines to account for the residual N remaining after a soybean crop.

ACKNOWLEDGEMENTS

The authors would like to thank the Arkansas Soybean Promotion Board for providing partial support of this research. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Selected soil chemical properties from the 0- to 6-inch soil depth at the Rohwer Research Station (RRS) and Lon Mann Cotton Research Station (LMCS). Composite soil samples were collected in the spring, before planting.

Location	Previous Crop	pH	NO_3-N	P	K	Zn
			ppm	ppm	ppm	ppm
RRS	Soybean	6.8	46	62	140	3.5
RRS	Grain Sorghum	6.6	10	50	271	4.2
LMCS	Soybean	7.3	24	52	131	1.6

Table 2. Grain sorghum yield means according to crop rotation (GS = grain sorghum; S = soybean) in trials conducted at the Rohwer Research Station (RRS) and Lon Mann Cotton Research Station (LMCS).

Location and Rotation	RRS GS:GS	RRS S:GS	LMCS S:GS
N Rate	-----	Yield bu/ac	-----
0	33 d†	87 b	88 b
40	68 c	94 b	87 b
80	89 b	128 a	108a
120	119 a	137 a	119 a
160	122 a	137 a	115 a
200	126 a	139 a	122 a
C.V., %	10	11	11
LSD	14	14	14

† Means within a column followed by different lowercase letters indicate statistical difference.

Soybean Science Challenge: Our Growing Value

K. Ballard[1] and L. Wilson[1]

ABSTRACT

The internet is a tool that has rapidly changed the public perception of farming. The shift in attitudes has been especially prevalent among our youth. The Soybean Science Challenge was launched in response to the Arkansas Soybean Promotion Board's identified desire to sponsor effective youth education supporting an increased awareness of the importance of soybean production to Arkansas and career opportunities for students in agricultural fields. The Soybean Science Challenge (SSC) is an educational program engaging high school science students and teachers in "real-world," Arkansas-specific soybean science education through original curriculum and a continuum of educational methods which include: classroom instruction, lab instruction, online and virtual live-streaming education, personal mentoring, student-led research and corresponding award recognition, and partnerships with state and national educators, agencies and the popular media. This program supports Arkansas STEM (science, technology, engineering and mathematics) educational goals, is aligned with the Next Generation Science Standards (NGSS), and engages high-school students in active learning and the co-creation of knowledge through support of applied student research.

INTRODUCTION

Since 1959, ACT, Inc. has been a leader in measuring college and career readiness trends. According to the 2014 Arkansas Condition of STEM (science, technology, engineering, mathematics) report, only 3 (0%) of the 978 participating Arkansas high school students indicated an interest in agronomy and crop science as a major/occupation (ACT, 2014). In the 2015 ACT Condition of STEM report, a 2% increase in expressed interest in agronomy and crop science as a major/occupation was reported, not a particularly significant increase, but at least an indication that information about the viability of a career in agriculture is beginning to crack open a door (ACT, 2015).

The Soybean Science Challenge (SSC) opens doors to support a higher level of student learning and discovery regarding the importance of soybean production to the state of Arkansas and the science undergirding agricultural sustainability. More than a single "event" strategy is required for this level of student learning. The program is supported by research-based instructional design strategies which facilitate a deeper understanding of why agricultural sustainability is personally relevant to a student's individual future. The SSC online curriculum is peer-reviewed and updated annually. The program's success is based on the investment of significant time establishing working relationships with Arkansas schools, science teachers, STEM coordinators and state education department officials. The online teacher course and resources are approved by the Arkansas Department of Education for professional in-service credit which is renewed annually.

PROCEDURES

The Soybean Science Challenge is first and foremost a real-life challenge to students. Students' progress through a six-level online course requires successful completion of interactive learning challenges and quizzes in order to achieve the next level. Pre- and post-course quizzes qualitatively measure student learning. Only after students score 80% or greater on the final quiz can they progress to the research challenge. Student research at this juncture is supported by vetted science-based resources, the soybean seed store, and individual consultations with science teachers and students to provide personalized mentoring support for the most highly motivated students and teachers. University of Arkansas System Division of Agriculture scientists have been instrumental in delivering customized and age-appropriate instruction and mentoring to student scientists. Teams of scientists and educators have produced original educational products and expanded the reach of soybean education by delivering online courses, instructional labs, Zoom webinar sessions, educational print and digital curriculum and products, and Virtual Field Trips to bring entire classrooms into fields and research labs, making agriculture a real-life first-hand experience for large groups of Arkansas youth.

Process and outcome/impact evaluation of the Soybean Science Challenge was also an integral part of the program

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implementation plan. A key evaluation goal involved listening closely to emerging issues and needs from diverse stakeholders to plan appropriate products and programs. Nine different evaluation methods were used: needs assessment, participant data, and pre/post test knowledge testing, online surveys, interviews with teachers and student researchers and use of digital analytics.

Educational methods included individual mentoring, face-to-face classroom/lab instruction, virtual class sessions, virtual field trip, on-campus research internship, evaluation of student research projects and award presentations, teacher training/development of educational print and digital curriculum and products.

RESULTS AND DISCUSSION

A series of key factors contribute to the evidence of real learning-based results in the Soybean Science Challenge Program. On the Soybean Science Challenge pre-test, student learning and knowledge regarding soybeans averaged 43%; however, the post-test average was 94%, a 118% increase in student knowledge of soybeans as a result of taking the online course.

An evaluation of the 2015 Virtual Field Trip (VFT) "Gardens of the Galaxy: A Battle of Food for the Future" showed a school participation increase of 333% and a student participation increase of 387% over the 2014 VFT. Participants numbered over 2000 from 65 schools with two from other states; 41 Arkansas counties were represented and 304 questions were submitted by students. (Fig. 1)

Teacher post-event evaluations from the 2015 VFT show that 100% of participating teachers surveyed (48) stated they "understand more about the role of GMOs in support of agricultural sustainability"; 100% of teachers also agreed they "understand more about plant research" and over 97% agreed they "understand more about the external stress that impact crops."

The Challenge's distribution reach through newspapers, magazines and other publications was 148,787; three national television and radio Rural Free Delivery Network interviews reached 71 million combined households. Direct contacts with teachers through Constant Contact, the ARSTEM Science Listserv, Arkansas Educational Cooperatives and individual science teacher emails were over 14,500 (Table 1).

The SSC demonstrated that Arkansas high-school science teachers are looking for ways to motivate and reward student inquiry. They value opportunities for their students to engage with working scientists in real time (i.e. project advisement and mentoring, judging research projects, virtual classes and field trips). Virtual education provides a promising platform for efficiently and effectively engaging a large number of students and scientists in real time. Finally, a blended educational strategy is critical to provide multiple avenues for student learning and for high-level learning opportunities for gifted and talented students.

PRACTICAL APPLICATIONS

The Soybean Science Challenge makes agricultural sustainability relevant and meaningful for Arkansas high-school students. The success of this project speaks to a significant void that has existed for engaging, timely and relatable education for high-school students that asks them to contribute to the discussion and to actively participate in relevant scholarship. Students have responded in remarkable ways. The greatest value to the soybean industry is that we are now present "at the table" as the attitudes of our youth are being shaped. Students statewide are being challenged to understand the complexity of the evolving science undergirding production agriculture and to critically think about issues regarding food, fuel, feed and agricultural sustainability that will directly impact their futures.

ACKNOWLEDGMENTS

This educational project was supported by the Arkansas Soybean Promotion Board through a partnership with the University of Arkansas System Division of Agriculture and the Cooperative Extension Service.

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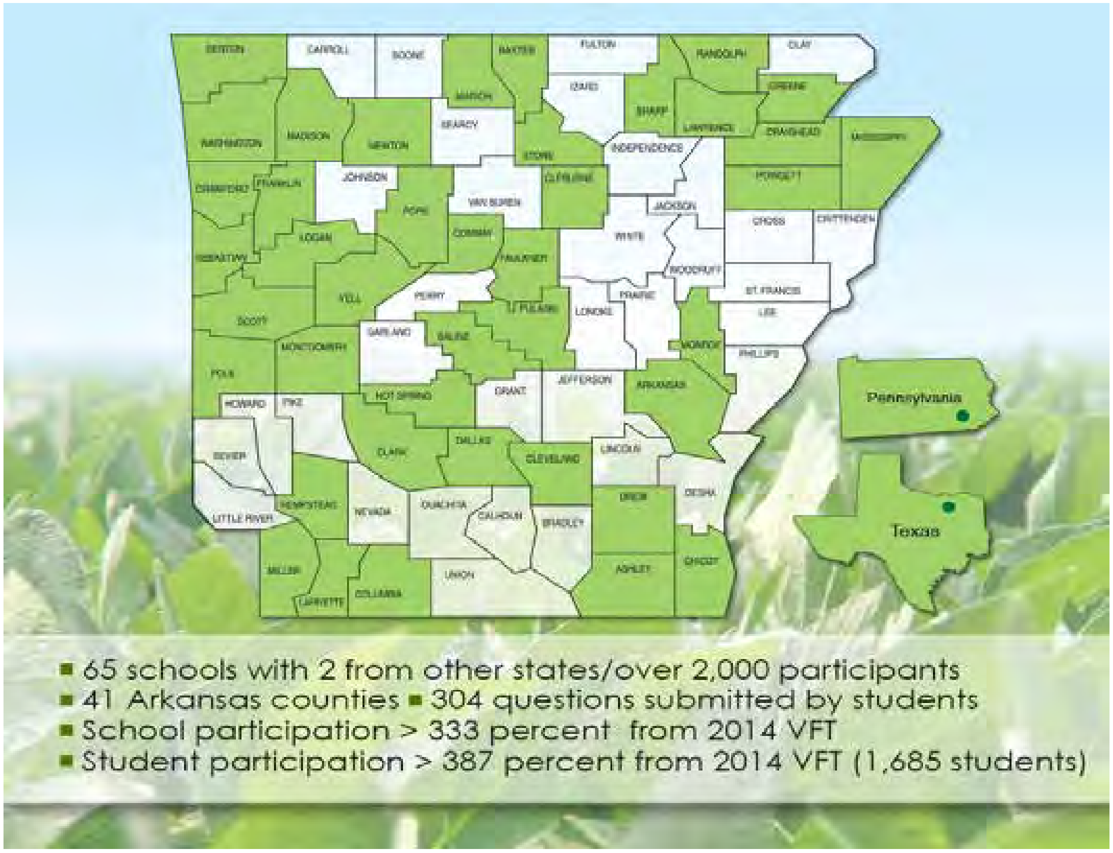

Fig. 1. 2015 Virtual field trip participant comparisons

Table 1. Soybean Science Challenge products, audience, activities and impact.

Product	Target Audience	Activities & Impact
Soybean Science Challenge Online Course – Student	9-12th grade	**86** Students enrolled and **34** completed
Soybean Science Challenge Online Course – Teacher In-Service (7 Hrs.)	Science Teachers	**20** Teachers enrolled and **4** completed
Soybean Science Challenge Online Course – Teacher Resources	Science Teachers	**35** Users
Partnered with 5 regional science fairs and the Arkansas State Science Fair. Attended and judged six Arkansas science fairs.	Science Teachers/Students **Science Fairs**	**7** articles published or posted in newspapers or on websites**47** individual student projects with **six** student awards; Totaling **$2500**
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 ARSTEM List Serve; ASTA List Serve, AR Educational Cooperatives, personal emails; mailed to **285** Arkansas Science Teachers
Research Internship for 2014 SSC Winner Amerah Taleb with Dr. Sami Dridi, Center for Excellence for Poultry Science, at the University of Arkansas at Fayetteville	High School Science Student	Amerah spent three weeks learning lab procedures and initiated her research exploring "Molecular Mechanism of Soybean Isoflavones in Bone Cells."
Soybean Science Challenge Winners Video – **U of A Division of Agriculture Cooperative Extension**	High School Science Students/Teachers	Posted CES web page
Participated in Arkansas State University – Heber Springs Earth Day, April 22.	First – 12th grade Teachers and Students	Over **1200** youth attended; directly educated **525** students. Extension provided soybean plants and edamame and soy smoothies were sampled. **Fifty (50)** elementary school and **20** high school teachers' packets with fact sheets, soy products and lesson activities were distributed with edamame tasting activities included in each.
Participated in Springdale High School Biology Field Day Labs on May 6. Created Soybean Lab Activity Sheet and taught 6 labs with 8 interactive soybean stations	Science Teachers/Students	**147** students directly educated about eight different soybean topics, including an edamame taste testing activity.
2015 Soybean Science Challenge Brochure	9-12th Grade High School Students/ Teachers	ARSTEM List Serve; ASTA List Serve; AR Educational Cooperatives; personal emails; SOYWhatsUP CES web page; the Miraclebean.com; conferences;
Soybean Science Challenge Seed Store announcement	High School Students/Teachers	ASTA List Serve; AR Educational Cooperatives; personal emails; SOYWhatsUP CES web page; the Miraclebean.com; conferences; mailed to **285** Arkansas Science Teachers.
Soybean Science Challenge Seed Packets	Science Teachers/Students	Over **750** distributed at Educational Conferences and other Soybean Science Challenge events, i.e. Rice Expo, AR Curriculum Conference, ASU-Heber Springs Earth Day and Springfield HS Biology Field Day; **55** seed orders from teachers/students.

Continued on next page.

Table 1. Continued.

Soybean Science Challenge Health and Nutrition Fact Sheets and Smoothie Recipes	Science Teachers/Students	Distributed in **50** elementary and **20** high school teachers packets at ASU-Heber Spring Earth Day events, conferences and direct mail to teachers.
Soy Science Explosion Booklet – Soybean Science Challenge Progress	ASPB; CES	Mailed to ASPB and CES
Soy What's Up? Flier on resources found on the CES Soybean Science Challenge webpage – www.uaex.edu/soywhatsup	Science Teachers/Students	ASTA List Serve; AR Educational Cooperatives; personal emails; SOYWhatsUP CES web page; the Miraclebean.com; conferences; mailed to **285** Arkansas Science Teachers.
Media Coverage of Soybean Science Challenge Events	Science Research, Agriculture Educators, and general public	**14** articles in newspapers, magazines and other publications (Distribution **148,787**; **3** National RFD interviews (TV – **50** Million households; Radio – **21** million households); Featured in Delta Farm Press Blog (Distribution **18,245**)

Development of an Online Course: Future of Biotechnology Crops

J.C. Robinson[1] and J.W. Ross[2]

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 that are produced by research institutions, learners have few reliable fact-based sources on the subject. Learners increasingly seek information via the internet. By developing an online course, we are providing material in the most palatable form for a large majority of people. The online biotechnology course developed covers basic knowledge, science, abilities of biotechnology, and the impact it can have on the Arkansas and global soybean industry. Components of the online course were peer reviewed, pilot tested, and launched to the general public. The materials developed for the online course were repurposed to develop an online professional development course for high school science teachers. This online professional development course also provided science educators with classroom resources. Classroom resources offer teachers the necessary materials to teach students about biotechnology using research-based curricula.

INTRODUCTION

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. The current interest in online information by the public and the growing popularity of free online courses offer an opportunity to teach a large audience the facts about biotechnology crops. The University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) can help educate the non-farming public about biotechnology, which is concerned about possible effects on human health or environmental quality. The Cooperative Extension Service objectively presents benefits and risks of biotechnologies, enabling people to make more informed decisions. (Hoban, 1989). A key audience that needs access to research-based, accurate information are educators and young people. Educators and young people today have little first-hand knowledge of biotechnology. This is the first generation that has unlimited access to digital information about agriculture, but few resources that help them filter accurate from inaccurate information. Educators who impact these students and future consumers and household decision-makers need access to accurate, science based information. Researchers from CES and The University of Arkansas System Division of Agriculture's Agricultural Experiment Station (AES) have researched-based curricula to share with the public and science teachers. Effective design for such training will maximize the likelihood that the teachers will use the materials in their classrooms (Konen and Horton, 2000). The changing requirements and expectations of classroom educators led us to provide educational materials that help decrease the knowledge gaps of Arkansas high school science teachers and students related to biotechnology. In Arkansas, teachers are required to maintain 6 days of professional development hours. This 36 hour continuing education requirement is a state minimum with some school districts requiring even more hours of its teachers. This project seeks to help create a reasonable link between what teachers need and what CES and AES researchers have to offer in the area of biotechnology.

PROCEDURES

An online course was developed and pilot-tested by 13 members of the general public and University of Arkansas System Division of Agriculture personnel. Pilot-testers identified needed changes and had some technical issues, as well as made suggestions to improve the course. These changes and suggestions were addressed and the course was successfully launched. The three module titles in the course cover 1) biotechnology in the field; 2) biotechnology in retail stores; and 3) biotechnology around the world. The course and lessons are viewable on numerous devices including PC, Mac, iPad, iPhone, Android mobile devices, and tablets.

The one hour interactive modular course was developed using accepted adult-learning methods and format. The course is hosted on a Moodle platform accessible via the Internet http://courses.uaex.edu/login/index.php. The course requires a user id and password, available to anyone who creates an account. New users have to create an account first, and instructions are on the login webpage. Content was provided by our science cooperators, who currently teach biotechnology principles and facts at the University of Arkansas. We adapted the content for the general public and

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adult learner levels of 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. The modules specifically address biotechnology use and best management practices in the field, nutrition and food safety information for consumers, as well as future trends in biotechnology crops worldwide—using soybean as the model crop (Fig. 1).

Online course materials were re-purposed to develop educational materials to support the Arkansas student education core proficiency standards for Arkansas high-school science teachers to utilize in the classroom. Science teachers for grades 9-12 were the target audience for the materials. A course guide indicated which Arkansas education standards and Next Generation Science Standards each lesson met. Lesson plans, classroom activities, presentations, and pre- and post-test evaluations were developed for each lesson in the course (Fig. 2). Teachers were able to download and use these materials in the classroom.

RESULTS AND DISCUSSION

Recently, eleven people have self-enrolled in the course. Course evaluation results show that 100% of respondents agree or strongly agree that the course content was appropriate for online learning, that the content was engaging, and that the course was well organized and easy to follow. Most respondents indicated that their knowledge increased in the following areas of biotechnology as a result of completing the course: arguments about food labels for products that contain GMO's, risks and benefits associated with biotechnology crops, biotechnology crops for livestock consumption, and biotechnology crops in other countries. Of these initial external learners, 60% of participants indicated that their opinion of biotechnology increased positively a little, and 20% indicated that their opinion of biotechnology increased positively a lot.

Online lessons and materials have also been used to develop an online professional development course for Arkansas high school science teachers to earn continuing education units (CEU). Arkansas teachers are required to complete 32 hours of continuing education or professional development hours each year. This course provides teachers the opportunity to complete three hours of CEU credits and provides classroom materials based on research-based content. Course developers proceeded to gain approval of the online course for continuing education credits from the Arkansas Department of Education.

PRACTICAL APPLICATIONS

An educated consumer is a powerful resource for agriculture. The widely held concerns about biotechnology are compounded by misinformation available online. 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 soybean to growers. If this trend continues to grow in the U.S., the outcomes here with regard to continued science-based progress in agriculture could be detrimental. For the agriculture industry, these outcomes could negatively impact the future challenge of feeding the world that is coming within many of our lifetimes. The belief that biotechnology crops, 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. Most of the current outreach effort about biotechnology is provided by companies who profit from it, so many people consider this effort untrustworthy. The current interest in online information by the public and the growing popularity of free online courses offer an opportunity to teach a large audience the facts about biotechnology crops. Progress will ultimately rest in the minds of the consuming public, and we believe there is great value that those minds know the facts.

ACKNOWLEDGEMENTS

The authors would like to thank the Arkansas Soybean Promotion Board for their funding of this research. Support was also provided by the University of Arkansas System Division of Agriculture.

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Module 1: In the Field

Objectives:

- Explain components of biotech field production in the United States
- Understand the cultivation process of biotech crops

First, we will watch a cool video showcasing soybeans, the foundation crop for future lessons, understand the effects of biotechnology on the soil, and explore water conservation efforts and biotech efficiency in production and cultivation. Click on "Soil and Water" below to begin.

Second, we will discuss famous soybean seed breakthroughs with the help of biotechnology. Then we will take a look at the benefits of increasing yields, understand the quality of products produced, and explore safety factors for humans and animals. Click on "Seeds" below to begin.

Third, we will check out the news on soybean disease-prevention breakthroughs. We will chat about how they came about, discuss why there is a need for these breakthroughs, and check out how biotechnology has been instrumental in the development of US agriculture. Click on "Disease Prevention" below to begin.

1. "Soil and Water" Interactive Lesson
   - NY Times Article: How I got converted to G.M.O. Food
   - Washington Post: Proof He's The Science Guy
2. "Seeds" Interactive Lesson
   - 2015 Arkansas Soybean Quick Facts
   - Arkansas Soybean Production Handbook
   - ABC's of Soybeans
3. "Human Disease Prevention" Interactive Lesson
   - Super Soy Cookies - P. Allen Smith
   - 60 Minutes: Killing Cancer Using a Re-engineered Polio Virus

Fig. 1. Example of the online course module: biotechnology in the field.

Navigating the Course-Start Here

- Teacher Instructions on Navigating the Course

Teacher Resources

- Biotechnology Standards & Curriculum Guide

Answer Key

Module 1-Pre-Tests & Post-Tests

- Module 1 Answers In Bold
- Module 2 Answers in Bold
- Module 3 Answers In Bold

Fig. 2. Example of teacher resources from the online biotechnology course.

Economic Analysis of the 2015 Arkansas Soybean Research Verification Program

C.R. Stark, Jr.[1]

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 2015 season results continue to confirm that yields can be increased by the use of irrigation. The Roundup Ready®/furrow-irrigation system generated the highest average revenue for the second straight year. Center-pivot systems, as expected, had highest average total costs and highest average fixed costs. Return to land and management on the one conventional furrow system field slightly exceeded the average of the eleven Roundup Ready/furrow-irrigation system.

INTRODUCTION

The Arkansas Soybean Research Verification Program (SRVP) originated in 1983 with an 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. The SRVP coordinators record input rates and production practices throughout the growing season including official yield measures at harvest. A state extension economist compiles the data into the 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

Eighteen cooperating soybean producers from across Arkansas provided input quantities and production practices utilized in the 2015 growing season. A state average soybean market price was estimated by compiling daily forward booking and cash market prices for the 2015 crop. The collection period was 1 Jan. through 31 Oct. for the weekly soybean market report published on the Arkansas Row Crops Blog (Stark, 2015). Data was entered into the 2015 Arkansas soybean enterprise budgets for each respective production system (Flanders, 2015). 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 2015 (Laughlin and Spurlock, 2016). Summary reports, by field, were generated and compiled to generate system results.

RESULTS AND DISCUSSION

The eighteen fields in the 2015 SRVP spanned five different production/irrigation systems (Table 1). Two of the system combinations utilized Roundup Ready® (RR) technology seed. One system used Liberty Link® (LL) seed and the final two systems had conventional seed. Eleven 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 one field was 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 16.0 to 67.9 bu/ac. Weighted average yield per field across all systems was 62.35 bu/ac. Irrigation was clearly a differentiating factor with the seventeen irrigated fields averaging 65.1 versus the 16.0 bu/ac yield in the lone non-irrigated field. Highest system yield was 67.9 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 2015 crop averaged $9.32 /bu over the period of 1 Jan.-1 Oct., 2015. This statewide average price was $1.89/bu lower than

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the $11.21 price of the same period in 2014. Market price multiplied by yield gave field revenues. No grade reductions or premiums were included. Highest average revenue per acre was $633.00 for the Roundup Ready/furrow-irrigation system.

Variable costs across all systems had a weighted average of $265.55, a decline of $11.67 from 2014, and ranged from $124.40 to $345.47/ac. Conventional/furrow irrigation system fields had total variable costs that were 15% to 18% lower than the Roundup Ready and Liberty Link irrigated systems. Fixed costs across all systems had a weighted average of $69.45 and ranged from $39.57 to $105.18/ac. Highest fixed costs, as expected, were found in the center pivot systems with an average of $89.20 versus $72.10 across Roundup Ready/furrow-irrigation systems, the second highest average.

Combination of the variable costs and fixed costs with revenue values allowed calculations of returns to land and management. The weighted average of return to land and management across all fields was $246.10/ac, a decline of $83.98 from 2014. The highest return to land and management was found on the one conventional/furrow-irrigation field with $295.17/ac. Roundup Ready/furrow-irrigation system fields generated a return to land and management of $286.62. An interesting observation was that conventional/furrow-irrigation system fields changed very little in return to land and management per acre from 2014 ($292.03) to 2015 ($295.17), while herbicide trait systems declined by a much greater percentage. These results should be carefully studied since only a limited number of fields were present each year in the conventional system.

PRACTICAL APPLICATIONS

The results of state research verification programs can provide valuable information to producers statewide. Comparisons across production systems can be made, but should be done with limited generalization due to the small number of fields in most of the systems. 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.

ACKNOWLEDGEMENTS

The author wishes 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 Mr. Chris Grimes and Mr. Chad Norton, Arkansas Soybean Research Verification Program Coordinators, and Dr. 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, 2015.

Production System	Roundup Ready	Roundup Ready	Liberty Link	Conventional	Conventional
Irrigation System	**Furrow**	**Center Pivot**	**Furrow**	**Furrow**	**None**
Number of Fields	**11**	**2**	**3**	**1**	**1**
	---------------------------	---------------*(Average per ac)*	----------------	----------------	----------------
Yield (bu)	67.9	58.0	59.8	63.8	16.0
Revenue ($)	633.00	540.56	557.34	594.62	149.12
Total Variable Costs ($)	274.28	282.01	281.14	231.02	124.40
Total Fixed Costs ($)	72.10	89.20	56.89	68.43	39.57
Total Costs ($)	346.38	371.21	338.03	299.45	163.97
Returns to Land and Management ($)	286.62	169.36	219.30	295.17	-14.85

Source: Grimes et al., 2014.

2016 Soybean Enterprise Budgets and Production Economic Analysis

W.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 Cooperative Extension Service recommendations or information from producers for their production practices. The budget program is utilized to conduct economic analysis of field data from 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, 2015). 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 2015. Representative prices for machinery and equipment are based on contacts with Arkansas dealers and industry list prices (Deere & Company, 2015; MSU, 2015). Revenue in crop enterprise budgets is the product of expected yields from following University of Arkansas System Division of Agriculture's Cooperative Extension Service recommended practices under optimal growing conditions and projected commodity prices.

RESULTS AND DISCUSSION

The University of Arkansas System Division of Agriculture's 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 Soybean 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 climactic conditions. Analyses are for generalized circumstances 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

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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 furrow-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 $105.55/ac. 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 actual production history (APH) yield of 49.5/ac. and an assumed projected price of $9.50/bu, input costs could be insured at selected coverage levels greater than 58%. Production expenses represent what is commonly termed as "out-of-pocket costs," and could be insured at coverage levels greater than 65%. Total specified expenses could be insured at coverage levels of 89%.

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 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.

ACKNOWLEDGEMENTS

This research is made possible by funding from the Arkansas Soybean Research and Promotion Board. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. 2015 Summary of revenue and expenses, furrow-irrigated soybeans, per acre and 1000 acres.

Revenue	Per Acre	Farm	Crop Insurance Information	Per Acre
Acres	1	1000	**Enter for Farm**	
Yield (bu)	55.0	55,000	APH Yield	49.5
Price ($/bu)	9.50	9.50	Projected Price	9.50
Grower Share	100%	100%		
Total Crop Revenue	**522.50**	**522,500**	**Revenue**	**470.25**
Expenses			**Percent of Revenue**	
Seed	88.80	88,800		19%
Fertilizers & Nutrients	32.21	32,207		7%
Chemicals	107.12	107,124		23%
Custom Applications	14.00	14,000		3%
Diesel Fuel, Field Activities	7.79	7792		2%
Irrigation Energy Costs	17.72	17,717		4%
Other Inputs	3.50	3500		1%
Input Costs	**271.14**	**271,139**		**58%**
Fees	0.00	0		0%
Crop Insurance	7.00	7000		1%
Repairs & Maintenance, Includes Employee Labor	16.54	16,545		4%
Labor, Field Activities	10.66	10,662		2%
Production Expenses	**305.35**	**305,345**		**65%**
Interest	7.25	7252		2%
Post-harvest Expenses	16.36	16,363		3%
Custom Harvest	0.00	0		0%
Total Operating Expenses	**328.96**	**328,960**		
Returns to Operating Expenses	**193.54**	**193,540**		
Cash Land Rent	0.00	0		0%
Capital Recovery & Fixed Costs	87.99	87,988		19%
Total Specified Expenses	**416.95**	**416,948**		
Returns to Specified Expenses	**105.55**	**105,552**		
Operating Expenses/bu	5.98	5.98		
Total Specified Expenses/bu	7.58	7.58		

Simulation of Equilibrium Moisture Content Controlled Natural Air, In-bin drying and Storage of Soybean Seed for Arkansas Weather Conditions

G.G. Atungulu[1], G. Olatunde[1], and S. Sadaka[2]

ABSTRACT

The objective for this study was to mathematically simulate natural air in-bin drying of soybean seed and determine the effects of drying strategy on drying duration, final moisture content (MC), percent overdrying and drying cost. Simulations were performed using five fan control strategies comprised of continuous natural air (CNA), natural air day only (NADO), natural air night only (NANO), equilibrium moisture content (EMC) controlled natural air (EMC-NA), and air EMC controlled with supplemental heating (EMCH), at five different airflow rates ranging from 1.04 to 5.20 $m^{-3}min\text{-}t^{-1}$, (1 to 5 cfm bu^{-1}, respectively) for soybean seed at initial MC of 16% wet basis (w.b.). Twenty years (1995-2014) of weather information of ambient air temperature and relative humidity for Stuttgart, Arkansas, was procured and used as input data for the simulation the study. The result showed that drying duration, final seed MC, percent overdrying, and drying cost were significantly affected by airflow rate and the drying strategies employed.

INTRODUCTION

Traditional in-bin drying and storage of soybeans for seed utilize unconditioned natural air (NA). The rate and duration for the seed conditioning which could involve drying or aeration are determined by the relative humidity, temperature and flow rate of the air. During the seed conditioning, the air may cause the soybean to lose or absorb moisture. Cyclic wetting and drying during unstable weather conditions may induce stresses in the seed. Also, prolonged adverse weather conditions could result in a situation where the fan may be shut off completely to prevent rewetting and invariably expose the soybean to mold attack. Therefore, in the case of in-bin drying, the duration for complete drying of grains, especially at the top layers, may be prolonged thereby raising the need to control the drying operation (Atungulu et al., 2015). It is therefore important to investigate how different airflow rates and drying strategies affect the drying kinetics of soybeans for in-bin systems so as to prevent mold growth, seed quality reduction and economic losses.

Conducting real-time field studies of in-bin, NA drying process for soybean would be too expensive and time consuming. A computer simulation program known as the Post-Harvest Aeration Simulation Tool Finite Difference Method (PHAST-FDM) that has been used for simulation of various conditions for corn could be modified for use with soybean (Bartosik and Maier, 2004; Lawrence et al., 2015). This program utilizes an equilibrium-based model (Thompson, 1972) to predict the grain conditions during NA in-bin drying. In the model application, it is assumed that the grain within a particular layer at certain duration are at equilibrium (Thompson, 1972). The program allows evaluating effectiveness of various drying strategies at locations with differing weather conditions.

The objective for this study was to mathematically simulate natural air in-bin drying of soybeans seed and determine the effects of drying strategy on drying duration, final moisture content (MC), percent overdrying and drying cost; specifically for Arkansas weather conditions.

PROCEDURES

Material, Sorption Equation and Coefficient Determination. Soybean with initial moisture content (IMC) of 16% wet basis (w.b.) and bulk density of 734.5 kg m^{-3} was used in this simulation. Chung and Pfost (1967) sorption parameter A (245.4), B (328.3) and C (0.139) and desorption parameter A (100.3), B (328.3), and C (0.139) were used in calculating the equilibrium moisture content (EMC; ASAE, 2012).

Simulation Methods. The simulation was carried out for a typical farm bin of 14 m (48 ft.) diameter and 6.1 m (20 ft.) depth with 15 August drying start date. The simulation evaluated the implication of five fan control strategies comprising continuous natural air (CNA), EMC controlled natural air (EMC-NA), air EMC controlled with supplemental heating (EMC-H), natural air day only (NADO), and natural air night only (NANO). For each fan control strategy, soybean were dried at four different airflow rates of 1.04, 2.08, 3.12, 4.16, and 5.20 $m^{-3}/min\text{-}t^{-1}$ (1, 2, 3, 4, and 5 cfm bu^{-1}).

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The Chung-Pfost (Chung and Pfost, 1967) sorption Eq. 1 and Eq. 2 were used to calculate the EMC of the soybean. Simulations were performed and results pooled as the average resulting from a 20 year (1995 to 2014) data set of air temperature and relative humidity (RH) at Stuttgart, Arkansas. The simulation runs were terminated when the average MC of soybean inside the bin attained 13%, or the top layer of the soybean inside the bin dried to 14%, or drying duration reached 90 days.

$$M \approx \frac{-1}{C} ln\left[-\frac{(T+B)}{A} ln(a_w)\right] \quad \text{Eq. 1}$$

$$a_w \approx exp\left[\frac{-A}{(T+B)} exp(-CM)\right] \quad \text{Eq. 2}$$

where, M is moisture content, % (d.b.); a_w is Equilibrium relative humidity (decimal); T is absolute temperature (K); A, B and C are constants specific to individual equations.

A total number of 500 simulation runs were completed (1 location × 1 harvest date × 5 airflow rates × 5 strategies× 20 years × 1 cultivars × 1 model). The effect of drying strategies and airflow rate on soybean were evaluated for drying duration, final MC, percent overdrying and drying cost. Equation 3 and equation 4 were used to determine the energy and moisture balance within a thin layer of soybean (Jindal and Siebenmorgen, 1994):

$$C_a T_o + H_o(h_v + C_v T_o) + c_g G_o r + c_w G_o(H_f - H_o) = c_a T_f + H_f(h_v + c_v T_f) + c_g T_f r \quad \text{Eq. 3}$$

$$H_f - H_o = \frac{(MC_o - MC_f) * z}{100} \quad \text{Eq. 4}$$

where C_a is specific heat of dry air (J (kg of dry air)$^{-1}$ K^{-1}); c_g is specific heat of grain (J (kg of wet grain)$^{-1}$ K^{-1}); c_v is specific heat of water vapor (J (kg of water vapor)$^{-1}$ K^{-1}); c_w is specific heat of water (J (kg of water in grain)$^{-1}$ K^{-1}); H_o is absolute humidity of air entering the control volume ((kg of water) (kg of dry air)$^{-1}$); H_f is absolute humidity of air leaving the control volume ((kg of water) (kg of dry air)$^{-1}$); T_o initial air temperature (°C); T_f is final air and grain temperature (°C); h_v is latent heat of vaporization of water (J (kg of water vapor)$^{-1}$); G_o is initial grain temperature (°C); r is grain mass to dry air ratio ((kg of wet grain) (kg of dry air)$^{-1}$); MC_o is initial MC of grain in percentage wet basis; MC_f is final MC of grain in percentage wet basis. Equation 5 was used to determine z:

$$z = \frac{\rho_g d_x}{\rho_a v_a t} \quad \text{Eq. 5}$$

where ρ_a is density of air ((kg of air) m^{-3}); ρ_g is density of grain ((kg of wet grain) m^{-3}); t is time interval (s); v_a is velocity of air (m s^{-1}); d_x is layer thickness (m). The adsorption and desorption models of Chung and Pfost (1967) with their corresponding coefficients were used in Eqs. 6, 7 and 8 to determine temperature, and partial and saturated vapor pressures of air.

$$RH = \frac{P_v}{P_s} \quad \text{Eq. 6}$$

$$P_v = \frac{101325H}{0.6219 + H} \quad \text{Eq. 7}$$

$$P_s = K \times Exp\left(\frac{A + BT + CT^2 + DT^3 + ET^3}{FT - GT^2}\right) \quad \text{Eq. 8}$$

where, RH is air relative humidity in decimal; P_v is partial vapor pressure of air (pascal, Pa); P_s is saturated vapor pressure of air (Pa); H is absolute humidity of air (kg of water) (kg of dry air)$^{-1}$; T is air temperature (°C); A, B, C and D are constant Chung-Pfost constants.

Statistical Analysis. The effect of drying strategies and airflow rates on drying duration, percent overdrying final MC, and drying cost were analyzed using SAS for the analysis of variance (ANOVA) and the Duncan multiple range test (SAS Institute, Inc., Cary, N.C.). Graphs were plotted using JMP statistical software JMP Pro v. 12, (SAS Institute Inc., Cary, N.C.).

RESULTS AND DISCUSSION

The results of the effect of different airflow rates and five fan control strategies on the final MC, duration of drying, and percent overdrying are shown in Figs. 1, 2, and 3, respectively. The target average MC was set at 13% which falls within what the industry considers to be safe short-term storage MC for soybean (Sadaka and Bautista, 2014). The final MC achieved ranged between 8% and 14% (w. b.). The fan control strategy employed had a significant effect on the final MC achieved ($P < 0.05$) as shown in Table 1. The NANO fan control strategy resulted in the highest final MC achieved with 14.1% (w.b.) obtained at airflow rate of 1.04 m^{-3}min-t^{-1}. The lowest MC (8.9%, w. b.) was obtained from NADO fan control strategy at airflow rate of 5.20 m^{-3}min-t^{-1}. Irrespective of the strategy, the final MC reduced with increased in airflow rate ($P < 0.05$) (Fig. 1). When airflow rates were 1.04 and 5.20 m^{-3}min-t^{-1}, the final MC obtained was 12.7% and 11.8% (w.b.), respectively for EMC-NA. Achieving safe storage MC soon after harvest is critical. Otherwise, if high MC soybean is stored for an extended period, the bin could be infested with mold leading to grain spoilage, and reduction in seed germination potential.

The best fan control strategy should be able to dry the soybean in the bin within a reasonable duration. The result showed that NANO and NADO with airflow rate of 1.04 m^{-3}min-t^{-1} required more than 60 days to dry the soybean; CNA with airflow rates of 4.16 and 5.20 m^{-3}min-t^{-1} required less than ten days (Fig. 2). However, for fan control strategies EMC-NA and EMC-H, the drying durations were found to be 44 and 37 days respectively at 1.04 m^{-3}min-t^{-1} airflow rate. At airflow rates of 1.04, 2.08 and 3.12 m^{-3}min-t^{-1}, producers could save 36, 20, and 5 drying days, respectively, when they switch from NANO to ECM-NA fan control strategy.

High airflow rate and continuous exposure of grain to low humidity air could result in overdried grain. Overdrying reduces the market weight of soybeans thereby causing the producer to incur economic losses since sale of grain is by weight. Also, overdrying may lead to partial degrading of the functional component of the soybean seed with negative impact on the seed viability and germination potential. In order to prevent overdrying, the lower limit of MC in the simulation was set at 12% (w.b.). High percent overdrying was observed in the soybean bed for conditions when the fan was set at NADO (82%) and CNA (70%) strategies. In general EMC-NA, NANO and EMC-H strategies resulted in 40% overdrying and the values obtained were not significantly different from one another ($P < 0.05$). The EMC-NA strategy results in lower overdrying because of the process-restrained fan run time and the quality of air that was pushed through the soybean bed. Similarly, increase in airflow rate resulted in an increased percent overdrying (Fig. 3). For instance using EMC-H, more than 50% increase in overdrying occurred when the airflow rate increase from 1.04 $m^{-3}min\text{-}t^{-1}$ to 5.20 $m^{-3}min\text{-}t^{-1}$. Producers need to consider carefully the choice of airflow rate, partly to reduce the percent overdrying and also the cost implication of running the drying fan at high airflow rates.

The result of cost incurred to drying soybean in an in-bin system at different airflow rates and fan control strategies is shown in Fig. 4. The cost increased by 300% as the airflow rate increased from 1.04 to 5.20 $m^{-3}min\text{-}t^{-1}$. It is important that the producer make a decision as to the airflow rate to be used so as to reduce cost of drying/storage. In terms of strategy, CNA, EMC-NA, EMC-H, NADO and NANO will cost $14.4/ton, $8.7/ton, $10.0/ton, $18.5/ton and $10.5/ton respectively. Hence EMC-NA was the most cost effective soybean drying approach and since the process uses NA, it could be suitable for drying soybean seed destined for use as planting seed.

PRACTICAL APPLICATIONS

The study presents a mathematical model for NA drying of soybeans of different cultivars and their relationship with various factors that affect the in-bin natural air drying process. The information will be critical to managing soybean in a bin, maintaining quality, and preventing mold development.

ACKNOWLEDGEMENTS

The authors greatly acknowledge the University of Arkansas System Division of Agriculture and the Arkansas Soybean and Promotion Board for financial support. The authors are also grateful for collaborations by Drs. Pengyin Chen, Terry Siebenmorgen and Donald Dombek of the University of of Arkansas System Division of Agriculture.

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Table 1. Statistical analysis of the effect of airflow and fan control strategy on soybean seed final moisture content (MC), percent over drying, drying duration, and drying cost.

Source	Final MC (% wet basis)		Percent over drying (%)		Drying duration (days)		Drying cost ($/ton)	
	F Value	Pr. > F	F Value	Pr. > F	F Value	Pr. > F	F Value	Pr. > F
Airflow ($m^3min\text{-}t^{-1)}$)	1706	<0.0001	1533	<0.0001	8262	<0.0001	5489	<0.0001
Fan control Strategy	3145	<0.0001	1335	<0.0001	1452	<0.0001	2633	<0.0001
Airflow * Strategy	128	<0.0001	59	<0.0001	426	<0.0001	130	<0.0001

Pr. = Probability.

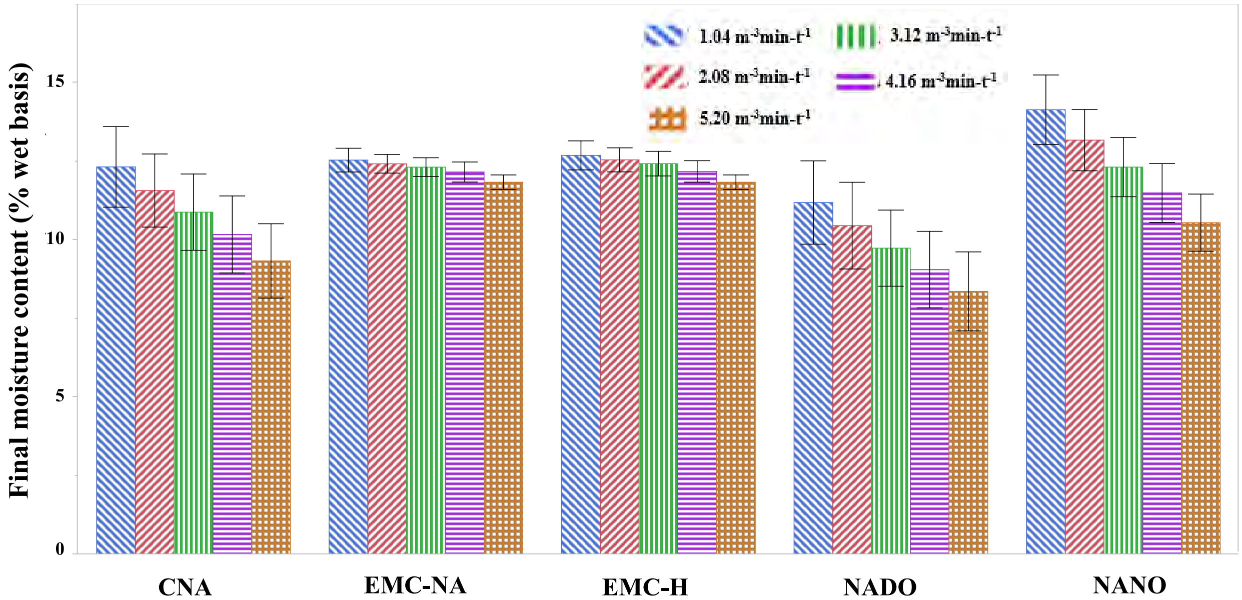

Fig. 1. Effect of fan control strategies on final moisture content of soybean at different air flow rates. CNA = continuous natural air, EMC-NA = controlled natural air, EMC-H = controlled with supplemental heating, NADO = natural air day only, and NANO = natural air night only fan operation strategies, respectively. Each error bar is constructed using one standard deviation of the mean.

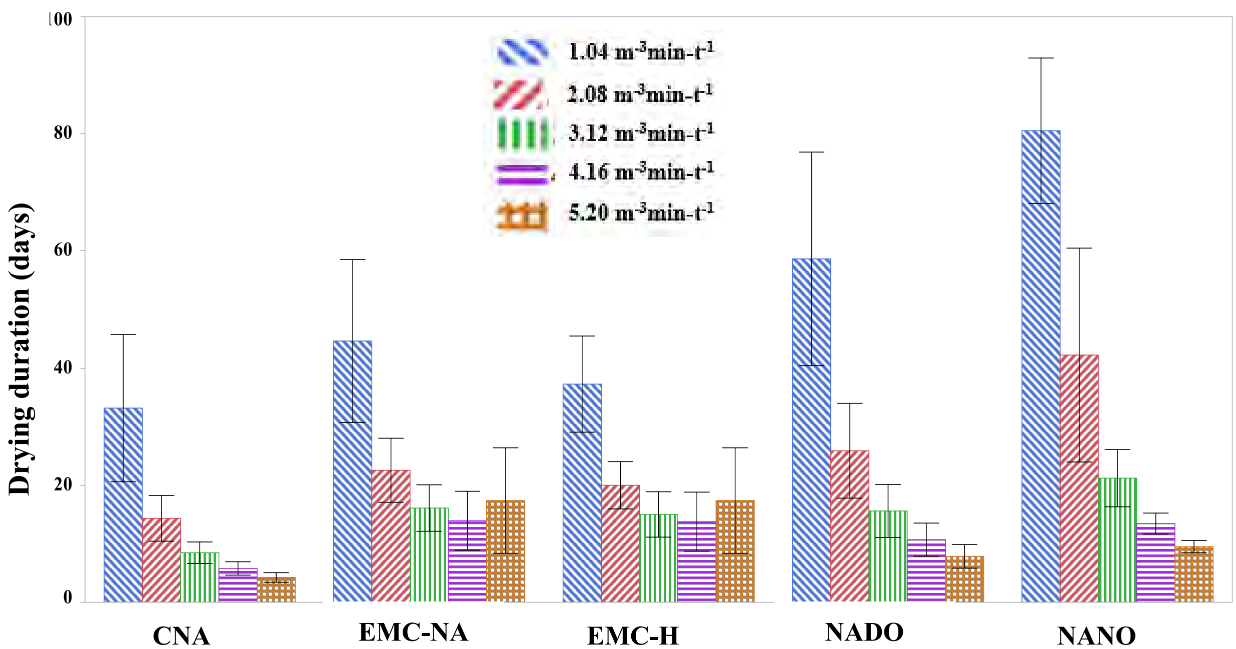

Fig. 2. Effect of fan control strategy on drying duration of soybean at different airflow rates. CNA = continuous natural air, EMC-NA = controlled natural air, EMC-H = controlled with supplemental heating, NADO = natural air day only, and NANO = natural air night only fan operation strategies, respectively. Each error bar is constructed using one standard deviation of the mean.

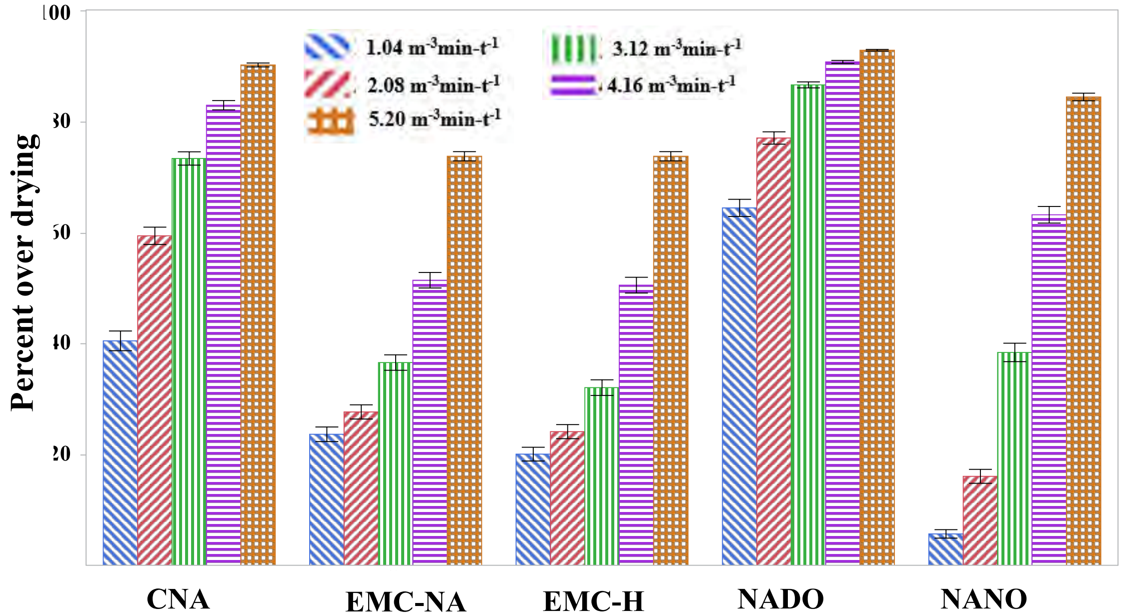

Fig. 3. Effect of fan control strategy on the percent overdrying of soybean at different air flow rates. CNA = continuous natural air, EMC-NA = controlled natural air, EMC-H = controlled with supplemental heating, NADO = natural air day only, and NANO = natural air night only fan operation strategies, respectively. Each error bar is constructed using one standard error of the mean.

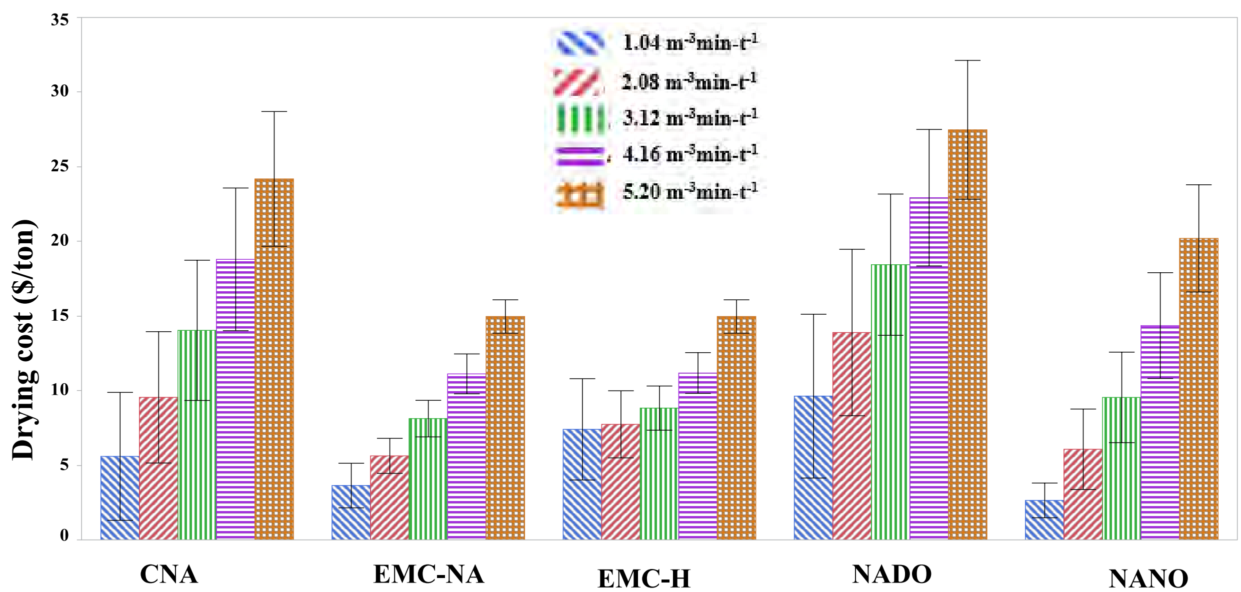

Fig. 4. Effect of fan control strategy on the drying cost of soybean at different airflow rates. CNA = continuous natural air, EMC-NA = controlled natural air, EMC-H = controlled with supplemental heating, NADO = natural air day only, and NANO = natural air night only fan operation strategies, respectively. Each error bar is constructed using one standard deviation of the mean.

Innovative and Value-Added Products from Arkansas-Grown Non-Genetically Modified (Non-GM) Soybean for Potential Commercialization

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ABSTRACT

Soy food products and beverages made with non-genetically modified (non-GM) ingredients are in demand due to increasing consumer interest in healthy eating habits. An edamame frozen dessert and a protein sport drink were prepared and evaluated for their physicochemical and sensory properties. A method to prepare ice cream-like edamame frozen dessert was optimized to confer desirable mouth-feel, texture and stability, while being low in saturated fat and calories with maintained green lush color. The edamame-frozen dessert could be prepared by using about 20% to 30% of edamame pressure-cooked in color-fixing solution containing a combination of 0.5% magnesium salt, zinc salt, and calcium salt; about 6%-10% by weight vegetable and/or fruit, such as green produce; about 35% soy milk; and about 18% sugar or artificial sweetener. The taste was maintained without the 'beany' flavor, and by imparting good green lush color, texture, body and all other attributes of ice cream. To develop protein drink from soybean protein, alcalase hydrolyzed protein from a non-transgenic (non-GM) soybean line was used. Three flavors: Chai tea, tangerine, and mixed berries were prepared using ingredients such as bitter blocker, masking agent, and citric acid to enhance the taste and sensory appeal for acceptance by a consumer panel. The tangerine and mixed berries flavored beverages received the overall highest score from the sensory panel. Citric acid alone or in combination with bitter blocker or masking agent lowered the bitterness in soy protein beverages. Overall, the tangerine and mixed berries flavored beverages have the potential for commercial application.

INTRODUCTION

Soy foods have gained more attention among U.S. consumers for wellness, especially since the Food and Drug Administration (FDA) approved the claim about the association between soy protein and the reduced risk of coronary heart disease (CHD). Health benefits of soy protein include decreasing blood cholesterol levels, body fat, bone loss, and the incidences of some cancers (Friedman and Brandon, 2001). Based on consumer attitudes, 75% of American consumers associate soy-based products with a healthy lifestyle and 40% are aware of FDA claims in which consuming 25 grams of soy protein per day reduces the risk of coronary heart disease (United Soybean Board, 2013).

Crops labeled as genetically modified organisms (GMO) make up 93% of soybean grown in the United States (Cornejo, 2013). Despite all the benefits of soy, this label is perceived negatively by consumers due to their concern about the safety of GMO foods and ingredients to their health. Recently, a trend to grow non-GMO soybean has been gaining in popularity amongst growers and a number of soybean companies have been joining the non-GMO Project. The state of Arkansas has been recognized as a potential leader in the production of non-GMO soybean (Roseboro, 2012); therefore, there is a need to study soybean composition and develop new, innovative, science-based products using Arkansas grown non-GMO soybean to ensure the availability of non-GMO food products. The outcome of this study can lead to commercial interest in utilizing the non-GMO soybean and encourage breeders/growers to select nutrient-dense, high protein, and high yielding non-GMO soybean lines with potential end uses.

Ice cream is a product that is consumed by all age groups, but is traditionally perceived as an unhealthy snack. Increasing health awareness led to the demand for food with reduced calories. Edamame is considered to be a natural vegetable with health benefits and foods prepared from such sources are in demand by the consumer. It is therefore desirable to provide frozen dessert compositions and methods of preparation that incorporate vegetable soybean (edamame) in order to increase servings for consumers. It is further desirable to provide methods of preparing frozen dessert that are fortified with soybean and vegetable-based produce while retaining the green lush color. The green color in a product is perceived as fresh by a consumer.

Protein-based beverages have experienced a record growth of approximately 23%, due to an increase in consumer demand and expanded market from 2008 to 2013 (Levesque, 2014). Protein products have also become popular as ready-to-drink protein beverages, which are more appealing to time-crunched individuals who are also looking to improve their diets (Haderspeck, 2014). Soy is the only known plant source that contains all nine essential amino acid at levels as high as those from meat, milk, and egg (Ang et al., 1985; Tockman, 2002). However, native soy protein cannot be used effectively as a supplement in beverages, es-

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pecially in acidic beverages, since it is largely insoluble and separates on storage (Cho et al., 2008). Clarity is a challenge when formulating high-protein drinks since insolubility of native protein isolate is undesirable to consumers (Cho et al., 2008). Previous research has shown that hydrolysates prepared from soy protein have better solubility and applicability in high protein products (Wu et al., 1998). However, a challenge that is faced by beverage developers when working with soy protein hydrolysate is a lack of appealing flavor and presence of bitter note (MacLeod, 1988).

The objectives were: 1) To optimize the conditions for preparing edamame frozen dessert to confer desirable mouthfeel, texture and stability, while being low in saturated fat and calories with maintained green lush color, and 2) To determine sensory acceptability, and physicochemical properties of a protein-rich drink developed utilizing soy protein hydrolysate prepared from non-GM soybean cultivar (R08-4004).

PROCEDURES

Two novel food products were developed using Arkansas-grown non-GM soybean cultivars. The products include edamame frozen dessert and protein sport drink. These products are targeted towards health conscious consumers.

Edamame Frozen Dessert. To optimize the conditions for preparing edamame frozen dessert, frozen edamame was thawed and pressure-cooked in a food grade coloring fixing solution containing magnesium chloride, zinc acetate, and or calcium lactate 5-hydrate. In addition to enhancing the green lush color, spinach leaves were blanched in a food grade color fixing solution and homogenized until the edamame formed a fine emulsion. Soy milk and cane sugar/low calorie sweetener were added and then homogenized to form a fine emulsion while maintaining the temperature constant at 5 °C and sonicated. The mixture was cooled, and transferred to an ice cream maker and churned while maintaining a temperature below freezing.

Protein-Rich Drink. The protein drinks were prepared using soy protein hydrolysate (SPH). Soy protein isolate (SPI) was prepared from ground and defatted soybean seeds of an Arkansas-grown non-genetically modified (non-GM) cultivar, and R08-4004 a conventional line. Three types of protein drinks were prepared in predetermined proportions using laboratory scale trials in order to optimize the formula. Protein drinks were prepared using two different bases: distilled water for tangerine flavor (beverage T), and mixed berries flavor (beverage MB); and brewed tea for Chai tea flavor (beverage C). A control formula was also prepared with no additional flavor for comparison. The sweetener, bitter block (BB), masking agent (MA), natural color and flavor agents, and citric acid were added as required for each formulation. The drink was mixed for 2-3 min to obtain a homogenous product. This freshly prepared drink was filled into pre-sterilized glass bottle and pasteurized at 90 ºC to 95 ºC with a 5 min holding time. Bottles were cooled to ambient temperature and stored in a refrigerator (5 ºC).

RESULTS AND DISCUSSION

*Edamame Frozen Dessert.*The edamame frozen dessert had a conventional ice cream texture with overall acceptability by consumers. The healthy image of ice cream can be enhanced by incorporating suitable vegetables, fruit or a combination of both with edamame. To get the creamy texture and taste, the edamame needs to be processed into a fine emulsion. This technology provides a fine texture, creamy mouth feel and taste without the inherent "beany flavor." The successful flavors developed included: 1) vanilla and 2) chocolate-chip mocha (Fig. 1). Other flavors that are being developed include combinations of fruits, vegetables, herbs, and spices. Another flavor being developed is a unique trendy blend that combines spicy hotness and tart sweetness. This frozen dessert had been offered to visiting groups for sampling and has received favorable feedback. In 2013, 100 servings were provided to scientists, physicians and nurses attending as participants at a symposium on obesity in Arkansas. Comments from the tasters included "awesome," "very tasty" and "will buy if available in a store." In addition, this frozen dessert developed from edamame with unique formulation (vegan, lactose -free, gluten-free, natural and healthy) were tasted by 200 attendees of the Annual National Association of Community Development Extension Professionals (NACDEP) Conference in Little Rock, Ark. in 2015 for further development and evaluation. Further enhancement is needed to prevent ice crystal formation. The flavors 'hot & spicy' and 'herbs', which are in demand by the consumer, need completion. A great potential exists for commercialization which needs exploration.

Protein-Rich Drink

Optimal Concentration of Ingredients to Minimize Bitterness. Products' sensory acceptability was achieved by masking products' bitter taste using a multifaceted approach which included addition of sweetener, flavor agent, organic acids, and food grade bitterness-lowering compounds. During the preliminary test, there was an increase in the bitter note of 4% SPH solution due to the increase in Stevia® higher than 0.02% for sweeter taste. Hence, 0.02% (w/w) pure Stevia was replaced with Truvia® (Cargill®, Wayzata, Minn.), which is commercially available with ingredients: erythritol, Stevia leaf extract, and natural flavors (Table 1). This boosted the sweetness without increasing the caloric content in the three beverages (Persinger, 2014). Research is underway to eliminate cloudiness in the clear beverage.

Sensory Evaluation. The overall appearance of the four beverages, including C, MB, T, and control, significantly varied according to the sensory panel evaluations ($P < 0.0001$). Panelists liked the appearance of MB and T beverages the most among the four beverages tested (Table 2). In addition, the panelists noted significant differences in flavor attribute ($P < 0.0001$), and overall, the panel liked better the flavor of beverage T. The four soy protein beverages significantly differed ($P < 0.0001$) with respect to oral tactile attribute (mouth-feel) which was enhanced with the addition of flavors (Table 2). The panelists liked the mouth-feel of beverage T the most overall.

The participants rated the color attribute of the control beverage as too light, while they rated beverages MB and T as 'just-about-right' for color attribute (Table 3). The color acceptance of beverage C was rated as too dark, which was implicit due to its formulation using prepared tea beverage. The four soy protein beverages significantly differed with respect to sweetness and bitterness attributes ($P < 0.0001$). Panelists rated the sweetness of T and MB beverages as 'just-about-right' in comparison to the control sample that was rated ('too little'). The control sample was also rated as 'too much' for bitterness attribute. However, bitterness for tangerine or mixed berries flavors was rated as 'just about right' (JAR), indicating that the added flavors decreased the bitterness intensity. The addition of citric acid for beverage T and BB, MA and citric acid combination for beverage MB successfully reduced the bitterness of the high protein beverages. Similar results were demonstrated by Lee (2011) using Alcalase-hydrolyzed soy protein formulated with lemon flavored sweet tea, indicating that citrus flavor or sour tasting ingredients might play an important role in minimizing bitter taste (Keast and Breslin, 2003). Additionally, Adler-Nissen (1986) demonstrated that citric acid could mask the bitter note of hydrolyzed proteins. Among the three flavored beverage types, Chai tea flavor was the least accepted, which might have resulted due to its dark color and strong flavor. Another possible reason may be because it is not widely popular among U.S. consumers.

PRACTICAL APPLICATIONS

An innovative processing technology has been developed to make frozen dessert with vegetable edamame as the main ingredient. Ice cream-like edamame frozen dessert with the following flavors have been developed using this technology to produce creamy emulsion without a gritty texture. These flavors include vanilla, lemon-lime, mint with chocolate chips, strawberry-banana, or pistachio (or nuts). The taste was maintained without the 'beany' flavor, and by imparting good green lush color, texture, and all other attributes of ice cream with a healthy product approach that caters to the needs of consumers. Prevention of ice crystal formation is in progress. The flavor "hot & spicy" which is in demand by the consumer needs more development as well.

This research provided, for the first time, a sensory study on the development of a novel beverage prepared with protein hydrolysates from a non-GM soybean. The results of this work showed that the use of citric acid alone or a combination of bitter-blocking and masking agents was effective in minimizing the bitter note caused by limited enzymatic hydrolysis of soy protein. Among the three flavors, tangerine flavored beverage was the most preferred followed by mixed berries flavored. Since the consumer trend for soy-based products, especially from a non-GM line, has been increasing in the recent years, these findings are relevant for developing formulations of protein-rich beverages. The beverage needs further improvements for elimination of cloudiness.

ACKNOWLEDGMENTS

The authors would like to thank the Arkansas Soybean Promotion Board for their funding of this research. Support was also provided by the University of Arkansas System Division of Agriculture.

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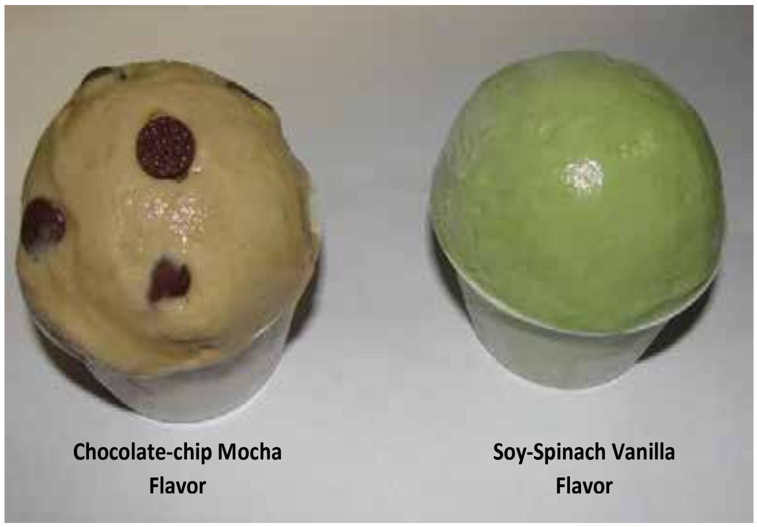

Fig. 1. Soybean frozen dessert (low calorie to reduce obesity).

Table 1. Formulas of flavored soy protein hydrolysate (SPH) beverages.

Formula	Ingredient	Weight (g)	Percentage (% w/w)
Control	Distilled water	462.3	92.46
	SPH†	22.7	4.54
	Truvia	15.0	3.00
	Total	500.00	100.00
Chai tea flavor	Brewed Chai tea	462.3	92.46
	SPH†	22.7	4.54
	Truvia	15.0	3.00
	Total	500.00	100.00
Tangerine flavor	Distilled water	452.8	90.56
	SPH†	22.7	4.54
	Truvia	15.0	3.00
	Tangerine flavor agent	4.5	0.90
	Annatto color agent	2.5	0.50
	Citric acid	2.5	0.50
	Total	500.00	100.00
Mixed berries (MB) flavor	Distilled water	440.7	88.14
	SPH†	22.7	4.54
	Truvia	15.0	3.00
	Bitter blocker	7.3	1.46
	Masking agent	5.0	1.00
	Berries flavor agent	5.0	1.00
	Cochinal color agent	3.0	0.60
	Citric acid	1.3	0.26
	Total	500.00	100.00

†Protein content of SPH = 88.3%; 22.7g SPH was added in order to have the final product that contained 20 grams of SPH per serving of 500 mL.

Table 2. Mean hedonic ratings (± standard deviation) of hedonic scale as a function of flavored soy protein beverages.

Attributes	Mixed berries flavor†	Tangerine flavor†	Chai tea flavor†	Control†
Overall appearance	7.1 ± 0.2^a	7.2 ± 0.1^a	3.9 ± 0.2^c	6.3 ± 0.2^b
Odor acceptance	7.0 ± 0.2^a	7.3 ± 0.1^a	5.6 ± 0.3^b	4.5 ± 0.2^c
Flavor acceptance	5.2 ± 0.3^b	6.4 ± 0.2^a	3.8 ± 0.3^c	2.9 ± 0.2^d
Oral tactile acceptance	5.9 ± 0.2^b	6.3 ± 0.2^a	5.0 ± 0.2^c	4.1 ± 0.2^d
Overall acceptance	5.4 ± 0.2^b	6.5 ± 0.2^a	3.8 ± 0.2^c	3.1 ± 0.2^d

† Mean ratings with different letters within a row are significantly different at $P < 0.05$.

Table 3. Mean Just-About-Right ratings (± standard deviation) of sensory attributes as a function of flavored soy protein beverages.

Attributes	Mixed berries flavor†	Tangerine flavor†	Chai tea flavor†	Control†
Color	3.0 ± 0.1^b	3.1 ± 0.0^b	4.1 ± 0.1^a	2.5 ± 0.1^c
Sweetness	2.9 ± 0.1^a	2.9 ± 0.1^a	2.1 ± 0.1^b	1.4 ± 0.1^c
Bitterness	3.4 ± 0.1^b	3.1 ± 0.1^b	3.9 ± 0.1^a	4.0 ± 0.1^a

† Mean ratings with different letters within a row are significantly different at $P < 0.05$.

Refining of Isotherm Prediction Models to Achieve Accurate Control of Recently Introduced In-Bin Drying and Storage Systems for Soybean Seed

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ABSTRACT

Recently introduced technology comprised of cables used to monitor grain moisture content (MC) and temperature throughout the entire grain bin mass offers a means to improve natural air drying and storage of soybean for 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 accurate determination of equilibrium moisture content (EMC) to determine fan run time. 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; with a particular focus on how the EMC predictions may be impacted by variability in chemical characteristics of newly developed soybean cultivars.

INTRODUCTION

The traditional method of allowing soybean for seed to dry in the field to moisture content (MC) of 12% to 13% wet basis (w.b.) before harvesting and storage in warehouses tend to result in reduction of seed germination potential and viability (TeKrony et al., 1980). During the field drying process, the seed experiences stresses of MC fluctuation, microbial contamination, and insect infestation among other factors that cumulatively lead to deterioration of seed germination and viability. It is critical that better management practices are employed to gently dry and store the seed in order to prevent related economic losses to seed producers and users.

Drying and storage of the soybean seed in-bin under controlled natural air conditions may help reduce negative stresses endured by the seed in the field. In-bin drying and storage systems operate by drawing drying air through a fan. In uncontrolled drying scenarios, the conditions of the air (temperature and relative humidity) that is introduced into the grain vary depending on prevailing weather situation and time of the day. Hence, overdrying may occur when the grain is exposed to high temperature air for an extended duration and the grain may re-absorb moisture when the air relative humidity (RH) is high. Since soybean is hygroscopic (Adu and Otten, 1993), the exposure of the soybean to drying and storage with uncontrolled natural air conditions could negatively impact the seed leading to significant reduction in seed germination and viability.

Recently introduced technology for in-bin drying and storage systems comprise cables with sensors installed inside the bin to aid monitoring and controlling of the grain drying and storage process. A network of sensors on the cables aid in determination of relative humidity of the air inside the bin, and the seed temperature and equilibrium moisture content (EMC; i.e., the MC that a specific grain will attain if exposed to air with a given RH and temperature for a long enough duration). The new technology also utilizes communication devices and fan control systems that allow turning the fan on or off to prevent pushing into the grain mass air that would cause soybean rewetting and overdrying. Data of the grain MC and temperature during the drying and storage process as well as operation conditions of the system are transmitted wirelessly and are accessible anytime via the internet; this has revolutionized monitoring capabilities during in-bin drying of soybean seed. However, for timely fan control leading to successful implementation of the new technology, it is very critical that accurate data of soybean EMC (absorption and desorption) is determined. Typically grain EMC at a known RH, temperature is predicted using empirical equations (Table 1) that use the grain specific coefficients (Ondier et al., 2011). The main objectives for this study is to establish the equation that fits best experimental data to predict soybean seed isotherms and define the specific coefficients to use alongside the equation for soybean seeds of different cultivars.

PROCEDURES

Samples of freshly harvested soybean seeds (cultivars R02-6268F (High Oil), R07-2000 (High Sugar), and R09-3789 (High Protein)) were procured from the University of Arkansas System Division of Agriculture's Agricultural Experiment Station. The high sugar cultivar was procured from the station’s Fayetteville location, while the high oil and high protein cultivars were both from the Pine Tree Research Station location near Colt, Ark. The samples were allowed to dry to 10% MC under room condition. The samples were cleaned to remove dirt and broken seed. The MC of each sample was determined using AM 5200 Grain Moisture Tester (PERTEN Instruments, Hägersten, Sweden). Samples were then transferred into a Vapor Sorption Analyzer (VSA)

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(Decagon Devices Inc., Pullman, Wash.) for EMC determination. The adsorption and desorption isotherms of the soybean at MC of 10% were determined using a DVS analysis equipment (AquaLab Vapor Sorption Analyzer (VSA), Decagon Devices, Inc., Pullman, Wash.). The absorption and desorption constants were calculated separately using the Modified Henderson (Henderson, 1952), Modified Chung-Pfost (Chung and Pfost, 1967), Modified Halsey (Halsey, 1948), Modified Oswin (Oswin, 1946) and Modified GAB (Van den Berg, 1985) models.

Statistical Analysis. The experimental sorption data of all samples of the soybean at the three different temperatures were fitted to five sorption equations. The parameters of the sorption model were determined by using non-linear regression analyses JMP Pro v. 12 (SAS Institute Inc., Cary, N.C.). The statistical difference between predicted and experimental data was evaluated using sum of square error (SSE) and root mean square error (RMSE).

RESULTS AND DISCUSSION

The results of sorption isotherms of soybean cultivars (R02-6268F (High Oil), R07-2000 (High Sugar), and R09-3789 (High Protein) are shown in Fig. 1(a-c). The sorption isotherms of soybean showed a relatively weak sigmoid shape curve at 35 °C (Fig. 1c). This showed that temperature had a marginal effect on absorption and desorption isotherm of soybean cultivars at 35 °C. Hysteresis effect tended to be higher with soybean at 15 °C over the entire range of the water activity (a_w) while hysteresis was insignificant for soybean at 25 °C and 35 °C where the curves of different soybean cultivar overlap. Hence, there is high potential that the drying and re-wetting process will induce stress in soybean stored at 15 °C.

Furthermore, the constant generated from the empirical equations (Table 1) for prediction of EMC of soybean using different cultivars are shown in Table 2. The Modified Chung-Pfost equation produced the highest value of coefficient 'A' ranging from 157 to 203, depending on the cultivar. In the case of coefficient 'B', the Modified Henderson and Modified Chung-Pfost models interchangeably produced the highest values while the Modified GAB model had the highest value for coefficient 'C'. Statistical analysis of the coefficient obtained for the selected equations for three different cultivars under adsorption and desorption isotherm is shown in Table 3. The Modified GAP had the best predictions for soybean EMC having the least sum of square error (SSE) and root mean square error (RMSE) that are less than 10% and 5%, respectively.

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.

ACKNOWLEDGEMENTS

The authors greatly acknowledge the University of Arkansas System Division of Agriculture and Arkansas Soybean and Promotion Board for financial support. The Authors are also grateful for collaborations by Drs. Pengyin Chen, Terry Siebenmorgen and Donald Dombek of the University of Arkansas System Division of Agriculture.

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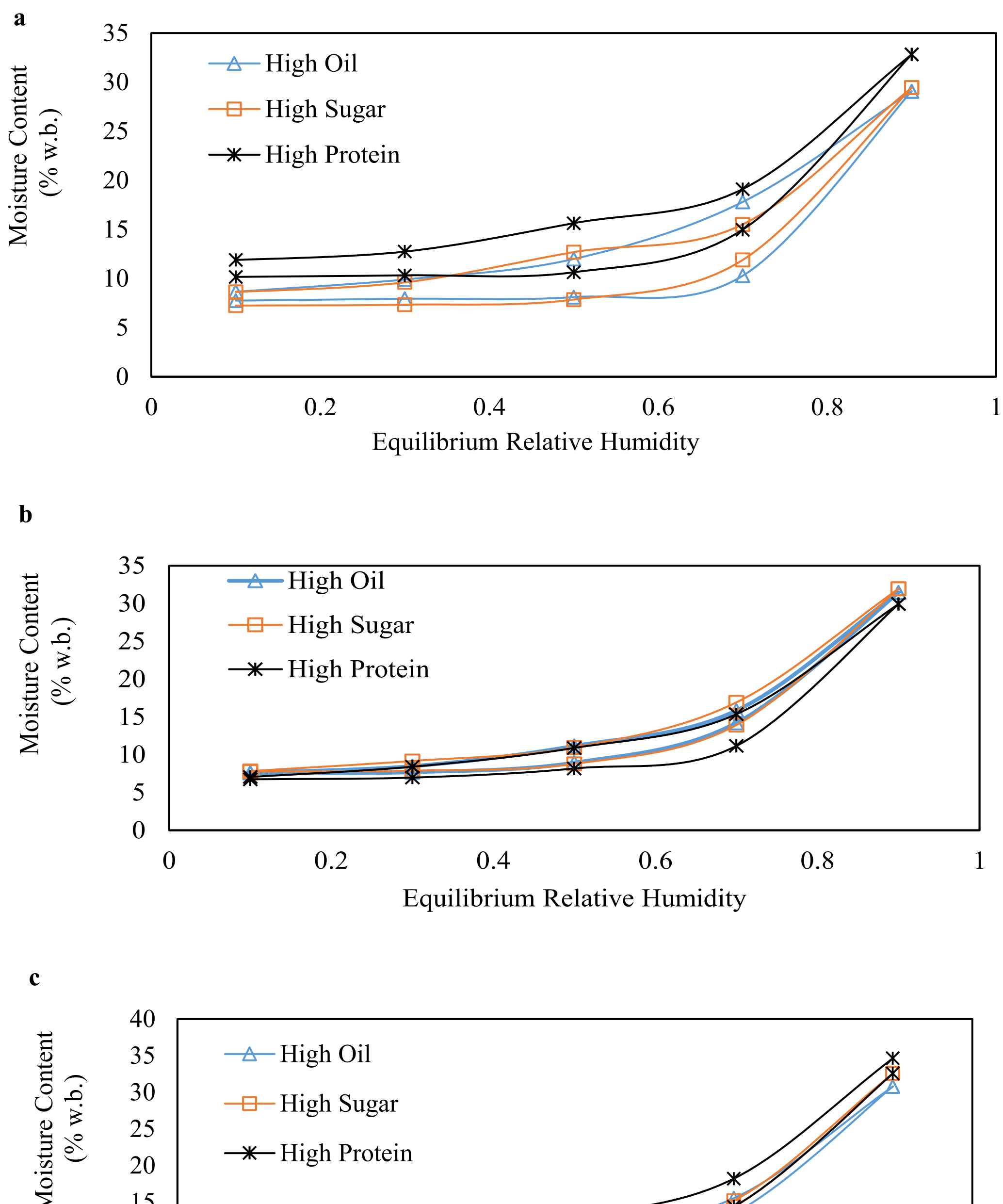

Fig. 1. (a) Comparison of sorption behavior of soybean of different chemical properties at (a) 15 °C; (b) 25 °C; (c) 35 °C.

Table 1. Five commonly used moisture sorption isotherm models.[†]

Name of model	Equilibrium moisture content model	Water activity / ERH model
Modified Henderson	$M \approx \left[\frac{-\ln(1-a_w)}{\mathrm{A}(T+\mathrm{B})}\right]^{1/\mathrm{B}}$	$a_w \approx 1-\exp[-\mathrm{A}(T+\mathrm{C})M^{\mathrm{B}}]$
Modified Chung-Pfost	$M \approx \frac{-1}{\mathrm{B}} ln\left[-\frac{(T+\mathrm{C})}{\mathrm{A}} ln(a_w)\right]$	$a_w \approx exp\left[\frac{-\mathrm{A}}{(T+\mathrm{B})} exp(-BM)\right]$
Modified Halsey	$M \approx \left[\frac{-\ln(a_w)}{\exp(\mathrm{A}+\mathrm{B}T)}\right]^{-1/\mathrm{C}}$	$a_w \approx exp[-exp(\mathrm{A}+\mathrm{B}T)M^{-C}]$
Modified Oswin	$M \approx (\mathrm{A}+\mathrm{B}T)\left[\frac{a_w}{1-a_w}\right]^{1/\mathrm{C}}$	$a_w \approx \frac{1}{\left[\frac{(\mathrm{A}+\mathrm{B}T)}{M}\right]^{\mathrm{C}}+1}$
Modified GAB	$M \approx \frac{\mathrm{AB}(\frac{\mathrm{C}}{T})a_w}{(1-\mathrm{B}a_w+(\frac{\mathrm{C}}{T})\mathrm{B}a_w)(1-\mathrm{B}a_w)}$	$a_w \approx \frac{2+\frac{C}{T}\left(\frac{\mathrm{A}}{M}-1\right)[\left(2+\frac{C}{T}\left(\frac{\mathrm{A}}{M}-1\right)\right)^2-4\left(1-\frac{\mathrm{C}}{T}\right)]^{\frac{1}{2}}}{2\mathrm{B}(1-\frac{\mathrm{C}}{T})}$

[†]*M*, moisture content, % (d.b.); a_w, water activity (decimal); *ERH*, Equilibrium relative humidity (decimal); *T*, absolute temperature, K; A, B and C, constants specific to individual equations.

Table 2. Parameters of proposed models for moisture sorption isotherms of three soybean cultivars of differing chemical properties.

		Adsorption			Desorption		
Models	**Parameters**	**High Oil**	**High Sugar**	**High Protein**	**High Oil**	**High Sugar**	**High Protein**
	A	166.97	199.48	203.05	196.83	167.045	157.73
Modified	B	23.6	23.6	23.6	23.6	23.6	23.6
Chung-Pfost	C	0.1254	0.1272	0.1356	0.1283	0.1255	0.1341
	A	0.0009	0.0004	0.0004	0.00039	0.00082	0.0013
Modified	B	19.697	27.555	19.726	22.76	35.131	27.051
Henderson	C	1.181	1.411	1.446	1.418	1.127	1.043
	A	13.80	-1576.46	13.175	14.44	9.9998	9.650
Modified	B	-0.123	63.555	-0.052	-0.087	0.0197	-0.021
Oswin	C	2.095	2.3983	2.4462	2.404	2.0285	1.908
	A	3.620	4.445	4.871	5.228	6.142	2.393
Modified	B	0.0014	-0.0008	-0.018	-0.033	-0.1051	0.0281
Halsey	C	1.718	1.9333	1.968	1.936	1.672	1.583
	A	5.332	6.3431	6.106	6.267	5.159	4.408
	B	0.9219	0.889	0.8833	0.888	0.9306	0.9462
Modified GAB	C	1.99×10^6	2.12×10^6	1.33×10^6	6.57×10^6	3.71×10^6	2.51×10^6

Table 3. Statistical tests for the selected models for moisture sorption isotherms of three cultivars of different functional properties.

		Adsorption			Desorption		
Models	**Statistics**	**High Oil**	**High Sugar**	**High Protein**	**High Oil**	**High Sugar**	**High Protein**
Modified	SSE	55.41	40.59	31.6	60.26	71.54	72.49
Chung-Pfost	RMSE	5.26	4.51	3.25	3.47	5.98	6.02
Modified	SSE	40.52	37.81	30.08	33.09	52.45	50.73
Henderson	RMSE	3.68	3.55	3.17	3.32	4.18	4.11
Modified	SSE	17.92	14.65	10.96	12.01	26.2	26.14
Oswin	RMSE	2.99	2.71	2.34	2	3.62	3.62
Modified	SSE	6.48	4.03	2.57	3	11.7	12.6
Halsey	RMSE	1.74	1.16	0.93	1	1.97	2.05
Modified	SSE	2.76	2.02	1.16	1.95	6.15	7.08
GAB	RMSE	1.47	1.01	0.76	0.99	1.75	1.88

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