Arkansas
Soybean Research Studies 2020

Jeremy Ross, Editor

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Cover photo: Soybean roots severely galled by the southern root-knot nematode, *Meloidogyne incognita*; the image was taken while rating soybean varieties for susceptibility to the southern root-knot nematode at the R5 growth stage.
Photo taken at the soybean variety research plots near Kerr, Arkansas, 13 August 2021.
Photo taken by Travis Faske, Professor-Plant Pathology, University of Arkansas System Division of Agriculture, Lonoke, Arkansas.

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Preface

The 2020 Arkansas Soybean Research Studies 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 data from a single year or limited 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 result 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 the research centers and stations; producers and cooperators; and industry personnel who assisted with the planning and execution of the programs.

Acknowledgments

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The Arkansas Soybean Promotion Board

Introduction

Arkansas is the leading soybean-producing state in the mid-southern United States. Arkansas ranked 11th in soybean production in 2020 when compared to the other soybean-producing states in the U.S. The state represented 3.42% of the total U.S. soybean production and 3.38% of the total acres planted in soybean in 2020. The 2020 state soybean average yield was 51.5 bushels per acre, setting a new state record and surpassing the previous yield record of 51.0 bushels per acre set in 2017. The top five soybean-producing counties in 2020 were Mississippi, Phillips, Crittenden, Arkansas, and Chicot Counties (Table 1). These five counties accounted for 35.96% of the soybean production in Arkansas in 2020.

Weather events during the 2020 growing season were much improved compared to those during 2019. However, frequent rain events hampered preplant tillage and delayed planting for some portions of the state. Soybean planting during 2020 was ahead of the previous year but delayed compared to the 5-year average for planting progress. According to the 1 June 2020 USDA-NASS Arkansas Crop Progress and Condition Report (USDA-NASS, 2020), only 66% of the soybean acreage had been planted as of the first of June compared to 51% and 73% for the 2019 and the 5-year average, respectively, planting progress, respectively. Because of the weather delays and low commodity prices, Arkansas soybean producers only planted 2.82 million acres in 2020. This was an increase in acreage compared to 2019, and the second year in a row not surpassing 3 million acres. The last time soybean acreage dropped below 3 million acres was in 2003. Multiple major weather events in 2020, both in the U.S. and abroad, led to smaller-than-expected production in the U.S., South America and elsewhere. In August 2020, a derecho storm event brought straight-line winds that destroyed millions of acres of soybean in Iowa and other Midwestern states. La Nina-related dryness resulted in a smaller soybean crop in key production areas of Argentina and Brazil. These events and others, paired with an increase in global demand, largely by China, contributed to rising market prices during the later months of 2020. During harvest, soybean prices had risen to $1 or more compared to earlier in the production season.

Overall, disease and insect issues were not a problem in 2020. Most soybean-producing counties in Arkansas have some level of Palmer amaranth that has multiple herbicide resistance, and soybean production in these fields is becoming very difficult due to the loss of many herbicides. The 2020 growing season was the fourth year where the use of dicamba was labeled for over-the-top applications on dicamba-tolerant soybean. Soybean producers in Arkansas were restricted from applications of dicamba from 25 May to 31 October. Even with these restriction on applications, complaints were filed with the Arkansas State Plant Board for non-dicamba soybean fields showing dicamba symptomology.

Table 1. Arkansas soybean acreage, yield, and production by County, 2019–2020[a]

	Acres Planted		Acres Harvested		Yield		Production	
County	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**	**2019**	**2020**
	------------acres------------		------------acres------------		----bu./ac----		--------------bu.-------------	
Arkansas	160,500	162,500	159,600	160,600	58	57.5	9,254,000	9,235,000
Ashley	39,400	49,200	38,900	48,600	50.6	53.7	1,970,000	2,610,000
Chicot	145,000	164,500	143,200	162,500	54.1	52.2	7,750,000	8,483,000
Clay	89,000	101,500	88,500	99,800	48	52	4,250,000	5,190,000
Conway	*	16,400	*	16,200	*	32	*	518,000
Craighead	74,100	78,900	73,600	77,900	46.3	47.1	3,404,000	3,669,000
Crittenden	179,000	197,000	176,400	194,900	46.1	49	8,130,000	9,550,000
Cross	135,000	130,000	132,900	128,200	52	49	6,915,000	6,282,000
Desha	135,500	144,500	133,700	142,800	59.8	55.9	8,000,000	7,983,000
Drew	27,800	28,500	27,500	28,000	57.5	55.2	1,580,000	1,546,000
Faulkner	*	7,900	*	7,720	*	33.4	*	258,000
Franklin	*	2,300	*	2,160	*	35.9	*	77,600
Greene	52,800	66,400	52,300	65,600	45.8	45.5	2,396,000	2,985,000
Independence	25,600	22,600	25,400	22,300	40.9	41.6	1,038,000	928,000
Jackson	102,000	94,500	101,100	93,400	40.3	39.3	4,070,000	3,671,000
Jefferson	73,900	78,600	70,600	77,700	54.3	54.2	3,835,000	4,211,000
Johnson	*	3,600	*	3,540	*	33.3	*	118,000
Lafayette	*	6,200	*	6,090	*	51.7	*	315,000
Lawrence	46,800	48,200	46,700	47,600	39.9	42.1	1,864,000	2,005,000
Lee	*	112,000	*	110,500	*	53.8	*	5,945,000
Lincoln	55,400	52,400	55,100	51,200	57.2	52.9	3,150,000	2,708,000
Little River	9,100	*	*	*	30.2	*	275,000	*
Logan	*	5,800	9,100	5,690	*	36.2	*	206,000
Lonoke	94,200	92,000	93,400	91,000	48.2	46.1	4,500,000	4,195,000
Mississippi	235,000	256,000	233,500	252,500	47.6	51.9	11,126,000	13,105,000
Monroe	73,000	79,200	72,000	78,200	47.7	49.6	3,435,000	3,879,000
Phillips	*	180,000	*	178,400	*	53.9	*	9,616,000
Poinsett	159,000	163,000	157,500	160,900	51	50.3	8,029,000	8,093,000
Prairie	102,000	100,500	101,600	99,200	44	48.5	4,470,000	4,811,000
Pulaski	*	17,500	*	16,100	*	34.3	*	552,000
Randolph	27,000	25,300	26,400	24,900	42.5	44.2	1,123,000	1,101,000
St. Francis	133,000	138,500	132,200	136,500	50.3	48.8	6,650,000	6,661,000
Sebastian	*	3,900	*	3,830	*	32.6	*	125,000
White	25,700	21,400	25,000	21,000	43	46.8	1,075,000	983,000
Woodruff	105,000	116,000	103,500	114,500	43.8	49.4	4,536,000	5,651,000
Yell	*	6,600	*	5,980	*	41	*	245,000
Other Counties	275,900	46,600	267,500	43,990	40.8	33.9	12,732,000	1,489,400
State Totals	2,650,000	2,820,000	2,610,000	2,800,000	49.0	51.5	127,890,000	144,200,000

[a] Data obtained from USDA-NASS, 2021.

* Included in "Other Counties".

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2020 Soybean Research Verification Program

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

Abstract

The 2020 Soybean Research Verification Program (SRVP) was conducted on 17 commercial soybean fields across the state. Counties participating in the program included; Arkansas (2), Clay, Cross, Desha, Drew, Faulkner, Jackson, Jefferson, Lafayette, Lee, Monroe, Perry, Poinsett, Randolph, White, and Woodruff for a total of 919 acres. Grain yield in the 2020 SRVP averaged 65.1 bu./ac ranging from 34 to 75.2 bu./ac. The 2020 SRVP average yield was 15.1 bu./ac greater than the estimated Arkansas state average of 50 bu./ac. The highest yielding field was in Arkansas County, with a grain yield of 75.2 bu./ac. The lowest yielding field was in Faulkner County and produced 34 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 net returns. The purpose of the Soybean Research Verification Program (SRVP) is to verify the profitability of CES recommendations in fields with less than optimum yields or returns. The goals of 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 researched-based recommendations, 3) aid researchers in identifying areas of production that require further study, 4) improve or refine existing recommendations which contribute to more profitable production, and 5) incorporate data from SRVP into CES educational programs at the county and state level. Since 1983, the SRVP has been conducted on 659 commercial soybean fields in soybean producing counties in Arkansas. The SRVP has typically averaged 10 bu./ac better than the state average yield. This increased yield can mainly be attributed 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 production recommendations in a timely manner from planting to harvest. A designated County Extension Agent from each county assists the SRVP coordinator in collecting data, scouting the field, and maintaining continual contact with the cooperator. Weekly visits by the coordinators and County Extension Agents were made to monitor the growth and development of the soybeans, determine which cultural practices needed to be implemented, and monitor the type and level of weed, disease, and insect infestation for possible pesticide applications.

An advisory committee consisting of CES specialists and 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 2020 the following counties participated in SRVP; Arkansas (2), Clay, Cross, Desha, Drew, Faulkner, Jackson, Jefferson, Lafayette, Lee, Monroe, Perry, Poinsett, Randolph, White, and Woodruff. The 17 SRVP fields totaled 919 acres. Seven Roundup Ready 2 Xtend® varieties (Armor 46-D08, Asgrow AG46X0, Asgrow AG46X6, Asgrow AG48X9, Local Seed LS5386X, MorSoy 4846RXT, and Pioneer P42A43X.), three LibertyLink® varieties (DynaGro 49L65, Pioneer P45A29L, and Pioneer P47A76L), three Enlist E3® (Delta Grow DG48E10, Delta Grow DG48E49, and Pioneer P48T22E) and one conventional variety (NSGA DrewSoy 5.0) were planted, and CES recommendations were used to manage the SRVP fields (Table 1). 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 was utilized based on CES recommendations. Data collected included components such as stand density, weed populations, disease infestation levels, insect populations, rainfall amounts, irrigation amounts, and dates for specific growth stages (Tables 1 and 2).

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

Results and Discussion

Yield. The average SRVP grain yield was 65.1 bu./ac ranging from 34 to 75.2 bu./ac (Table 2). The SRVP average yield was 15.1 bu./ac higher than the estimated state average yield of 50 bu./ac. The difference has been attained many times since the program began and can be attributed in part to intensive management practices and utilization of CES recommendations. The highest soybean grain yield, 75.2 bu./ac, was planted with Pioneer P45A29L in Arkansas County.

Planting and Emergence. Planting was initiated with Arkansas County 2 on 15 April and concluded on 17 June in Perry County, with an average planting date of 21 May. The average seeding rate across all SRVP fields was 144,000 seeds/ac ranging from 120,000 to 180,000 seeds/ac. The average emergence date was 30 May ranging from 28 April to 25 June. On average, across all SRVP fields, eight days were required for emergence. Please refer to Tables 1 and 2 for agronomic information for specific locations.

Fertilization. Fields in the SRVP were fertilized according to University of Arkansas System Division of Agriculture's Soil Test Laboratory soil analysis and current soybean fertilization recommendations. Refer to Table 3 for detailed fertility information on each field.

Weed Control. Fields were scouted weekly, and CES recommendations were utilized for weed control programs. Refer to Table 4 for herbicide rates and timing.

Disease/Insect Control. Fields were scouted weekly and CES recommendations were utilized for disease and insect control programs. Refer to Table 5 for fungicide/insecticide applications.

Irrigation. All irrigated fields were either enrolled in the University of Arkansas Irrigation Scheduler Program or had moisture sensors placed in the field to determine irrigation timing based on soil moisture deficit. All irrigated fields utilized computerized hole selection programs such as PHAUCET or Pipeplanner to maximize irrigation efficiency. Thirteen of the 17 SRVP fields were furrow irrigated, 2 were flood irrigated, 1 was pivot irrigated, and 1 was non-irrigated.

Practical Applications

Data collected from the 2020 SRVP reflected higher soybean yields and maintained above-average returns in the 2020 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 CES estimated soybean production budgeted costs (Watkins, 2020).

Acknowledgments

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

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Table 1. Agronomic information for 2020 Soybean Research Verification Fields.

County	Variety	Field size	Previous crop[a]	Production system[b]	Seeding rate	Stand density
		ac			seed/ac	plants/ac
Arkansas 1	Asgrow AG46X6	38	Rice	LSI	140K	115K
Arkansas 2	Pioneer P45A29L	30	Soybean	ESI	125K	100K
Clay	MorSoy 4846RXT	39	Corn	FSI	130K	114K
Cross	Pioneer P48T22E	96	Rice	LSI	180K	129K
Desha	Asgrow AG46X6	50	Soybean	FSI	150K	148K
Drew	Armor 46-D08	60	Rice	LSI	160K	100K
Faulkner	Delta Grow DG48E10	54	Soybean	LSNI	150K	105K
Jackson	Delta Grow DG48E49	19	Rice	LSI	140K	97K
Jefferson	Pioneer P43A42X	86	Corn	ESI	140K	128K
Lafayette	Asgrow AG46X0	58	Corn	FSI	120K	100K
Lee	Asgrow AG48X9	39	Soybean	FSI	140K	123K
Monroe	Asgrow AG46X6	70	Rice	FSI	140K	137K
Perry	Local Seed LS5386X	52	Soybean	LSI	140K	124K
Poinsett	NSGA Drewsoy 5.0	70	Soybean	FSI	150K	125K
Randolph	Pioneer P47A76L	29	Rice	LSI	140K	125K
White	Pioneer P47A76L	24	Soybean	LSI	140K	112K
Woodruff	Dyna-Gro 49L65	105	Rice	LSI	160K	115K
Average		**59**			**144K**	**117K**

[a] Rice = *Oryza sativa;* Corn = *Zea mays;* Soybean = *Glycine max*;

[b] Production Systems; ESI = Early-season irrigated; FSI = Full-season irrigated; LSI = Late-season irrigated; LSNI = Late-season non-irrigated.

Table 2. Planting, emergence, and harvest dates and adjusted soybean grain yield for 2020 Soybean Research Verification Program Fields.

County	Planting	Emergence	Harvest	Yield[a] adj. to 13% moisture
	------------------------date------------------------			bu./ac
Arkansas 1	5/30	6/8	10/18	52.5
Arkansas 2	4/15	4/28	10/3	75.2
Clay	5/20	5/27	10/17	65.3
Cross	6/1	6/9	11/1	48.5
Desha	5/5	5/18	10/4	72.0
Drew	6/3	6/9	11/4	54.0
Faulkner	6/5	6/15	11/6	34.0
Jackson	6/1	6/6	11/4	59.6
Jefferson	4/18	4/29	9/23	74.0
Lafayette	5/12	5/20	10/7	64.3
Lee	5/14	5/20	10/2	62.0
Monroe	5/16	5/23	10/28	67.0
Perry	6/17	6/25	11/5	59.4
Poinsett	5/3	5/13	10/8	64.5
Randolph	6/6	6/14	10/16	41.4
White	6/3	6/9	11/3	40.8
Woodruff	6/13	6/23	11/5	41.9
Average	**5/21**	**5/30**	**10/20**	**65.1**

[a] 2020 Arkansas state soybean average yield was 50.0 bu./ac.

Table 3. Soil test results, fertilizer applied and soil classification for 2020 Soybean Research Verification Fields.

County	Soil test results pH	P	K	Pre-plant applied fertilizer N-P- K	Soil classification
		--------ppm--------		lb/ac	
Arkansas 1	6.2	30	112	0-0-60	Stuttgart, Dewitt silt loam
Arkansas 2	6.2	34	110	0-0-60	Rilla, Hebert silt loam
Clay	6.8	15	71	0-0-0	Falaya silt loam
Cross	6.6	10	127	0-60-75	Crowley and Hillemann silt loam
Desha	6.5	84	84	0-0-90	Sharkey and Desha clays
Drew	7.4	30	188	0-90-45	Portland clay
Faulkner	6.9	11	303	0-0-0	Perry clay
Jackson	6.4	18	125	1 ton poultry litter	Amagon, Forestdale silt loam
Jefferson	7.2	78	86	0-0-120	Rilla, Roxana, McGehee silt loam, Perry clay
Lafayette	7.2	85	285	0-0-0	Billyhaw clay, Caspiana silt loam
Lee	6.5	25	85	0-54-108	Calloway, Hillemann silt loam
Monroe	6.7	80	96	0-0-90	Foley-Calhoun-Bonn and Grenada silt loam, Lafe-Bonn complexes
Perry	6.2	29	236	0-0-0	Perry clay
Poinsett	7.1	23	73	0-50-100	Hillemann silt loam
Randolph	7.0	5	135	0-80-50	Jackport silty clay, Overcup silt loam
White	6.4	26	71	0-0-120	Calloway silt loam
Woodruff	6.7	12	56	0-80-120-.5B	Calhoun, Calloway silt loam

Table 4. Herbicide rates and timing for 2020 Soybean Research Verification Program Fields.

	Herbicide (rates/ac)	
County	**Burndown/Pre-emergence**	**Post-emergence**
Arkansas 1	Pre-emerge: 1.25 pt Boundary® + 24 oz RoundUp® PowerMax™	3 pt Warrant® + 1 qt Cornerstone
Arkansas 2	Pre-emerge: 1.5 pt Boundary	1.45 oz Pursuit® + 2 oz Zidua WG + 1 qt Liberty®
Clay	Pre-emerge: 1.25 pt *S*-metolachlor + 0.3 lb metribuzin	1st: 0.33 oz Classic® + 16 oz Classic + 1 qt glyphosate
Cross	Pre-emerge: 1.5 pt. Galvan®	1st: 1 qt glyphosate + 1 qt Enlist
Desha	Pre-emerge: 2 oz Valor + 1.5 pt Me-Too-Lachlor	1st: 1 qt Cornerstone 2nd: 1.5 pt Flexstar® + 1.2 pt Dual Magnum II + 1 qt Cornerstone
Drew		1st: 1qt Prefix® + 1 qt Cornerstone 2nd: 1 qt Cornerstone + 1 pt Dual Magnum II + 1 pt Ultra Blazer®
Faulkner	Pre-emerge: 1 qt Ledger® + 1 qt glyphosate + 1 oz Sharpen®	1st: 1 qt Interline® + 1 qt Enlist 2nd: 1 qt glyphosate + 1 qt Enlist
Jackson	Pre-emerge: 1.5 pt Enlist® + 1 qt glyphosate + 1 pt *s*-metolachlor + 0.33 lb metribuzin	1st: 1 qt Roundup PowerMax + AMS
Jefferson	Burndown: 40 oz Cornerstone® + 8 oz 2,4-D + 1.5 oz Afforia® Pre-emerge: 1 qt Boundary	1 qt Cornerstone + 2 oz Zidua WG Harvest Aid: 1 pt Gramoxone + 1% NIS
Lafayette	Burndown: 0.67 lb Metrubuzin 75 + 3 oz Fierce + 1 qt Credit®	26 oz RoundUp PowerMax + 3.25 oz Zidua SC
Lee	Pre-emerge; 1.33 pt Boundary + 2 oz Zidua® WG	1 qt Cornerstone + 0.4 oz First Rate® + 12 oz Outlook
Monroe	Pre-emerge: 1 qt Cornerstone + 1 pt Dual Magnum® II	1st: 22 oz RoundUp PowerMax + 1.33 pt Dual Magnum II 2nd: 22 oz RoundUp PowerMax
Perry	Pre-emerge: 40 oz paraquat + 1.25 pt *S*-metolachlor	1st: 1 qt glyphosate + 1.5 pt Blazer® + .5 oz Classic + 1 pt *S*-metolachlor
Poinsett	Pre-emerge: 3 oz Fierce®	1st: 8 oz Intensity® + 1.25 pt *S*-metolachlor +1% COC
Randolph		1st: 1 qt Liberty + 8 oz Intensity® 2nd: 1 qt Liberty
White	Pre-emerge: 40 oz Gramoxone® + 3 oz Fierce® + 7 oz MTZ	1st: 8 oz Clethodim +1% COC 2nd: 36 oz Glufosinate 280
Woodruff		1st: 40 oz Glufosinate 280 + 1.25 pt *S*-metolachlor 2nd: 32 oz Glufosinate 280

Table 5. Fungicide and insecticide applications for 2020 Soybean Research Verification Program Fields.

County	Aerial web blight	Frogeye leaf spot	Bollworms/ Defoliators	Stink bugs
Arkansas 1	--	--	1.28 oz Heligen + 1% COC	--
Arkansas 2	--	--	--	--
Clay	--	--	--	--
Cross	--	--	--	--
Desha	--	--	--	--
Drew	--	--	--	--
Faulkner	--	--	1.28 oz Heligen	--
Jackson	--	--	--	--
Jefferson	--	--	--	--
Lafayette	--	--	--	6.4 oz Brigade® + 0.5 lb acephate
Lee	--	--	--	--
Monroe	--	--	--	--
Perry	--	--	1.9 oz Lambda-Cyhalothrin	--
Poinsett	--	--	--	--
Randolph	--	--	1.28 oz Heligen	--
White	--	--	--	--
Woodruff	--	--	6 oz Intrepid Edge	--

Soybean Science Challenge: Sustaining Education During a Pandemic

J. C. Robinson[1] and D. Young[1]

Abstract

The Soybean Science Challenge (SSC) continues to support Arkansas STEM (science, technology, engineering, and mathematics) educational goals, is aligned with the Next Generation Science Standards (NGSS and engages junior high and high school students in active learning and the co-creation of knowledge through support of classroom-based lessons and applied student research. The SSC educates and engages junior high and high school science students and teachers in 'real-world' Arkansas specific soybean science education through original NGSS aligned curriculum in 7E and Gathering Reasoning and Communicating (GRC)-3D format and a continuum of educational methods which include: teacher workshops, online and virtual education, NGSS aligned mini-lessons for science classrooms, community gardens, personal mentoring, student-led research and corresponding award recognition, and partnerships with state and national educators, agencies, and the popular media. The COVID-19 global pandemic altered the educational landscape in 2020 and continues to do so. The new educational environment has seen an increase in virtual classrooms, online courses, and interactions with Zoom©. The Soybean Science Challenge (SSC), by nature of its existing design and methodology, was and is amid these methods by launching online Next Generation Science Standards (NGSS) aligned Gathering Reasoning and Communicating (GRC)-3D and 7E lesson plans for teachers, adding an online course, adding NGSS aligned mini-lesson videos for the science classroom, and adding virtual field trips to the list on the Soybean Science Challenge website. The Challenge also sponsored the virtual Arkansas Science Teacher Association Conference, and the SSC Coordinator taught virtual workshops on bringing agriculturally based lessons into science classrooms. The Soybean Science Challenge virtually judged participants at both the regional and state level, and SSC added a junior level award at regional science fairs. Through the SSC, teachers now have access to a plethora of educational instructions that bring real-world agricultural critical thinking both into the classroom and the homes of students.

Introduction

The Soybean Science Challenge (SSC) has been active and growing since its inception in 2014. The SSC has always used a 'high tech' approach through online classes, virtual field trips, virtual mentoring, and communication through emails and Zoom©. It has also balanced this with 'person to person' interactions at teacher workshops, conventions, and science fairs. The goal of the SSC is to support a higher level of student learning and research regarding the importance of soybean production and agricultural sustainability in the state of Arkansas. For this to happen, the SSC has worked tirelessly at developing relationships with Arkansas' teachers by supplying them with cutting-edge educational tools and the knowledge they need through online teacher in-service and face-to-face workshops. The SSC has also worked with students through mentorship and the online course. The real questions are, "have we made a difference, especially in light of the COVID-19 pandemic that has closed schools?" and "are we still making an impact?"

Procedures

The Soybean Science Challenge is, foremost, an instructional tool for teachers and a real-life critical thinking program for students (Ballard and Wilson 2016). One of the flagships of this program is the SSC cash awards given out to soybean-related science fair projects at the regional science fairs, the FFA Agriscience Fair, and the State Science Fair. For students to enter the SSC award competition at these fairs, students must submit a project for judging that is either soybean-based or an agriculturally sustainable project and have passed the six-module SSC online course. Students must receive at least an 80% or better on each quiz before they can progress to the next module. Pre- and post-course quizzes qualitatively measure student learning. Student research for these projects is supported by vetted science-based resources, the soybean seed store, and researcher mentoring for students interested in projects that require a higher level of exploration than available at the local high school.

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To determine the outcomes and impact of SSC during COVID-19, the number of students enrolled in the SSC online course and the fairs over the last year, plus usage of resources were tabulated and noted in Tables 1 and 1A. This includes Spring of 2021, based on the funding cycle. Community Garden and online course numbers are reported to date at the time of article submission.

Results and Discussion

A series of key factors contribute to the evidence of real learning-based results in the SSC pm. For 2020–2021, the SSC pre-test, student learning, and knowledge averaged 35%; however, the post-test average was 97%, a marked increase in student knowledge of soybean attributed to the completion of the online course. Another factor is the number of students taking and completing the course. The number of students completing the online course in 2020–2021 was 119. This number is down from last year, but the reduced number could be due to many factors associated with virtual schools, a no school, and hybrid schools as a result of the COVID-19 pandemic. Fifty-six percent (56%) of students completed the course with a 97% or higher total score. This is a strong indication that the course is successful at teaching students about soybean.

Along with the online course, the SSC student research awards presented at Arkansas regional and state science fairs played a major role in increasing student knowledge about sustainability and the impact of the Arkansas soybean industry. This year, the number of projects increased due to the addition of the Jr. Division SSC Award. Due to COVID-19, one regional fair was canceled after only one project was submitted, another fair only had 12 participants, and except for the Central Arkansas Regional Science and Engineering fair, all the fairs saw a drop of over 50% in entries. Even so, each fair had at least one or more entries in the SSC. This includes the aforementioned canceled regional fair; the single project submitted was an SSC project, and that project was judged. Despite COVID-19 issues and challenges, SSC had 7 projects enter the virtual state science fair. Judges were provided an abstract and a video of each student researcher explaining their project, and students were interviewed via Zoom©. This year, at least one regional SSC winner was awarded an International Science and Engineering Fair (ISEF) Finalist position. This award is only given to those who receive the ‘Best in Fair’ awards. This continues to demonstrate an increase in the quality and rigor of projects competing for the SSC award in the area of soybean and agricultural sustainability and suggests that the SSC is a successful program for junior high and high school students by providing student information and education to reach a higher level of research.

Through this program, the Arkansas Soybean Promotion Board (ASPB) invested $8200 this year in student research awards for science projects with a soybean-related focus. This recognition raised the educational profile about soybean in Arkansas and the importance of ASPB’s goal of supporting effective youth education emphasizing agriculture. A total of 41 individual projects were judged, with 17 student awards presented on behalf of the ASPB.

The SSC has also chosen this year to continue to focus on helping teachers bring critical thinking into the classroom through agriculture. In 2016, science teachers throughout the state were required to start phasing in the new Arkansas State Science Standards (based on the NGSS) into their classrooms. This included lessons to be written in the new GRC-3D format. To this end, the SSC now has ten different soybean and/or agriculturally based lessons written in both the standard 7E format and in the new GRC-3D format for teacher use. The SSC also has nine different Virtual Field Trips (VFT) with NGSS Aligned manuals for teachers to use. All are available in paper form and online at https://uaex.uada.edu/soywhatsup website. Over 100 lesson plans and VFT lesson manuals have been distributed through workshops and emailed to teachers this grant year. The SSC has written and uploaded 11 different virtual mini-lessons to the soywhatsup website covering a variety of subjects that are NGSS aligned and bring an agricultural bent to everyday science concepts.

During the COVID-19 pandemic, the overarching question was ‘During this difficult time, will the Soybean Science Challenge Program be an asset to students and teachers?’ Schools have adjusted multiple times during the pandemic from virtual, hybrid, and in-person. Virtual and hybrid teaching is done primarily via Zoom© or other web-based platforms. All science fairs chose to host ‘virtual’ fairs, which required students to submit videos for their presentations and/or participating in live virtual interviews, which decreased the number of students participating considerably. To see the success of the SSC during this pandemic, one only needs to look at the numbers. The SSC had 41 entries in this year’s science fairs, a record high even when including the new Jr. Division award. This increase also occurred despite the added video component. At least one of the regional winners was awarded the ISEF finalist position, showing the increased quality and caliber of projects judged. The Science Fair 101 online course had 13 participants enroll, and the Science Fair 101 Resources online course had 12 enrolled. The online teacher in-service course had 6 participants enroll this year. These enrollment numbers are positive considering the length of the course and the strain teachers were under to teach in unfamiliar circumstances during the pandemic. The SSC’s online educational tools have shown to be a strong asset in helping teachers be successful in the virtual classroom.

The second question to consider for SSC is, “are we still making an impact?” The numbers show that, yes, the SSC is making an impact, but the stories tell more. The SSC team was told several times by science fair directors how much the support of the SSC means to them, especially during COVID-19. The SSC team has been told by several teachers, especially junior high teachers, what a difference the SSC has made to their students and the impact the SSC has had on their classrooms. Students are excited to research soybean projects and want to win! The SSC team has even been emailed and called by parents and told how much it has influenced their child's decision regarding future careers in agriculture. These stories cannot be quantified, but they do demonstrate some of the impacts the SSC is having in the classroom and the home. It shows people notice our presence and increases the likelihood that students, teachers, and parents will spread the news about the Soybean Science Challenge!

Practical Applications

The Soybean Science Challenge makes agricultural sustainability relevant and meaningful for Arkansas junior high and high school students and helps teachers teach through real-world critical thinking lessons, mini-lessons, and virtual field trips. The success of this project shows that high school and junior high school students are up to the task of handling real-world, real-time problems that require critical thinking while being exposed to the world of agriculture in ways they never expected to see. Students now understand that agriculture is a STEM field that needs highly educated youth to take the reins of the future from our current professionals. They are continuing to learn that agriculture is more than farming, it is a technical career that offers them the opportunity to make a difference on a worldwide scale. The Soybean Science Challenge's goal is succeeding, helping youth to discover the world of agriculture.

Acknowledgments

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Table 1. Year-to-date Soybean Science Challenge online course enrollment: 1 July 2020–9 April 2021.

Student Enrollment	Current Student Course Completion	Average Student Pre-Test Score	Average Student Post-Test Score	Teacher In-Service Enrollment
119	68	35%	97%	12

Table 1A. Year-to-date Science Fair 101 online course enrollment: 1 Nov. 2020–9 April 2021.

Student/Teacher Enrollment	Course Completion	Average Pre-Test	Average Post-Test
13	13	80%	90%

Table 2. Soybean Science Challenge products, audience, activities and impact 2020–2021.

Product	Target Audience	Activities and Impact
Soybean Science Challenge Online Course–Student	6–12th grade	**119** Students enrolled; **68** completed
Soybean Science Challenge Online Course–Teacher In-Service (7 Hrs.)	Science Teachers	**6** Teachers enrolled; **4** completed
Soybean Science Challenge Online Course–Teacher Resources	Science Teachers	**12** Teachers
Science Fair 101 Online Course	Science Teachers and Students	**13** Users (Teachers and Students). All completed the course.
Mini Ag related lessons for the science classroom	Science Teachers and Students	Teachers can either download the PowerPoint or show the video.
Partnered with 7 regional science fairs, the FFA Agriscience Fair, and the Arkansas State Science Fair. Virtually judged 9 Ark. science fairs, 2020–2021	Science Teachers/Students Science Fairs	**55** articles published or posted in newspapers or on websites; **41** individual student projects with **17** student awards; Totaling **$8,200**
Soybean Science Challenge and Science Fair 101 Online Course, Science Fair Awards, Virtual mini lessons for the classroom Constant Contacts	Science Teachers/Students	Released multiple times to ARSTEM List Serve; ASTA List Serve, Ark. Educational Cooperatives, personal emails; mailed to over **500** Arkansas Science and Ag Teachers each year for 2020–2021.
Supported and participated in Virtual Arkansas Science Teachers Association Conference, October 2020	1–12th grade Science teachers and students	Thirty participants in the conference, Soybean Science Challenge was displayed prominently in the conference's online brochure. Did presentation on bringing Agriculture in the classroom.
Presented to 4 Award-Winning Science Teachers in Washington State a workshop on bringing Ag-related science into the classroom.	2–6th grade Science Teachers	Teachers took Soybean Science Challenge resources and presented them at their schools.
Did a one-on-one workshop with a science teacher in Poyen, Ark. on how to do a science fair and how to send students to Ouachita Mountain Regional Science Fair.	9–11th grade teacher	
Did a one-on-one workshop with a curriculum coordinator in New Mexico on how to bring Ag into the science classroom. Handed out lessons and VFTS for her Ag and science teachers.	High School Ag Teachers	Coordinator took resources and presented them to her Ag and science teachers.

Continued

Table 2. Continued.

Product	**Target Audience**	**Activities and Impact**
Soybean Science Challenge Seed Store announcement	High School Students/Teachers	ASTA List Serve; Ark. Educational Cooperatives; personal emails; soywhatsup web page; workshops; teacher conferences; mailed to over 500 Arkansas science and Ag teachers.
Soybean Science Challenge Seed Packets	Science Teachers/Students	Over **100** distributed at workshops and other Soybean Science Challenge events and mailings.
Bringing Ag into the classroom workshop with teachers in Washington State	Science Teachers	Four award-winning teachers participated in this workshop. These teachers, in turn, took the information to their local schools
Soy Science Scholars Booklet; Soybean Science Challenge Progress Report	ASPB; CES	Mailed to Arkansas Soybean Promotion Board and University of Arkansas System Division of Agriculture's Cooperative Extension Service.
Soy What's Up? Flier on resources found on the Soybean Science Challenge webpage: www.uaex.uada.edu/soywhatsup	Science Teachers/Students	ASTA List Serve; Ark. Educational Cooperatives; personal emails; soywhatsup web page; virtual conferences workshops, mailed to over **500** Ark. science and Ag teachers.
Media Coverage of Soybean Science Challenge Events	Science Research, Agriculture Educators, and general public	**55** articles in newspapers, magazines, and other publications
2016–2017 Arkansas High School Science Project Development Guide	Science Teachers/Students	Posted on soywhatsup webpage.
Soybean Science Challenge Direct Contacts regarding online courses/events/activities	Science Teachers/Students Other partners, i.e., ADE, STEM, Educational Coops	Over **10,000** direct contacts through Constant Contact, ARSTEM Science List Serve, Arkansas Educational Cooperatives, and individual science teacher/student emails.
Developed/produced 5 Soil and Water Conservation research-based Virtual Field Trips with NGSS Aligned Lesson Manuals for 2020–2021. Developed/produced 3 additional Soybean-based NGSS Aligned (in 7E and GRC-3D Format) lesson plans for classroom use for 2020–2021.	Science Teachers/Students	**18** schools participated; over **360** youth from diverse backgrounds; over **68** University of Arkansas System Division of Agriculture Cooperative Extension Service faculty/staff participated; over **50** questions fielded by CES faculty/staff; Videos and Teachers Guide posted on soywhatsup webpage. Mailed out over **50** lessons to interested teachers.
Soybean Science Challenge Community Gardens	Science teachers, students, County Ag Agents, Master Gardeners, Community Garden Participants	Currently **37** gardens across the state for 2020–2021. Advertising through Constant Contact, email, and on the soywhatsup website, reaching over **1000** contacts. COVID-19 has impacted schools choosing to plant gardens. As restrictions continue to lift, we anticipate an upswing in school registrations.

Continued

Table 2. Continued.

Products	Target Audience	Activities and Impact
Developed/produced 3 additional Soybean-based NGSS Aligned (in 7E and GRC-3D Format) lesson plans for classroom use for 2020–2021.		Mailed out over 50 lessons to interested teachers.
Soybean Science Challenge Community Gardens	Science teachers, students, County Ag Agents, Master Gardeners, Community Garden Participants	**Currently 37 gardens** across the state for 2020–2021. Advertising through Constant Contact, email, and on the soywhatsup website, reaching over 1,000 contacts. COVID-19 has impacted schools choosing to plant gardens. As restrictions continue to lift, we anticipate an upswing in school registrations.

Classification of Soybean Chloride Sensitivity using Leaf Chloride Concentration of Field-Grown Soybean: 2020 Trial Results

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Abstract

Soybean [*Glycine max* (L.)Merr.] varieties are currently categorized as being chloride (Cl) includers, excluders, or a 'mixed' population. A more specific rating system is needed to differentiate between true Cl excluding varieties and a considerable proportion of varieties that may be mixed includer/excluder plant populations or a population of plants having multiple genes that influence Cl uptake. A field-based Cl monitoring program has been developed in conjunction with the Arkansas Soybean Performance Tests to provide a more detailed categorization of Cl tolerance in soybean varieties. A 1 to 5 rating system was developed and implemented on 181 varieties belonging to relative maturity groups 3.5 to 5.9 based on trifoliolate leaf-Cl concentrations included in the University of Arkansas System Division of Agriculture's Rohwer Research Station location of the 2020 Arkansas Soybean Performance Tests. Trifoliolate-leaf samples were collected when soybean reached the R3 to R4 growth stage. Ratings of 1 (strong excluder), 2, 3 (intermediate), 4, and 5 (strong includer) were assigned to 55, 14, 46, 23, and 43 varieties, respectively. The detailed rating system provides producers with more information regarding the relative Cl tolerance of available soybean varieties

Introduction

Soybean varieties have historically been categorized as being chloride (Cl) includers, excluders, or a 'mixed' population. Cox (2017) showed that this three-class categorization and the method of assigning the trait leads to inaccurate categorization of some varieties, and a more robust system is needed to accurately describe soybean tolerance to Cl. Abel (1969) concluded that a single gene controlled Cl inclusion attributes of soybean, which contributed to the oversimplification of the Cl trait rating. Zeng et al., (2017) recently suggested that multiple genes may control Cl uptake by soybean adding complexity to an already poorly understood phenomenon. Research by Cox (2017) supports this hypothesis and highlights the varying levels of Cl inclusion and exclusion across a wide range of soybean varieties. Individual plants of some commercial varieties are mixed populations, with some plants being strong includers with high Cl concentrations, some being strong excluders with very low Cl concentrations, and some plants having intermediate Cl concentrations. The large range of Cl concentrations in individual plants suggests that there may be multiple genes that regulate Cl uptake. Traditional methods of assessing Cl sensitivity of soybean varieties involve short greenhouse trials (completed before reproductive growth begins) with a limited number of plants (5 – 10), which limits the scope and applicability of the results. Our research objective was to examine leaf Cl concentration of commercial soybean varieties in a field production setting to assign a numerical Cl rating from 1 to 5, which provides a more robust classification of Cl tolerance.

Procedures

All varieties entered in the Arkansas Soybean Variety Performance trials were sampled at the Rohwer Research Station in 2020. The trial included late 3, early 4, late 4, and 5 maturity group categories that ranged from 3.5–5.9. Soybean was planted on 15 June 2020 and emerged on 20 June 2020 in a field having soil mapped as a Desha silt loam following corn (*Zea mays* L.) in the rotation. Soybean was planted on beds spaced 38-in. apart, with each plot having 2 rows. Plots were furrow irrigated 6 times based on an irrigation scheduling program and managed using the University of Arkansas System Division of Agriculture's Cooperative Extension Service guidelines for furrow-irrigated soybean. Based on the information provided by the originating company or institution, varieties were divided into three relative maturity (RM) ranges RM 3.5–4.4, RM 4.5–4.9, and RM 5.0–5.9. Soybean varieties with Xtend® technology were tested separately from varieties with all other herbicide technologies. Varieties were arranged as a randomized complete block design with three replications. Additional details of this trial along with yield

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data are available from Carlin et al., (2020). Varieties with known chloride tolerance (strong includer, strong excluder, and mixed) were included in each block of each maturity group and herbicide grouping to serve as a 'check' to provide a baseline response for relative comparison amongst varieties and locations within the field.

A composite sample comprised of one recently matured (top three nodes) trifoliolate leaflet (no petiole) collected from 10 individual plants in each plot and placed in a labeled paper bag when soybean was in the R3 to R4 stages. Plant samples were oven-dried, ground to pass a 2-mm sieve, and extracted with deionized water as outlined by Liu (1998). Extracts were analyzed for Cl on an inductively coupled plasma atomic emission spectrophotometer.

The tissue-Cl concentration mean and standard deviation (SD) were calculated for each variety, and Cl concentration was ranked from lowest to highest. A numerical rating of 1 to 5 was assigned to each variety, with 1 indicating a strong excluder (very low Cl concentration), 3 indicating a mixed population or a variety having an intermediate Cl concentration, and 5 indicating a strong includer variety with a very high Cl concentration. The ratings of 2 and 4 represented the gradient between the adjacent ratings. Breakpoints for specific categories in the numerical rating system shifted slightly from each soybean variety grouping to the next due to differences in the Cl concentrations of known check varieties that were included for standardization across the entire trial.

Results and Discussion

The mean leaflet-Cl concentrations ranged from 82 to 15,386 ppm Cl across the 181 varieties sampled (Tables 1 – 3). In general, the standard deviation increased linearly as the mean Cl concentration increased, suggesting greater variability in variety Cl concentrations for mixed and includer varieties. The late 3 and early 4 tests had the lowest total varieties with 21 entries combined. Within this group, 5 varieties were identified as strong excluders in category 1 (Table 1). For this maturity group class (late 3 and early 4), over half of the total varieties were classified as a 3 or mixed population. This is a significant change from the 2019 data that indicated many of the varieties in the late 3 and early 4 maturity groups were includers (Roberts et al.,, 2019). However, it appears that there are limited options available for producers who need Cl excluder varieties in the late 3 and early 4 maturity group range. For producers that may have areas prone to increased soil or irrigation water Cl concentrations, there was no maturity group 3 varieties that showed Cl tolerance as the lowest rating was a category 3, and the only other maturity group 3 variety was rated as a strong includer.

The late 4 class of varieties had the most overall entries with 123 and mean Cl concentrations ranging from 100–15,386 ppm. Within this maturity group range, 45 varieties were identified as being strong excluders which all fell within a range of Cl concentrations (Table 2. 100–329 ppm Cl). There were only four varieties that fell within ranking 2 as moderate excluders. In contrast to 2019, the vast majority of the entries into this late 4 class of varieties were identified as mixed or includers (Roberts et al., 2019). Twenty-three varieties fell within category 3 or mixed trait varieties. The moderate and strong includers were similar to the strong excluder category with 45 total varieties falling under Cl rankings of 4 or 5. These results indicate that there is an even distribution of Cl excluders and includers within the late 4 class of varieties allowing producers to choose from a wide variety of herbicide-tolerant traits and agronomic characteristics.

For the maturity group 5 class, there were a total of 37 entries, and the mean Cl concentration ranged from 192–12,172 ppm across this group of varieties. Similar to the late 3 and early 4 class of varieties, there was a limited number of varieties (5) identified as strong excluders (Table 3) with the majority of the varieties falling in the rankings of 4–5 in terms of Cl tolerance. Roughly half of the varieties in the maturity group 5 class were identified as either moderate or strong includers. It appears that there are limited varieties that have strong Cl exclusion ratings in the maturity group late 3, early 4, and 5 classes.

The very low standard deviation for varieties with a rating of 1 indicates that the composite sample Cl concentration variability among blocks was minimal for excluders, which would be expected based on research by Cox et al., (2018). The Cl concentration thresholds for assigning numerical variety rating will likely change from one year to the next as the fields used for the variety trials, rainfall amounts and timing, total irrigation water use, environmental factors, and irrigation water Cl concentrations may vary from year to year. The overall Cl concentrations presented in the 2020 field trial results are much larger than values reported for 2019 but similar to 2018. The field location in 2020 was the same field used in 2018 and our results from several years of implementing field-based assessment of Cl tolerance indicates several factors: 1) fields with high levels of Cl appear to persist over time, 2) identification of Cl tolerance or sensitivity can be accomplished over a wide range of soils and environments, 3) slight shifts in measured Cl tolerance can occur within a variety over years.

Practical Applications

Accurate variety Cl sensitivity ratings are important for growers that have irrigation water with high Cl concentrations or fields that may harbor Cl ions in the soil profile due to poor internal drainage from clayey soil texture or elevated sodium (Na) concentrations. The numerical rating system (1 to 5) based on the Cl concentrations of field-grown plants provides clear ratings that more accurately represent the variability of Cl uptake by soybean varieties than the 3-tier rating system of includer, excluder, and mixed. One primary benefit of the new 1 to 5 rating system is that it provides higher resolution data for producers to use when selecting soybean varieties. Producers can now compare Cl tolerance with higher resolution across a wide range of herbicide tolerance and agronomic characteristics. If the producer is in search of a variety with specific traits and a high level of Cl tolerance, this new ranking system can allow him to tease out differences in Cl tolerance amongst varieties that would traditionally be lumped together as "mixed." When comparing 2 varieties with similar traits, a producer can now differentiate between varieties traditionally classified as mixed and select a variety rated as 2 over one rated as 4 knowing that there are distinct differences in the Cl tolerance of those two varieties. The new rating system will especially benefit growers that farm with marginal irrigation water high in Cl concentration.

Acknowledgments

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Table 1. Mean and standard deviation (SD) leaflet chloride (Cl) concentrations and preliminary rating for late Maturity Group 3 and early Maturity Group 4 varieties (3.5–4.4) as determined from field-grown plants at the University of Arkansas System Division of Agriculture's Rohwer Research Station Soybean Variety Performance trial in 2020. A rating of 1 means strong excluder and a rating of 5 means strong includer.

Variety[a]	Mean	SD	Rating[b]
	ppm	ppm	
Armor 44-D92	82	8	1
Local LS4299XS	104	9	1
Progeny 4265RXS	107	10	1
Dyna-Gro S43XS70	148	2	1
REV 4311X	155	51	1
Asgrow AG 43X0	933	55	2
Armor 44-E44	1889	322	2
Dyna-Gro S43EN61	2042	776	3
Mission A4448X	3231	21	3
Credenz CZ 3930GTLL	3267	190	3
USG 7447XTS	3358	686	3
DM 44X31	3461	1556	3
Credenz CZ 4410GTLL	3564	2153	3
Credenz CZ 4341X	3838	47	3
Progeny 4241E3	4422	1170	3
Local LS4407X	4625	1671	3
LGS4464RX	4808	1094	3
Local LS3906GL	4898	1879	3
Armor 44-D49	5277	1314	3
Credenz CZ 4280X	5524	383	4
Local LS3976X	6511	1774	5

[a] Abbreviation key: DM = DONMARIO; LGS = LG Seeds; USG = UniSouth Genetics, Inc.

[b] Varieties may have varying leaflet chloride concentrations within the same numerical rating due to blocking within the field.

Table 2. Mean and standard deviation (SD) leaflet chloride (Cl) concentrations and preliminary rating for late Maturity Group 4 varieties (4.5–4.9) as determined from field-grown plants at the University of Arkansas System Division of Agriculture's Rohwer Research Station Soybean Variety Performance trial in 2020. A rating of 1 means strong excluder and a rating of 5 means strong includer.

Variety[a]	Mean	SD	Rating[b]	Variety[a]	Mean	SD	Rating[b]
	ppm	ppm			ppm	ppm	
Integra 54660NS	100	7	1	LS4806XS	220	116	1
AgriGold G4820RX	102	44	1	Pioneer P47A76L	222	124	1
LGS4899RX	117	34	1	AgriGold G4620RX	230	102	1
Taylor T4880XS	127	27	1	Local ZS4694E3S	235	128	1
Progeny 4602LR	129	17	1	Dyna-Gro S45ES10	236	104	1
USG 7489XT	129	38	1	Credenz CZ 4730X	237	63	1
Armor 48-D25	131	51	1	Delta Grow DG46X65/STS	237	71	1
Progeny 4821RX	132	30	1	Pioneer P46A86X	245	118	1
Local LS4999X	133	6	1	Delta Grow DG48E49/STS	271	22	1
S16-5504R	137	36	1	GT Ireane	274	24	1
Pioneer P49A41L	140	57	1	Dyna-Gro S49XT70	309	135	1
Local LS4565XS	145	84	1	LS4706GL	311	30	1
Asgrow AG 46X0	147	44	1	Progeny 4816RXS	329	253	1
Armor 47-E02	152	56	1	Progeny 4902E3	349	54	2
Local LS4795XS	157	28	1	Integra 54816N	511	165	2
Dyna-Gro S46XS60	158	75	1	Armor 46-D09	582	314	2
Dyna-Gro S47XT20	158	42	1	R17-2000	1735	155	2
Pioneer P48A60X	160	107	1	Petrus Seed 4619 GTS	3533	1495	3
Dyna-Gro S46ES91	160	77	1	Delta Grow DG45E28XP	3548	186	3
Asgrow AG 46X6	163	38	1	Credenz CZ 4770X	3580	721	3
Petrus Seed 4916 GT	167	33	1	R13-14635RR:0010	3790	2296	3
Progeny 4620RXS	171	62	1	R17C-1266	3860	1691	3
REV 4927X	172	58	1	Delta Grow DG45E10	4002	843	3
Delta Grow DG4880	173	90	1	Credenz CZ 4869X	4197	1359	3
Delta Grow DG47E20/STS	178	49	1	Delta Grow DG47X95/STS	4218	1927	3
Progeny 4775E3S	187	19	1	USG 7461XT	4257	1763	3
Asgrow AG 48X9	191	34	1	Taylor T4990XS	4279	1990	3
Armor 46-E50	192	63	1	Armor 49-D14	4338	302	3
Delta Grow DG48X45	195	46	1	R13-14635RR:0009	4369	1275	3
Mission A4618X	204	51	1	R16-247	4408	2167	3
Go Soy 463E20S	205	80	1	R16-259	4444	722	3
Eagle Seed ES4640RYX	217	29	1	Credenz CZ 4600X	4589	998	3

Continued

Table 2. Continued.

Variety[a]	Mean	SD	Rating[b]	Variety[a]	Mean	SD	Rating[b]
	ppm	ppm			ppm	ppm	
Dyna-Gro S49EN79	4720	2481	3	USG 7491ETS	6209	1213	5
Credenz CZ 4979X	4756	784	3	Delta Grow DG49E00/STS	6213	68	5
R17C-1182	4800	1534	3	Progeny 4970RX	6222	930	5
Integra 54891NS	4897	488	3	Delta Grow DG48X65	6271	2376	5
Credenz CZ 4941X	4917	2090	3	Asgrow AG 49X0	6319	1683	5
R17C-1056	4921	1333	3	AGS GS49X21	6349	526	5
DM 45X61	4997	1756	3	Integra 54606NS	6388	952	5
Delta Grow DG49X15	5039	2098	3	DM 49X13	6469	447	5
LS4607XS	5111	3002	3	R17-2069	6521	2309	5
R17C-1308	5124	1876	3	USG 7471ETS	6585	2549	5
Progeny 4700RXS	5130	1128	3	R15-2422	6595	1658	5
AGS GS47X19	5170	1174	3	DM 47X39	6878	1761	5
Dyna-Gro S48XT90	5215	1091	3	R13-14635RR:0013	6927	1015	5
Delta Grow DG48X05	5229	520	3	AgriGold G4995RX	6936	407	5
USG 7480XT	5345	1978	4	Armor 48-E81	7163	1626	5
USG 7496XTS	5377	909	4	Progeny 4908E3S	7344	2266	5
Mission A4828X R	5406	801	4	Progeny 4444RXS	7374	347	5
Progeny 4807E3S	5407	1060	4	Delta Grow DG47E80/STS	7442	1513	5
Dyna-Gro S48XT40	5483	1961	4	Integra 54920NS	7459	3143	5
Progeny 4505RXS	5681	2283	4	Eagle Seed ES4880RYX	7525	876	5
AGS GS48X19	5693	488	4	REV 4940X	7675	2252	5
Delta Grow DG49X25	5707	1373	4	Delta Grow DG46X05/STS	7701	1278	5
Progeny 4682E3	5781	1466	4	Pioneer P49T62E	7722	1400	5
Asgrow AG 45X8	5825	3279	4	Mission A4950X	7794	1878	5
Delta Grow DG48E10	5838	497	4	LGS4632RX	7999	877	5
Go Soy 481E19	5877	2208	4	Credenz CZ 4810X	8368	310	5
Progeny 4851RX	5917	2003	4	Go Soy 491E19S	8488	1062	5
R16-253	6043	3495	4	REV 4679X	10199	3258	5
Eagle Seed ES4772R2Y	6197	539	5	Credenz CZ 4570X	15386	3628	5

[a] Abbreviation key: AGS and Go Soy = Stratton Seeds; Dyna = Dyna Gro; DM = DONMARIO; Eagle = Eagle Seed; LGS = LG Seeds; R = University of Arkansas System Division of Agriculture; USG = UniSouth Genetics, Inc.

[b] Varieties may have varying leaflet chloride concentrations within the same numerical rating due to blocking within the field.

Table 3. Mean and standard deviation (SD) leaflet chloride (Cl) concentrations and preliminary rating for maturity group 5.0–5.9 varieties as determined from field-grown plants at the University of Arkansas System Division of Agriculture's Rohwer Research Station Soybean Variety Performance trial in 2020. A rating of 1 means strong excluder and a rating of 5 means strong includer.

Variety[a]	Mean	SD	Rating[b]	Variety[a]	Mean	SD	Rating[b]
	ppm	ppm			ppm	ppm	
Delta Grow DG50E10XP	192	73	1	Progeny 5211E3	5236	2049	4
R15-1587	234	44	1	Credenz CZ 5299X	5415	2707	4
R13-13997	263	16	1	Progeny 5170RX	5416	2189	4
Progeny 5554RX	271	21	1	Delta Grow DG54X25	5489	2693	4
S16-11651C	284	21	1	Credenz CZ 5251X	5536	2170	4
R16-1445	321	59	2	Asgrow AG 53X9	5649	981	4
R14-1422	354	156	2	Asgrow AG 52X9	5725	1457	4
Go Soy 512E21	358	139	2	Petrus Seed 5319 GT	5873	1023	4
Credenz CZ 6020X	378	66	2	Dyna-Gro S52XS39	6369	1215	5
Delta Grow DG51E60	521	261	2	Armor 51-E53	6826	2086	5
Credenz CZ 5700X	528	274	2	Donmario Seeds 51X61	6847	1273	5
S16-3747RY	744	24	2	Progeny 5252RX	7063	491	5
Local LS5009XS	1878	862	2	Delta Grow DG52E22	7197	1488	5
R17-7443RR	3992	2121	3	Local LS5087X	7316	1896	5
Delta Grow DG52X05/STS	4385	1646	3	Credenz CZ 5000X	7454	2738	5
R13-14635RR	4467	817	3	Asgrow AG 53X0	8809	1450	5
Progeny 5016RXS	4531	1304	3	Local ZS5098E3	8979	1574	5
Progeny 5008E3	5225	379	3	Local LS5386X	9400	5610	5
				Delta Grow DG52E15/STS	12172	1261	5

[a] Abbreviation key: AGS and Go Soy = Stratton Seeds; Dyna = Dyna Gro; DM = DONMARIO; Eagle = Eagle Seed; LGS = LG Seeds; R = University of Arkansas System Division of Agriculture; USG = UniSouth Genetics, Inc.

[b] Varieties may have varying leaflet chloride concentrations within the same numerical rating due to blocking within the field.

Irrigated Rotational Cropping Systems, 2014–2020 Summary

J.P. Kelley[1] and T.D. Keene[1]

Abstract

A large-plot field trial evaluating the impact of crop rotation on yields of winter wheat (*Triticum aestivum* L.) and irrigated corn (*Zea mays* L.), early planted soybean [*Glycine max* (L.) Merr], double-crop soybean, full-season grain sorghum [*Sorghum bicolor* (L.) Moench] and double-crop grain sorghum was conducted from 2013–2020 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station near Marianna, Arkansas. Yields of April-planted group 4 soybean yields improved 5 and 7 bu./ac, respectively, when planted following corn or grain sorghum compared to continuous soybean. Crop rotation impacted June-planted, double-crop soybean yield 1out of 7 years, and average yields were 3 and 4 bu./ac greater when following corn or grain sorghum than a previous double-crop soybean crop. Corn yields were impacted by the previous crop 1 out of 7 years, where corn following corn yield was 26 bu./ac lower than when following April-planted soybean in 2016. On average, corn following corn yielded 6 and 7 bu./ac less than when following April-planted soybean or double-crop soybean, respectively. Wheat yields were impacted by the previous crop in 4 out of 6 years of the trial. Wheat following full-season grain sorghum across all years yielded 8 bu./ac less than when following April-planted soybean, and 3 or 5 bu./ac less when following corn or double-crop soybean. Full-season grain sorghum was always planted following April-planted soybean or double-crop soybean, and yields averaged 114 bu./ac with no difference in yield between previous crops. Double-crop grain sorghum averaged 82 bu./ac across all years.

Introduction

Arkansas crop producers have a wide range of crops that can be successfully grown on their farms, including early-season group 4 soybean [*Glycine max* (L.) Merr] (typically planted in April), corn (*Zea mays* L.), full-season grain sorghum [*Sorghum bicolor* (L.) Moench], wheat (*Triticum aestivum* L.), double-crop soybean, double-crop grain sorghum, cotton, and rice depending on soil type. As crop acreages in Arkansas have changed over the years due to grain price fluctuations and changing profitability, more producers are incorporating crop rotation as a way to increase crop yields and farm profitability. Crop rotation has been shown in numerous trials to impact crop yields. In studies near Stoneville, Mississippi Reddy et al., 2013, found that corn yields following soybean were 15%–31% higher than when corn was continuously grown, however, soybean yields were not statistically greater but trended to higher yields when planted following corn. In Tennessee, Howard et al., 1998, found that soybean following corn yielded 11% higher compared to continuous soybean and attributed soybean yield increases following corn to reduced levels of soybean-cyst nematodes. As crop acreage 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 responses 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 Research Station near Marianna, Arkansas in April of 2013. The following eight crop rotations were evaluated:

1. *Corn/Soybean/Corn/Soybean*. Corn planted in April each year followed by early-planted group 4 soybean planted in April the following year.
2. *Corn/Wheat/Double-Crop Soybean/Corn*. Corn planted in April, followed by wheat planted in October following corn harvest, then double-crop soybean planted in June after wheat harvest, and corn planted the following April.
3. *Wheat/Double-Crop Soybean/Wheat*. Wheat planted in October, followed by double-crop soybean planted in June, then wheat planted in October.
4. *Full-Season Grain Sorghum/Wheat/Double-Crop Soybean/Full-Season Grain Sorghum*. April-planted

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full-season grain sorghum, followed by wheat planted in October, then double-crop soybean planted in June after wheat harvest, then full-season grain sorghum planted the following April.

5. *Continuous Corn*. Corn is planted in April every year.
6. Continuous Soybean. Early planted group 4 soybean planted in April every year.
7. *Full-Season Grain Sorghum/Early Planted Soybean*. Full-season grain sorghum planted in April, followed by April-planted group 4 soybean planted the following year.
8. *Early Soybean/Wheat/Double-Crop Grain Sorghum/Soybean*. April-planted group 4 soybean, followed by wheat planted in October, then double-crop grain sorghum planted in June after wheat harvest, followed by early planted group 4 soybean the following April.

The soil in the trial was a Memphis Silt Loam (Fine-silty, mixed, active, thermic Typic Hapludalf), which is a predominant soil type in the area. Crop rotation treatments were replicated 4 times within a randomized complete block design and all rotation combinations were planted each year. Plot size was 25-ft wide (8 rows wide) by 200-ft long with a 38-in. row spacing. Before planting summer crops each year, plots were conventionally tilled, which included; disking, field cultivation, and bed formation with a roller-bedder so crops could be planted on a raised bed for furrow irrigation. Prior to planting wheat in October, plots that were going to be planted were disked, field cultivated, and rebedded. Wheat was then planted on raised beds with a grain drill with six-inch row spacing with a seeding rate of 120 lb of seed/ac.

Soybean varieties planted changed throughout the trial. For April-planted group 4 soybean, maturity ranged from 4.6–4.9 each year. Double-crop soybeans planted each year had a maturity range of 4.6–4.9. Corn hybrids varied by year and maturity ranged from 112–117 days. Full-season grain sorghum was Pioneer 84P80 from 2014-2018 and DKS51-01 in 2019–2020. Double-crop grain sorghum hybrids grown included; Sorghum Partners 7715 and DKS 37-07, which are sugarcane aphid tolerant hybrids. In each year of the trial, Pioneer 26R41 soft red winter wheat was planted.

Summer crops were furrow irrigated as needed according to the University of Arkansas System Division of Agriculture's 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 was collected from the center two rows of each plot at crop maturity and remaining standing crops were harvested with a commercial combine. Soil nematode samples were collected at the trial initiation and each subsequent fall after crop harvest and submitted to the University of Arkansas System Division of Agriculture's nematode diagnostic lab at the Southwest Research and Extension Center at Hope, Ark. for analysis. Soybean-cyst nematode was the only nematode that was found to be above economic thresholds levels during this trial, and levels were generally greater than 500 nematodes/100 cm^3 of soil (data not shown). No root-knot nematodes were found in the trial area.

Results and Discussion

Soybean. April-planted group 4 soybean yields were good each year with an average yield of 55–62 bu./ac depending on rotation over the 7-year period (Table 1). The yield of April-planted group 4 soybean was statistically impacted by the previous crop in 3 out of 7 years of the trial. Continuously grown soybean without rotation yielded 55 bu./ac on average, while soybean rotated with corn or full-season grain sorghum yielded 60 and 62 bu./ac, respectively (Table 1). Similar trends were noted with June-planted double-crop soybean yields when followed by wheat. When double-crop soybean followed a previous crop of wheat/double-crop soybean, yields on average were only 42 bu./ac, while yields increased to 46 and 45 bu./ac when corn or full-season grain sorghum had been grown the previous year. However, double-crop soybean yields were only statistically influenced by the previous crop in 1 out of 7 years (Table 2). The average yield across rotations of 59.5 bu./ac for early planted group 4 soybean and 44.3 bu./ac for double-crop soybean are similar yield differences that many Arkansas producers see on their farms between the early planted production system and double-crop system.

Differences in early-planted and double-crop soybean yields between crop rotations can likely be partially attributed in part to lower Soybean-Cyst Nematode (SCN) numbers following corn or grain sorghum. The SCN egg numbers from soil samples collected in the fall of 2020 were 110 eggs/100 cc of soil in continuous April-planted soybean plots compared to 19 and 58/100 cc of soil where the previous crop was corn or grain sorghum, respectively. The SCN egg numbers in continuous double-crop soybean plots were 358/100 cc of soil and 85 and 289/100 cc of soil in plots that previously had corn and wheat or grain sorghum and wheat planted previously. The SCN egg numbers indicate that rotation to a non-host for one year will reduce numbers but will not eliminate SCN.

Corn. Corn yields were generally good over the 7 years and averaged 201–208 bu./ac depending on rotation (Table 3). Yields were statistically influenced by rotation in 1 out of 7 years with corn following corn yielding 26 bu./ac less than when following April-planted group 4 soybean in 2016. Visually it was not apparent why there was a yield difference in 2016 as there were no notable differences in plant stands, foliar disease level, or late season lodging, and all inputs between rotations were constant. Over the 7-year period, corn following April-planted group 4 soybean, or June-planted double-crop soybean yielded 6 or 7 bu./ac more, respectively, than continuously grown corn. These results are similar to other trials in that corn grown in rotation with soybean often yields more than if grown without rotation (Sindelar et al., 2015). As corn is grown continuously for more years without rotation, yields may decline greater, but that trend is not evident after 7 years of this trial.

Wheat. Wheat yields were generally good, with an average yield of 65–73 bu./ac (Table 4), depending on rotation. Wheat yield was influenced by previous crop 4 out of 6 years. Averaged across all years, wheat yield following April-planted soybean was 73 bu./ac, 8 bu./ac greater than wheat following full-season grain sorghum. The reason for lower wheat yields following full-season grain sorghum is not clear; however, fall and early winter growth was visibly reduced in some years. Grain sorghum has been reported to be possibly allelopathic to wheat under some circumstances. Although not definitive, allelopathy is suspected of having reduced wheat growth and yields in this study some years since all other management inputs such as tillage, seeding rate, fertilizer, foliar disease level, and plant stands were constant between treatments. Wheat yield following corn was on average 5 bu./ac less than when following April-planted soybean and 2 bu./ac less than when following double-crop soybean.

Grain Sorghum. Full-season grain sorghum was grown as a rotational crop and was always planted following soybean or double-crop soybean. Yields of full-season grain sorghum averaged 114 bu./ac (Table 5) and did not differ between April-planted group 4 soybean or double-crop soybean treatments over the 7-year period. State average grain sorghum yields generally range from 80–95 bu./ac (Table 5). June-planted double-crop grain sorghum planted following wheat averaged 82 bu./ac (Table 5), a relatively low yield despite irrigation.

Practical Applications

Results from this ongoing trial provide Arkansas producers with local non-biased information on how long-term crop rotation can impact yields of early planted soybean, double-crop soybean, corn, grain sorghum, double-crop grain sorghum, and wheat on their farms, which ultimately impacts the profitability of their farms.

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Table 1. Effect of previous crop on yield of April-planted irrigated group 4 soybean yield grown at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas, 2014–2020.

	April-Planted Soybean Grain Yield							
Previous Crop	2014	2015	2016	2017	2018	2019	2020	Avg.
	-------------------------------------bu./ac-------------------------------------							
April-Planted Soybean	43	49	47	65	56	62	62	55
Corn	64	49	52	71	67	58	62	60
Full-Season Grain Sorghum	64	51	56	74	64	62	61	62
Wheat/Double-Crop Sorghum	--	50	54	71	65	58	66	61
LSD (0.05)	13	NSD[a]	NSD	6	6	NSD	NSD	--

[a] NSD = No Significant Difference at α = 0.05.

Table 2. Effect of previous crop on yield of June-planted irrigated double-crop soybean grown following wheat at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas 2014–2020.

	Double-Crop Soybean Grain Yield							
Previous Crop	2014	2015	2016[a]	2017	2018	2019	2020	Avg.
	bu./ac							
Double-Crop Soybean/Wheat	30	38	46	46	43	45	46	42
Corn/Wheat	39	43	49	48	46	47	47	46
Grain Sorghum/Wheat	40	42	50	48	46	46	46	45
LSD (0.05)	4	NSD[b]	NSD	NSD	NSD	NSD	NSD	--

[a] Wheat was not planted during the fall of 2015, but soybean was planted in June 2016 during the normal time for double-crop planting.

[b] NSD = No Significant Difference at $\alpha = 0.05$.

Table 3. Effect of previous crop on yield of irrigated corn grown at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas 2014–2020.

	Corn Grain Yield							
Previous Crop	2014	2015	2016	2017	2018	2019	2020	Avg.
	bu./ac							
April-Planted Soybean	250	221	207	205	196	181	194	208
Wheat/Double-Crop Soybean	250	214	198	207	199	186	196	207
Corn	245	224	181	201	191	173	196	201
LSD (0.05)	NSD[a]	NSD	20	NSD	NSD	NSD	NSD	--

[a] NSD = No Significant Difference at $\alpha = 0.05$.

Table 4. Effect of previous crop on yield of winter wheat grown at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas 2014–2020.

	Wheat Grain Yield							
Previous Crop	2014	2015	2016	2017	2018	2019	2020	Avg.
	bu./ac							
April-Planted Soybean	75	72	--	76	67	69	80	73
Double-Crop Soybean	75	69	--	73	64	64	75	70
Corn	72	68	--	74	69	61	65	68
Full-Season Grain Sorghum	69	73	--	56	62	65	64	65
LSD (0.05)	NSD[a]	4	--	12	6	NSD	8	--

[a] NSD = No Significant Difference at $\alpha = 0.05$.

Table 5. Yield of irrigated full-season grain sorghum and double-crop grain sorghum grown at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas 2014–2020.

	Grain Sorghum Grain Yield							
Previous Crop	2014	2015	2016	2017	2018	2019	2020	Avg.
	bu./ac							
Full-Season Grain Sorghum	143	123	113	99	98	106	118	114
Double-Crop Sorghum	--	88	92	86	87	81	88	82

Nitrogen and Phosphorus Losses from Soybean Production: A Summary of Results from the Arkansas Discovery Program

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Abstract

The overall goal of the Arkansas Discovery Farms program is to assess the need for and effectiveness of on-farm conservation practices, document nutrient and sediment loss reductions, soil health, and water conservation in support of nutrient management planning and sound environmental farm stewardship. Utilizing state-of-the-art edge-of-field runoff monitoring on several commercial, row crop farms in Eastern Arkansas, 449 water samples were collected from 19 different fields from 2013 to 2019 representing 38 site years. Nutrient loss loads were determined by multiplying the concentration of the nutrient in the runoff sample by the total runoff volume for each runoff event. Mean values for soybean across all sites and years for NO_3-, total nitrogen (TN), soluble reactive phosphorus (SRP), and total phosphorus (TP) were 0.14, 0.45, 0.08, and 0.17 lb/ac, respectively. These results indicate relatively low mass losses relative to nutrients applied as fertilizer. This implies that soybean producers that cooperated in this study closely and consistently matched fertilizer needs to crop needs so that there were only small amounts of fertilizer nutrients (P and N) available to be transported via runoff from the field following application. Overall, Discovery Farm studies have indicated that less than 5% of N and P applied as fertilizer leaves the field in surface runoff.

Introduction

Row crop producers in the Lower Mississippi River Basin (LMRB) are under increased scrutiny to demonstrate that current production systems are environmentally viable with respect to water quality and sustainability (Daniels et al., 2018). These concerns are manifested from regional issues such as hypoxia in the Gulf of Mexico (United States Environmental Protection Agency, 2018a) and critical groundwater decline in the Lower Mississippi Alluvial Valley aquifer (LMAV) (Reba et al., 2017; Czarnecki et al., 2018). Nutrient enrichment remains a major impairment of water quality to the designated uses of fresh and coastal waters of the U.S. (Schindler et al., 2008). Nutrient runoff from cropland is receiving greater attention as a major source of nutrients from nonpoint sources (Dubrovsky et al., 2010). This is especially true in the Mississippi River Basin (MRB), as recent model estimates suggest that up to 85% of the phosphorus (P) and nitrogen (N) entering the Gulf of Mexico originates from agriculture (Alexander et al., 2008). These estimates are based on large-scale modeling within the MRB, with limited localized calibration or verification of the field losses of P and N. Furthermore, there have been few farm-scale studies of P and N loss, particularly the LMAV region of agriculture-dominant Arkansas and Mississippi (Dale et al., 2010; Kröger et al., 2012).

This scrutiny has prompted much activity aimed at reducing nutrients lost to the Gulf within the Mississippi River Basin, including the formation of the Mississippi River/Gulf of Mexico Hypoxia Task Force, a consortium of Federal agencies and states (USEPA, 2018a). This consortium developed an action plan to reduce nutrients entering the Gulf, which includes nutrient reduction strategies prepared by each state (USEPA, 2018b).

Arkansas Discovery Farms are privately owned farms that have volunteered to help with on-farm research, verification, and demonstration of farming's impact on the environment and natural resource sustainability (Sharpley et al., 2015, 2016). The overall goals of the program are to assess the need for and effectiveness of on-farm conservation practices, document nutrient, sediment loss reductions, and water conservation in support of nutrient management planning and sound environmental farm stewardship. Edge-of-field monitoring (EOFM) of runoff from individual agricultural fields is critical to improving our understanding of the fate and transport of nutrients applied as animal manures and fertilizer to agricultural lands along the complex watershed continuum (Reba et al., 2013; Harmel et al., 2016; Sharpley et al., 2016).

Additionally, EOFM helps producers more clearly see how their management systems affect in-stream water quality and watershed functions (Sharpley et al., 2015). The objective of this paper was to provide a summary of mean nutrient

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losses for an individual runoff event from soybean production across all years, locations, and production practices

Procedures

Edge-of-field runoff monitoring stations were established on several commercial farms in Arkansas, Cross, Jefferson, Pope, and St. Francis counties in Arkansas. From 2013 to 2019, 442 water samples were collected from 19 different fields equipped with EOFM stations representing 38 site years.

At the lower end of each field, automated runoff water quality monitoring stations were established to 1. measure runoff flow volume, 2. collect water quality samples of runoff for water quality analysis, and 3. measure precipitation. Either a 60-degree, V-shaped, 8-in. trapezoidal flume that was pre-calibrated and gauged was installed at the outlet of each field or if an existing drainage pipe served as the outlet, it was instrumented. (TRACOM, 2018). The ISCO 6712, an automated portable water sampler (Teledyne-ISCO, 2018), was used to interface and integrate all the components of the flow station. Where flumes were used, an ISCO 720 pressure transducer and flow module were used. For existing drainage pipes, an ISCO 750 flow velocity and flow module were utilized. All samples were analyzed at the Arkansas Water Resources Laboratory (Arkansas Water Resources Center, 2018), an EPA-certified laboratory for total nitrogen (TN), nitrate + nitrite-N (NO_3-), total phosphorus (TP), and soluble reactive phosphorus (SRP). Nutrient loss loads (mass per unit area) were determined by multiplying the concentration of the nutrient in the runoff sample by the total runoff volume for each runoff event and normalized to field size.

Results and Discussion

In a previous article, runoff water quality was summarized by reporting the concentration NO_3-, TN, SRP, and TP in mg/L (Daniels et al., 2020). Reporting the nutrient concentration in runoff is useful when comparing to the water quality status of nearby streams and other water bodies that are not gauged for flow determination. However, reporting the data in mass loading per unit area allows more insight to fertilizer and nutrient management than concentration as it can be expressed relative to fertilizer or nutrient applications. The summary of nutrient losses (lb/ac) for NO_3-, TN, SRP, and TP across all years and locations greatly varied while mean values were relatively low (Tables 1 and 2). These data represent the average nutrient loss per individual runoff event and do not reflect annual or seasonal losses. The data was highly skewed (standard deviation as large or larger than mean) as expected as it represents all sites and years, associated management practices, and variability in precipitation and hydrology among individual runoff events. Nutrient losses from soybean compared to other crops were similar in magnitude with all losses relatively small compared to nutrients applied as fertilizer.

Practical Applications

Data from EOFM can help provide perspective on agriculture's impact on water quality in terms of nutrient losses. For illustration purposes, the mean values in Tables 1 and 2 could be used to provide rough estimates of seasonal or annual nutrient losses. For example, the mean TP loss for soybean is 0.17 lb/ac.

If a given 100-acre field had 10 runoff events during the year, then 0.17 lb/ac × 10 = 1.7 lb/ac per year. The total loss from the field would be 1.7 lb/ac × 100 ac = 170 lb of total P loss. The University of Arkansas System Division of Agriculture's soil test recommendations for phosphorus fertilizer ranges from 40 to 80 lb/ac depending on the soil test level.

Assuming that this hypothetical field test is in the low category for P, the recommendation would be for 60 lb/ac P_2O_5 fertilizer. Since P_2O_5 is 43.7% P, the application rate for P would be 26 lb/ac of P or 2600 lb of total P applied to the entire field. The ratio of loss of P in runoff to fertilizer applied is 1.7 lb/ac /26 lb/ac P = 0.065 or 6.5% loss.

This approach is a very rough estimate of annual loss and is not recommended for estimating seasonal losses as it does not account for variability in management, precipitation, soils, and other site-specific conditions, but it was used in this paper to put the observed runoff data in perspective to fertilizer application, the main nutrient source.

Overall, Discovery Farm studies have indicated that less than 5% of N and P applied as fertilizer leaves the field in surface runoff. The fact that much of Arkansas' row crops are grown on long rows with very little slope helps reduce energy associated with runoff so that transport is dampened or reduced. This implies that soybean producers that cooperated in this study closely and consistently matched fertilizer needs to crop needs so that there were only small amounts of fertilizer nutrients (P and N) available to be transported via runoff from the field following application.

Acknowledgments

The authors wish to acknowledge funding sources for the Arkansas Discovery Farm program including the University of Arkansas System Division of Agriculture, soybean checkoff funds administered by the Arkansas Soybean Promotion Board, the USDA-Natural Resources Conservation Service, the Arkansas Corn and Grain Sorghum Promotion Board, the Arkansas Department of Agriculture – Natural Resources Division, and the Environmental Protection Agency. We also acknowledge our partner, the Arkansas Association of Conservation Districts, and the many volunteers who serve on our Stakeholder and Technical Advisory Committees. Most of all, we wish to acknowledge our cooperators, the Arkansas Discovery Farmers.

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Table 1. Mean and standard deviation of nitrogen loss for an individual runoff event averaged across all 38 site-years for soybeans.

Crop	Mean Nitrate	Standard Deviation Nitrate	Mean Total Nitrogen	Standard Deviation Total Nitrogen
	--	-lb/ac-	---	
Corn	0.08	0.05	0.22	0.41
Soybeans	0.14	0.20	0.45	1.57
Rice	0.02	0.02	0.20	0.34
Cotton	0.16	0.11	0.43	0.80

Table 2. Mean and standard deviation of phosphorus loss for an individual runoff event averaged across all 38 site-years for soybeans.

Crop	Mean Soluble Reactive Phosphorus	Standard Deviation Soluble Reactive Phosphorus	Mean Total Phosphorus	Standard Deviation Total Phosphorus
	--	-lb/ac-	---	
Corn	0.03	0.05	0.10	0.13
Soybeans	0.08	0.20	0.17	0.44
Rice	0.01	0.02	0.04	0.06
Cotton	0.07	0.11	0.17	0.27

Selecting Soybean for Improved Water Use Efficiency

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Abstract

As aquifer levels drop, as the competition among crops for irrigation increases, and as drought frequency and intensity increases due to climate change, improving soybean [*Glycine max* (L.) Merr.] drought tolerance will benefit both rainfed and irrigated production systems. Soybean breeding lines were developed with either a high or low ratio of C^{13} to C^{12}, which is a surrogate measure of water use efficiency (WUE). Five lines with low WUE, 4 lines with high WUE, and 2 check cultivars were grown in irrigated and rainfed blocks at Fayetteville and at Pine Tree. At both locations and for both irrigated and rainfed blocks, the check cultivars had substantially greater yields than breeding lines with High or Low WUE. There was some indication that the Low WUE genotypes as a group had greater yields than the High WUE genotypes. Overall, there was considerable variation in the response to drought, and additional breeding efforts are needed to improve the overall yield of genotypes with High WUE.

Introduction

Although more than 80% of the Arkansas soybean [*Glycine max* (L.) Merr.] crop is irrigated, there is a need to develop varieties that can perform better under drought conditions than currently available varieties. Improved drought tolerance would benefit Arkansas soybean producers because irrigation capacity on many farms and declining aquifer levels limit the ability to fully irrigate soybean and other crops as needed. Additionally, increased salinity of irrigation water in some areas makes irrigation unfeasible, and a projected increase in weather extremes may exacerbate drought conditions and place increased demands on irrigation needs.

Both management and genetic strategies have important roles in mitigating the impact of drought on soybean production. The widespread adoption of maturity group (MG) 4 cultivars planted in April has decreased the irrigation requirement in most years (Bowers, 1995; Heatherly, 1999) compared with the production of MG 5 and 6 cultivars planted in May and June. Importantly, irrigated yields of MG 4 cultivars planted early are greater than those of MG 5 and 6 cultivars (Salmeron et al., 2016).

Breeding efforts to improve drought tolerance in soybean by focusing strictly on yield have not been successful (Carter et al., 1999). The primary reason for this lack of success is that breeders have traditionally evaluated the yield of elite germplasm and restricted crosses to only include elite lines, essentially reshuffling the same genes repeatedly. As such, genetic diversity is very limited and potential progress is inherently limited in soybean (Gizlice et al., 1993).

The research focused on targeted traits that confer drought tolerance in soybean has had major successes because it has drawn upon the genetic diversity of soybean found in the United States Department of Agriculture's (USDA) Germplasm collection. This research has identified specific genotypes that, compared to commercial cultivars, are delayed in wilting during the onset of drought (Kaler et al., 2017b), have a cooler canopy during drought (Bazzer et al., 2020b), and have a higher C^{13}/C^{12} ratio (Bazzer et al., 2020a; Kaler et al., 2017a). The C^{13}/C^{12} ratio (C^{13} ratio) is closely associated with water use efficiency (WUE) (Farquhar et al., 1982), which can be defined as the amount of dry matter produced for each unit of water transpired.

In the present research, grain yield was evaluated under irrigated and rainfed conditions in four breeding lines selected to have a high C^{13} ratio (i.e., high WUE), five breeding lines selected to have a low C^{13} ratio, and two check cultivars.

Procedures

Agronomically-improved, F_6-derived breeding lines were developed at the Crop Genetics Research Unit of the USDA- Agricultural Research Service (ARS) at Stoneville, Mississippi from a cross between PI 567201D and DS25-4. In previous research, PI 567201D had among the lowest C^{13} ratio of 373 MG 4 accessions (Kaler et al., 2017a), and DS25-4 had high germinability and permeable seed coats. DS25-4 was derived from a cross between PI 587982A and another breeding line from Stoneville, DT98-9102. The F_2 population derived from the cross between PI 567201D and DS25-4 was grown in Stoneville in 2012, and leaf tissue was collected from individual plants during the season. At maturity, upright plants with good agronomic characteristics were harvested individually, and seeds from selected plants were

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germinated. Tissue from those plants with germination rates >90% were analyzed for C^{13} ratio, and only plants that were extremes for C^{13} ratio (High and Low WUE) were advanced to F_2-derived, F_3 plant rows. The same process was followed in the F_3 (2013), F_4 (2014), F_5 (2015), F_6 (2016), and $F_{6:7}$ (2017) generations, eventually producing the 2 sets of divergently selected F_6-derived lines. In each cycle, we selected first for plant type, then germination, and then for C^{13} ratio. In 2018, selected lines were increased in yield trials, followed by large strip increases in 2019. This process led to the development of a set of 4 lines with high WUE and another set of 5 lines with low WUE with all the lines being derived from the same original cross and having high germination.

Experiments were planted at the University of Arkansas System Division of Agriculture's Milo Shult Agricultural Research and Extension Center in Fayetteville (1 June 2020) and Pine Tree Research Station near Colt (13 June 2020) in an irrigated block and a rainfed block. At both locations, there were 4 lines that were selected with high WUE, 5 lines with low WUE, and 2 check cultivars of similar maturity (AG46X6 and AG51X8) to the breeding lines. Plots consisted of 4 rows spaced 36-in. (Fayetteville) or 30-in. (Pine Tree) apart on raised beds; plot length was 20-ft. At both locations, there were 4 replications arranged in a randomized complete block design within each irrigated or rainfed block. The irrigated blocks at both locations were furrow irrigated once the cumulative estimated soil-moisture deficit reached 1.5 in. (Purcell et al., 2007).

Grain was harvested from a bordered section of the 2 center rows of each plot, and yield was adjusted to a 13% moisture content. Yield data were analyzed by location using analysis of variance, assuming irrigation was the main plot and genotypes were subplots. Genotypes were also assigned to an *a priori* WUE group as 'Low,' 'High,' or Check (Chk) and nested within a WUE group in the analysis. Means were separated using a protected least significant difference at a *P*-value of 0.05. We also considered the relative decrease (Rel_Dec, %) in yield between the irrigated and rainfed blocks for each genotype using Eq. 1:

$$\text{Rel\_Dec} = ((\text{Rainfed} - \text{Irrigated})/\text{Irrigated})*100 \qquad \textit{Eq. 1}$$

where Rainfed and Irrigated refer to the average rainfed and irrigated yields for each genotype.

Results and Discussion

Fayetteville. Irrigation was applied to the irrigated block six times during the season. Averaged over genotypes, there was a significant decrease ($P < 0.01$) in yield from 42 bu./ac for the irrigated block to 30 bu./ac for the rainfed block (Table 1). There was a significant ($P < 0.0001$) main effect of the *a priori* group indicating that averaged over irrigation blocks and genotypes, the check-cultivar group had the highest yields (56 bu./ac), followed by the Low WUE group (33 bu./ac), with the lowest yields in the High WUE group (28 bu./ac). Given that the lines in the Low and High WUE groups trace their genetics to 75% of unimproved land races, it is not unexpected that yields of the Low and High breeding lines were considerably lower than the check cultivars.

There was also a significant interaction between how genotypes within a group responded to irrigation. For both irrigated and rainfed blocks, the checks had considerably greater yield than other genotypes (Fig. 1). Among the other genotypes, for both the irrigated and rainfed blocks, 110-18-38-51 tended to have the highest yields. Generally, the genotypes in the High WUE group tended to have lower yields than genotypes in the Low WUE group. If we consider the relative decrease in the yield of genotypes in the rainfed block versus the irrigated block, genotypes in the High WUE group tended to have a smaller decrease in yield than genotypes in the Low WUE group (Fig. 2).

Pine Tree. Although irrigation was applied to the irrigated block seven times during the season, ANOVA indicated that there was not a significant main effect of irrigation ($P = 0.81$, Table 2). As with the Fayetteville data, there was a significant ($P < 0.0001$) main effect of the *a priori* group indicating significant differences among all three groups with the check-cultivar group having the highest yields (49 bu./ac), followed by the Low WUE group (33 bu./ac), with the lowest yields in the High WUE group (28 bu./ac).

There was a significant interaction ($P = 0.007$) between genotypes within a group and irrigation block (Fig. 3). The check cultivars had considerably greater yields than genotypes within the Low and High groups for both irrigated and rainfed blocks. As with the Fayetteville location, 110-18-38-51 had the greatest numerical yield for the Low and High groups and for irrigated and rainfed blocks. When comparing the irrigated and rainfed blocks, however, all genotypes in the Low and High groups had greater numerical yields in the rainfed blocks than the irrigated blocks (Fig. 4).

Practical Applications

To our knowledge, this is the first effort at breeding for improved WUE in soybean using the C13 ratio. The yields of lines from the Low and High WUE groups were considerably lower than the check cultivars and indicate the need for additional breeding efforts. Three other breeding lines with high WUE have been developed that have yields comparable to the check cultivars and are currently being evaluated for potential yield advantage under rainfed conditions.

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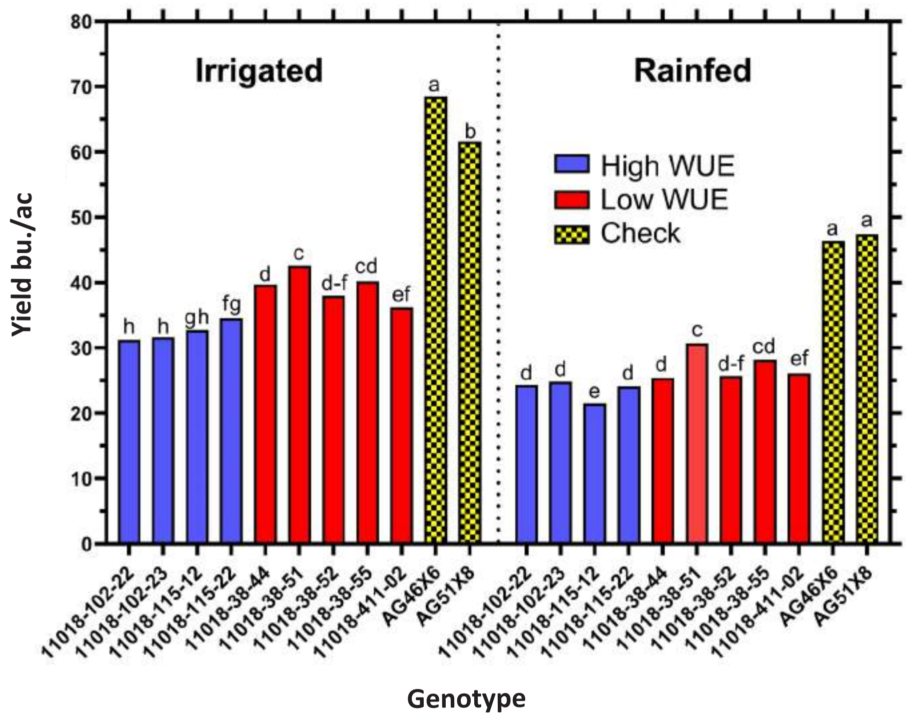

Fig. 1. Yield response to irrigated and rainfed conditions for genotypes with high water use efficiency (WUE), low WUE, or check cultivars. at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark. Different letters above bars within an irrigation block indicate significant difference as determined by a Least Significant Difference test (*P* = 0.05).

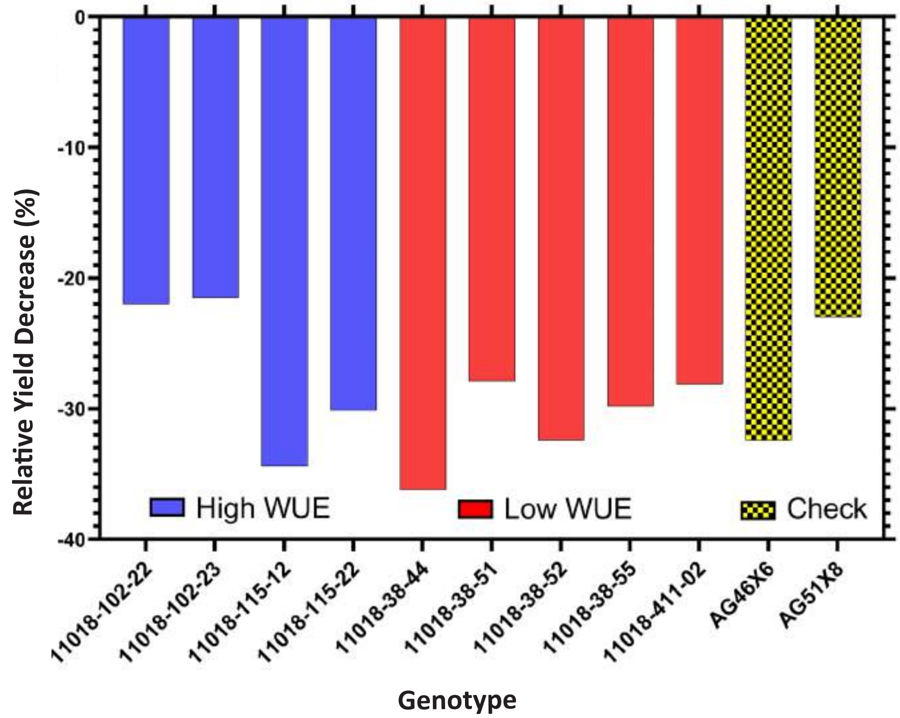

Fig. 2. Relative decrease in yield of the rainfed block relative to the irrigated block of genotypes with high water use efficiency (WUE), low WUE, or check cultivars at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center, Fayetteville, Ark.

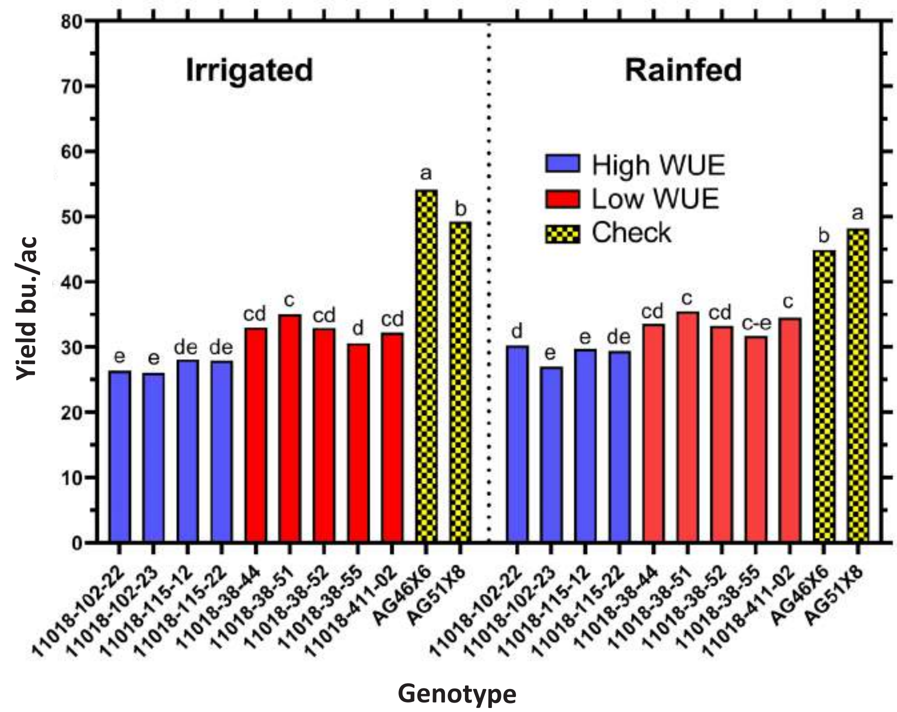

Fig. 3. Yield response to irrigated and rainfed conditions for genotypes with high water use efficiency (WUE), low WUE, or check cultivars at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark. Different letters above bars within an irrigation block indicate significant difference as determined by a Least Significant Difference test (*P* = 0.05).

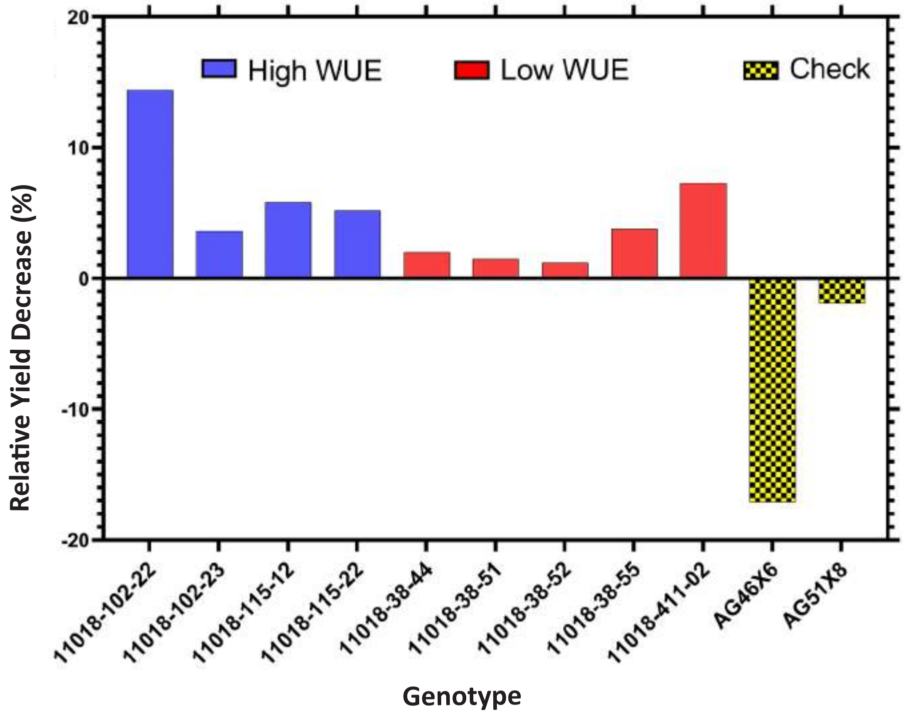

Fig. 4. Relative decreases in yield of the rainfed block relative to the irrigated block of genotypes with high water use efficiency (WUE), low WUE, or check cultivars at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark.

Table 1. Analysis of variance table for yield (bu./ac) at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center, Fayetteville in 2020. Factors included replication (Rep), irrigation (rainfed or irrigated), an *a priori* classification of water use efficiency (WUE, Low WUE, High WUE, or Check), and genotype (Geno) nested within WUE classification.

Source	DF	Mean Square	F value	Prob > F
Model	27	468	35	<0.0001
Error	60	13.22		
Corrected total	87			
Rep	3			0.07
Irrigation (I)[a]	1			<0.0001
Rep*I	3			0.02
WUE	2			<0.0001
Geno(WUE)	8			0.07
I*Geno(WUE)	10			0.01
R-square = 0.94	CV = 10.2	RMSE = 3.64	bu./ac mean = 35.5	

[a] Effect of Irrigation tested using Rep*I as the error term. DF = Degrees of Freedom; CV = coefficient of variation; RMSE = root mean square error.

Table 2. Analysis of variance table for yield (bu./ac) at Pine Tree in 2020. Factors included replication (Rep), irrigation (rainfed or irrigated), an *a priori* classification of water use efficiency (WUE, Low WUE, High WUE, or Check), and genotype (Geno) nested within WUE classification.

Source	DF	Mean Square	F value	Prob > F
Model	27	199	25	<0.0001
Error	60	8.1		
Corrected total	87			
Rep	3			<0.0001
Irrigation (I)[a]	1			0.69
Rep*I	3			0.085
WUE	2			<0.0001
Geno(WUE)	8			0.18
I*Geno(WUE)	10			0.007
R-square = 0.92	CV = 8.3	RMSE = 2.85	bu./ac mean = 34.2	

[a] Effect of Irrigation tested using Rep*I as the error term. DF = Degrees of Freedom; CV = coefficient of variation; RMSE = root mean square error.

Breeding Soybean Cultivars in Arkansas with High Yield and Local Adaptation

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Abstract

The main objective of the University of Arkansas System Division of Agriculture's Soybean Breeding Program is developing high-yielding maturity group (MG) 4 and 5 soybean cultivars with an adequate disease package and adapted to various environments and production systems in Arkansas. To this day, our program has developed and released numerous conventional and glyphosate-tolerant cultivars. The breeding activities and process include 1. Selection of exotic- and Arkansas germplasm and breeding lines for crossing; 2. Advancement of breeding populations until a high percentage of homozygosity is reached; 3. Selection and growth of single plants as progeny rows; 4. Selection of best-performing progeny rows; 5. Evaluation of yield and agronomic traits in preliminary and advanced yield trials across multiple Arkansas environments; and 6. Selection of best promising lines for further evaluation in the Arkansas State Variety Testing, the United States Department of Agriculture's Uniform Soybean Tests, and other southern states' official variety testing programs. In 2020, one early MG 4 conventional variety (UA46i20C) and one MG 5 glyphosate-tolerant variety (UA54i19GT) were publicly released through the Arkansas Foundation Seed Program, and one MG 5 conventional (R13-13997) variety was released for commercial production via non-exclusive licensing agreements.

Introduction

The University of Arkansas System Division of Agriculture's Soybean Breeding Program continuously makes efforts to develop and release elite soybean cultivars with high yield, pest and disease resistance, high seed quality, and good adaptation to Arkansas growing environments. In the last two decades, the breeding program has publicly released 14 soybean cultivars including Lonoke (Sneller et al., 2004), Ozark (Chen et al., 2004), Osage (Chen et al., 2007), UA5612 (Chen et al., 2014a), UA5213C (Chen et al., 2014b), UA5014C (Chen et al., 2016), UA5814HP (Chen et al., 2017), UA5414RR, UA5615C, UA5115C (Florez-Palacios et al., 2019), UA5715GT (Orazaly et al., 2019), UA54i19GT, R13-13997, and UA46i20C. These elite cultivars have been commercially produced and used for variety development in other breeding programs. In addition, Osage and UA5612 have been previously used as yield checks in the United States Department of Agriculture's (USDA) Uniform Soybean Tests. The work herein reported highlights the efforts made to develop new and improved MG 4 and 5 commercial soybean varieties.

Procedures

Our breeding objective is to combine the best traits from different cultivars and/or lines to release the top soybean varieties to Arkansas' farmers. To achieve this, we use a conventional breeding scheme in conjunction with Marker Assisted Selection (MAS) and genomic selection. The breeding scheme includes 1. Identification and selection of high-yielding parents with desirable complementary traits for cross and population development, 2. Advancement of breeding populations for 3 to 4 generations to allow genetic segregation and recombination, and 3. Selection of superior lines with the traits of interest and subsequent performance evaluation in multi-location tests across several years. In 2020, a total of 107 new crosses were made. The bulk-pod descend method was used to advance 299 plant populations in early generations, and 9392 progeny rows were evaluated for adaptation and agronomic performance. Off-season nurseries were used to speed up the breeding process. Preliminary (1st year) yield trials were grown in three Arkansas locations in non-replicated tests. Intermediate (2nd year) yield trails were grown in 4 Arkansas locations with 1 replication. Advanced (3rd year) yield trials were grown in 4 Arkansas locations with 2 replications. Purity rows were from each entry in Fayetteville, Ark. The most promising lines from Arkansas Advanced yield trials were entered in our pre-commercial test, the USDA Southern Uniform Tests, the Arkansas Soybean Variety Performance Tests, and variety tests at other southern states. Breeder seed was produced concurrently and

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provided for foundation seed production in preparation for release. Pre-commercial lines were screened for resistance to soybean cyst nematode (SCN), root-knot nematode (RKN), stem canker (SC), and frogeye leaf spot (FLS). Drought and flood tolerance were also screened under either greenhouse or field conditions.

Results and Discussion

In 2020, 1 high-yielding conventional MG 4 and 1 glyphosate-tolerant MG 5 cultivar, UA 46i20C (formerly R16-259) and UA 54i19GT (formerly R13-14635RR) were publicly released and sent to the Arkansas Foundation Seeds Program for Arkansas soybean production. In addition, one MG 5 conventional variety (R13-13997) was released through a non-exclusive commercial agreement.

Lines R13-13997 and UA 54i19GT were evaluated in the 2020 USDA Uniform Test 5 with yields of 57.2 and 54.7 bu./ac (98.1% and 93.8% of check mean; 58.3 bu./ac, respectively). Three conventional MG 4 lines R16-253, UA 46i20C, and R15-2422 were evaluated in the 2020 USDA Uniform Preliminary MG 4 late Soybean Test and yielded 55.2, 56.3, and 57.3 bu./ac respectively (85.6%, 87.3%, and 88.8% of the check mean; 64.5 bu./ac). Two conventional promising lines (R15-1587 and R14-1422) were evaluated in the 2020 USDA Uniform Test MG 5 and yielded between 57.0 and 57.2 bu./ac (97.8% and 98.1% of the check mean; 58.3 bu./ac). A total of 8 promising lines (R16-1445, R16-8295, R17-2442, R17-283F, R13-11034, R15-5695, R16-45, and R17-7481RR) were also evaluated for yield in the 2020 Uniform Preliminary MG 5 Soybean Tests. Line R13-11034 was the best performer of our MG 5 lines, yielding 58.5 bu./ac with 100.5% of the check mean (58.2 bu./ac) and ranking 2nd out of 24 entries in the test.

A total of 1386 conventional breeding lines were evaluated for yield in multi-location advanced, intermediate, and preliminary Arkansas yield tests in 2020 (Table 1), with approximately 59% of entries being MG 4 and 41% MG 5. Of the pre-commercial lines (64 conventional and 5 glyphosate-tolerant lines) evaluated, 1 MG 4 line (R13-14635RR:0010) with glyphosate tolerance was the best-performing entry at 77.1 bu./ac (100.5% of the check mean; 76.7 bu./ac). This line along with the other 17 promising lines, were selected for further evaluation in the 2021 USDA Uniform Soybean Tests. A total of 9392 progeny rows was grown in Stuttgart, Ark., and 1266 lines (12.8%) were selected based on field appearance for yield trial evaluation in 2021. Finally, 7541 single plants were pulled from F3–F5 breeding populations and have been evaluated as progeny rows at a winter nursery (Table 1).

Practical Applications

We aim to provide Arkansas soybean growers with high-yielding, locally adapted, and valuable cultivars at low cost. The continued release of public cultivars including Ozark, Osage, UA5612, UA5213C, UA5014C, UA5414RR, UA5715GT, UA54i19GT, and UA46i20C offers low-cost seeds for Arkansas farmers and provides sources of germplasm for public and private breeding programs in the United States.

Acknowledgments

The authors acknowledge the support provided by Arkansas soybean producers through check-off funds administered by the Arkansas Soybean Promotion Board. We would like to thank the University of Arkansas System Division of Agriculture's Experiment Station personnel for their help and support with our fieldwork. We also thank the Arkansas Crop Variety Improvement Program for testing our lines before release.

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Table 1. Overview of University of Arkansas System Division of Agriculture's Soybean Breeding and Genetics Program tests in 2020.

Testing stage	Number of entries
USDA Uniform/Preliminary Tests	15
AR Variety Testing Program	19
Arkansas Advanced Lines	200
Arkansas Intermediate Lines	376
Arkansas Preliminary Lines	810
Progeny Rows	9392
Single plants	7541
Breeding Populations (F_1–F_5 generation)	299
New Crosses	107

Soybean Germplasm Enhancement Using Genetic Diversity

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Abstract

To build a diverse soybean [*Glycine max* (L.) Merr.] germplasm pool for breeding and genetic research, the University of Arkansas System Division of Agriculture's Soybean Breeding Program continuously introduces exotic germplasm into elite Arkansas lines to develop and release maturity group (MG) 4 varieties and germplasm with high yield, high grain quality, disease resistance, and local adaptation. In 2020, 4 MG 4 (R18C-1450, R18-14142, R18-14147, R18-13333) and 4 MG 5 advanced lines (R18-4614, R18-5783, R15-7063, R13-11034) derived from crosses with diverse/exotic germplasm were tested in pre-commercial trials. These lines will be further evaluated for yield and other agronomic traits in the United States Department of Agriculture's Uniform Soybean MG 5-Late Test and the University of Arkansas Variety Test. If released, this germplasm will be used as parental sources in second-generation breeding crosses for variety development. In addition, multiple breeding lines and populations with early maturity, disease resistance, and/or indeterminate exotic pedigrees were developed and advanced to introgress these traits in our program. These breeding efforts are the backbone of the sustained pertinence and genetic gain of the Arkansas Soybean Breeding Program.

Introduction

It is well known that soybeans [*Glycine max* (L.) Merr.] have a narrow genetic base, with only 26 ancestors accounting for 90% of the total ancestry of the commercial cultivars (Gizlice et al., 1994). For this reason, it is critical to introduce exotic soybean germplasm to the public and private breeding programs for variety and germplasm development (Carter et al., 1993; Gizlice et al., 1994). A highly active germplasm exchange system is currently in place among public soybean breeding programs in the United States (U.S.). In addition, the U.S. National Plant Germplasm System is frequently accessed by breeders to obtain exotic soybean accessions. These combined efforts are important to ensure a continuous flow of new genes to the breeding programs.

To meet the needs of Arkansas soybean growers, the University of Arkansas System Division of Agriculture's Soybean Breeding Program (SBP) uses exotic germplasm to introduce diverse key traits into elite Arkansas germplasm, including high yield, early maturity, local adaptation, disease resistance, and abiotic stress tolerance. In the last two decades, a total of 9 (R01-416F, R01-581F, R99-1613F, R01-2731F, R01-3474F, R10-5086, R11-6870, R10-2436, and R10-2710) germplasm lines with diverse genes were developed and released by the Soybean Breeding program (Chen et al., 2007; Chen et., 2011; Manjarrez-Sandoval et al., 2018; Manjarrez-Sandoval et al., 2020). Through the efforts made in this project, we can enhance Arkansas soybean germplasm genetic diversity. Herein, we report activities conducted under this project in 2020.

Procedures

In 2020, multiple exotic germplasms with diverse traits of interest, such as early maturity, high yield, and disease resistance were requested in exchange with other public breeding programs. These exotic germplasms were crossed with Arkansas' elite high-yielding lines, and F_1 seeds were harvested and sent to a winter nursery. Breeding populations were advanced from F_1 to F_3 generations by using a modified single-pod descent method (Fehr 1987). In the F_3 generation, populations were either advanced to F_4 or single plants were selected, harvested, and individually threshed for evaluation as progeny rows. Progeny rows with acceptable overall field performance and appearance were selected for preliminary yield testing in multiple locations. Further testing takes place at the intermediate and advanced stages, increasing the number of replications and testing locations gradually. Precommercial lines are then regionally evaluated, and breeder seed is increased concomitantly in preparation for potential release and use as a parent in new crosses.

Results and Discussion

Yield Improvement Using Genetic Diversity. A total of 6 high-yielding advanced lines (R17-2069, R17-2000, R17-

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2115, R15-7063, R13-11034, and R17-2056) with exotic genes were evaluated for yield in multiple regional yield trials. Line R13-11034 showed high yield performance (58.5 bu./ac, ranking 2nd among 24 entries) in the 2020 USDA Preliminary Maturity Group (MG) 5 Late test, with 100.5% of the check mean yield (58.2 bu./ac). In addition, 4 MG 4 (R18C-1450, R18-14142, R18-14147, R18-4614) and 4 MG 5 advanced lines (R18-5783, R15-7063, R13-11034, and R18-13333) with exotic pedigrees were selected for further evaluation in the 2021 USDA Uniform Soybean Tests, the 2021 Arkansas Variety Tests, and 2021 SBP Pre-commercial tests. A total of 30 lines (22 MG 4 and 8 MG 5) with high yield and exotic germplasm were selected for evaluation in the 2021 advanced yield tests. In addition, 14 diversity lines (10 MG 4 and 4 MG 5) in 2020 preliminary testing were selected for intermediate-stage yield evaluation in 2021. Sixty-five progeny rows (21 MG 4 and 44 MG 5) out of 1358 derived from crosses with exotic pedigrees were selected based on field performance and appearance and entered for preliminary-stage yield testing in 2021. A total of 43 breeding populations with exotic pedigrees were advanced in 2020. We also made 11 new cross combinations between high-yielding Arkansas lines and lines with exotic pedigree.

Disease Resistance. In 2020, the line R17-2442 developed from high-yielding and disease-resistant pedigrees was evaluated for yield and disease resistance in the USDA Preliminary MG 5 Early test, yielding 62.0 bu./ac with 96.7% of the check mean yield 64.1 bu./ac. This line showed resistance to stem canker (SC). In addition, 5 advanced MG 4 lines (R18C-13116, R18C-11739, R18C-11784, R18C-12063, and R18C-11658) derived from high-yielding parents resistant to sudden death syndrome (SDS) and soybean cyst nematode (SCN), were evaluated for yield in a 2-replication test grown in 4 Arkansas locations. Due to poor performance, none of the lines were selected for advancement. In 2020, 59 MG 4 and 8 MG 5 lines with SDS, SCN, or rust-resistant pedigrees were tested in multiple intermediate trials in 4 Arkansas locations. Of those, 17 lines with good yield performance were selected for the 2021 advanced trial evaluation. In addition, 5 preliminary lines (MG 4) derived from SDS and SCN resistant parents were selected for 2021 intermediate yield tests. In 2020, we also made 13 new crosses with high-yielding and southern root-knot nematode (SRKN) resistant parents and advanced 17 breeding populations.

Practical Applications

The University of Arkansas System Division of Agriculture's Soybean Breeding Program has made significant progress in the development of value-added germplasm with diverse genetic traits of early maturity, high yield, and disease resistance through exchanging of exotic germplasm within the public breeding community. All efforts supported by this project help to integrate and stack diverse necessary genes into elite Arkansas breeding lines and germplasm for parental stock and potential release.

Acknowledgments

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Table 1. Overview of the germplasm enhancement project in 2020.

Test	Multi-state trial stage entries	Advanced stage entries	Preliminary stage entries
	--------------------------Number of entries----------------------		
High Yield/Early Maturity	6	47	538
Disease Resistance	1	72	117

Breeding Soybean Under Reduced Irrigation Conditions

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Abstract

Water scarcity is a limiting factor for soybean [*Glycine max* (L.) Merr.] production. Soybean irrigation could be problematic in the mid-South, specifically in Arkansas, due to water irregularity, inaccessibility, or unavailability. The purpose of the study was to evaluate the response of soybean wilting, maturity, and yield under different irrigation regimes in Arkansas. A total of 165 determinate MG 5 soybean lines with contrasting wilting potential were planted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart and the Rohwer Research Station during the summers of 2019 and 2020 with 4 different irrigation treatments. The experiment was conducted as an augmented strip plot design. Witling, maturity, and yield were assessed. Analysis of variance (ANOVA) was conducted for each trait. Results showed significant differences for wilting and yield in terms of irrigation levels but no significant differences in maturity. As irrigation was delayed, wilting severity increased. Also, our results indicated that irrigation could be delayed until the R3 stage without any significant decrease in yield. These results will help soybean breeders to have an insight into how to approach soybean line selection under reduced irrigation practices.

Introduction

Aquifer level decline is causing water restrictions to some farmers in Arkansas, especially in sections of the Cache River (Craighead and Poinsett Counties.) and Grand Prairie (Lonoke, Prairie, and Arkansas Counties) Critical Groundwater Areas. As 85% of soybean acreages are irrigated in Arkansas (AFBF, 2021), maximizing yield under deficit irrigation is becoming critical. Moreover, drought can cause a yield loss of up to 40% in soybeans each year (Dogan et al., 2007). To mitigate this risk, soybean varieties that exhibit slow-wilting and/or prolonged nitrogen fixation under drought conditions are being developed by the University of Arkansas System Division of Agriculture's Soybean Breeding Program (Manjarrez et al., 2020). However, there is no information on the performance of slow wilting lines under reduced irrigation, as opposed to dryland production. It is vital to understand how different irrigation levels impact soybean performance and to adopt an appropriate breeding strategy.

Procedures

A total of 165 determinate MG 5 soybean lines and commercial checks were grown during the summer of 2019 and 2020 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart and the Rohwer Research Station as an augmented strip-plot design. The irrigation levels were: 1. Full irrigation (irrigation initiated at R1 growth stage), 2. Irrigation initiated at R2 growth stage, 3. Irrigation initiation at R3 growth stage, and 4. Irrigation initiated at the R4 growth stage. Irrigation at each designated stage was triggered using the decision table developed by Henry et al., (2014) for atmometer measurements based on 50% of the plots reaching the desired stage. Plots consisted of 2 rows 30- to 38-in. apart, 15-ft long with 5-ft alleys. Visual wilting severity was recorded using a scale from 0 = no wilting to 9 = plant death. Maturity was taken in days and reported as days after 31 Aug. Soybean yield (bu./ac) was obtained based on seed weight and moisture, and plot size. Data were analyzed using PROC GLIMMIX in SAS. The fixed effect was the irrigation treatment. Random effects were lines, environment—which is the location-year combination block nested within the environment, treatment-by-lines interaction, treatment-by-environment interaction, treatment-by-location-year combination-by-lines interaction. A pairwise comparison was made using Tukey's honestly significant difference test.

Results and Discussion

Overall, we observed that the environment had the largest variance component for yield, maturity, and wilting severity; with 0 or near 0 variances for the interaction of genotypes and environment. We did not see yield differences between

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fast- or slow-wilting genotypes under the delayed-irrigation methods studied. As irrigation was further delayed, higher wilting severity occurred (Fig. 1). Also, delaying irrigation until the R4 stage led to a reduction in yield (Fig. 2). However, delaying irrigation did not affect maturity under our experimental conditions (Fig. 3). Based on the results, we conclude that soybean response, crop management, and breeding decisions, when the onset of irrigation is delayed to the R2 or R3 stage, are similar to that of fully irrigated soybean.

Practical Applications

Understanding the effects of different water regimes on wilting, maturity, and yield in soybean is important to define the breeding objectives and subsequent deployment of soybean lines under limited irrigation.

Acknowledgments

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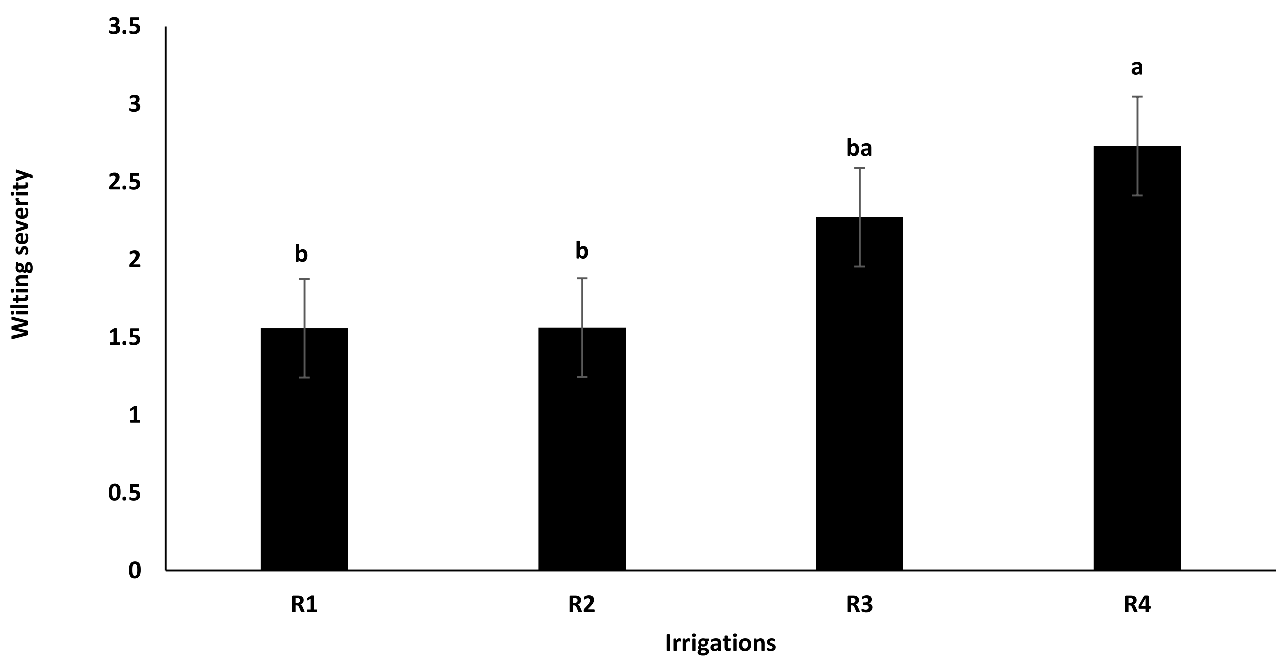

Fig. 1. Average wilting severity of 165 determinate MG 5 soybean lines under different irrigation initiations (R1, R2, R3, or R4 stage) at the University of Arkansas System Division of Agricultures' Rice Research and Extension Center near Stuttgart and the Rohwer Research Station in 2019 and 2020. Different letters indicate significant differences among the treatments at *P*-value < 0.05 by Tukey's honestly significant difference test.

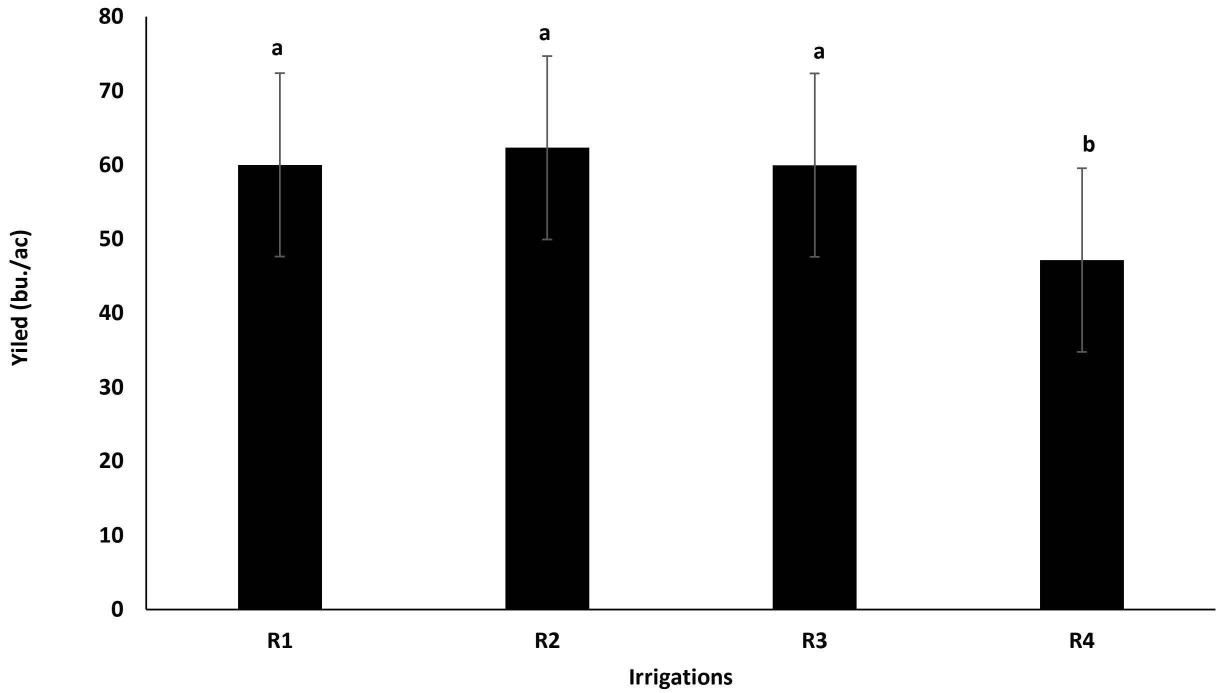

Fig. 2. Average seed yield (bushels per acre) of 165 determinate MG 5 soybean lines under different irrigation initiations (R1, R2, R3, or R4 stage) at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart and the Rohwer Research Station in 2019 and 2020. Different letters indicate significant differences among the treatments at *P*-value < 0.05 by Tukey's honestly significant difference test.

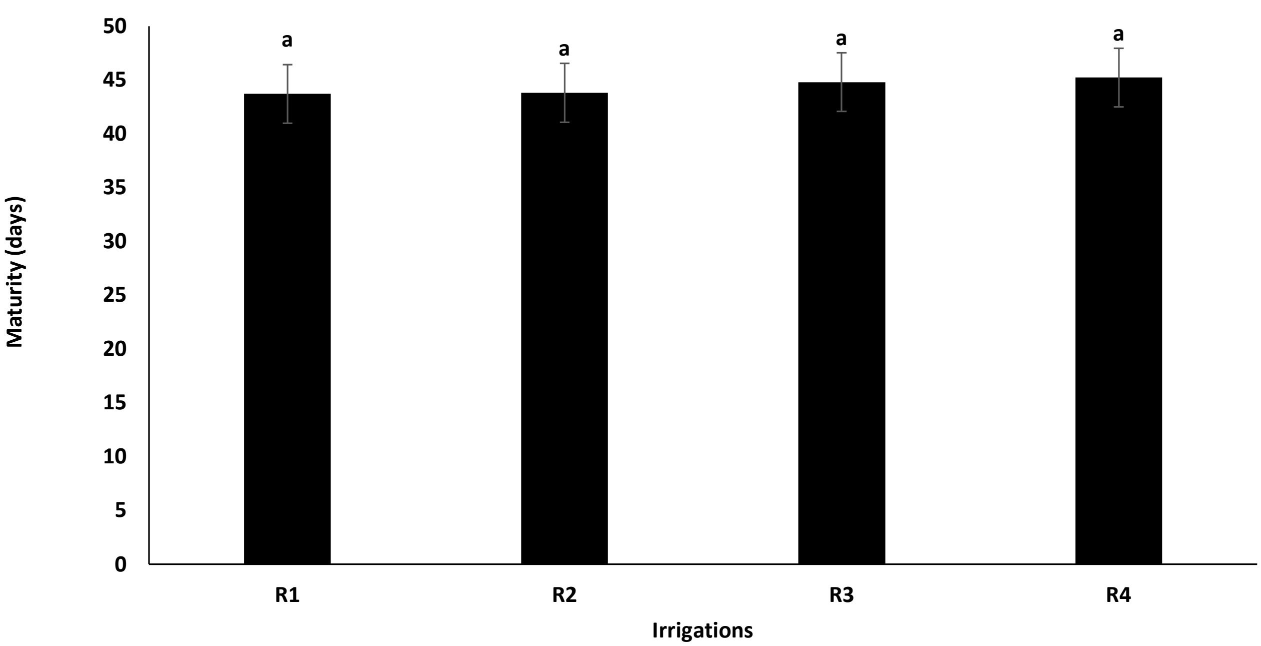

Fig. 3. Average maturity (days) of 165 determinate MG 5 soybean lines under different irrigation initiations (R1, R2, R3, or R4 stage) at the University of Arkansas System Division of agricultures' Rice Research and Extension Center near Stuttgart and the Rohwer Research Station in 2019 and 2020. Different letters indicate significant differences among the treatments at *P*-value < 0.05 by Tukey's honestly significant difference test.

Soybean Variety Advancement Using a Winter Nursery

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Abstract

One of the main goals of the University of Arkansas System Division of Agriculture's Soybean Breeding Program is to develop and release maturity group (MG) 4 soybean [*Glycine max* (L.) Merr.] varieties with superior performance and other desirable traits that are well adapted to Arkansas' growing conditions. The advancement of materials in the breeding process is limited to only 1 cycle per year in the United States (U.S). In order to overcome this challenge and increase efficiency, the program has a contract with a South American nursery for generation advancement during the U.S. winter months. In October 2019, approximately 2800 MG 4 single plants from 20 breeding populations were selected and individually harvested from the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark. Seed was subsequently sent to Quillota, Chile, to grow as progeny rows. In April 2020, 569 lines (8.2% MG 3, 67.5% MG 4, and 24.3% MG 5-early) were selected based on drone imagining data, bulk-harvested, and sent back for yield evaluation in preliminary trials in 3 Arkansas locations with 1 replication. Having implemented the use of a winter nursery into our workflow has shortened the breeding cycle by 1 year, increasing the proportion of MG 4 in testing from 46% to 52%, and even adding 3% in MG 3 entries, which brings us 1 step closer to reach our goal of 75% MG 4 efforts in 2021.

Introduction

The University of Arkansas System Division of Agriculture's Soybean Breeding Program's goal is to meet the needs of the Arkansas soybean [*Glycine max* (L.) Merr.] growers. Thus, developing and releasing competitive conventional maturity group (MG) 4 cultivars in a timely manner is critical. The rate of genetic gain is indirectly proportional to the number of years per breeding cycle. Therefore, reducing the time from crossing to product development will heavily impact the product's performance (Cobb et al., 2019). Consequently, the employment of winter nurseries is vital to speed up the development of new cultivars and germplasm by reducing the time per breeding cycle (O'Connor et al., 2013). In this project, progeny rows are grown in Chile during the United States winter months in an environment like Arkansas' growing conditions for phenotypic selection. There, the best performers are selected for preliminary yield testing in Arkansas. By following this workflow, the breeding cycle is shortened by 1 year, thus increasing the rate of genetic gain.

Procedures

Two-thousand eight hundred single plants were selected from 20 genetic populations from the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark. Fourteen of these populations (R13-354/S13-3851, LG14-6879/R13-816, S09-13635/R11-328, S10-7543/R13-1019, LG04-6000/R13-816, S09-13635/R13-816, R11-1578/V11-2149, TN12-3002/R12-937, LD11-7311/R13-816, R16-2495/R15-818, R13-354/DA10x30-09F, R16-253/LD11-2170, R15-818/SA13-1385, R16-2507/KS4117Ns) were developed from crossing high-yielding conventional MG 4 parents. Another population (DS43-72/S14-15138R) was derived from an MG 4 conventional parent and an MG 4 glyphosate-tolerant parent. A separate population (LG11-6208/R01-3474F) was developed from crossing 2 high-yielding conventional MG 4 lines with exotic pedigree. Two other populations (LD10-4612/R13-532, UA 5115C/DA10x30-09F) were developed from crossing a high-yielding MG 4 line and a high-yielding MG 5 line. In addition, 2 populations (FNA1.31/R12-2142, FNA1.32/R11-1057) were derived from crosses between an MG 5 early parent with an MG 5 late parent. Single plants were individually harvested, the seed was cleaned for purity, treated with fungicide, and sent to Quillota, Chile, to be grown as progeny rows during winter 2019-2020. In April 2020, 569 lines (47 MG 3, 384 MG 4, and 138 MG 5 early) were selected based on drone imaging data using an experimental procedure involving image-predicted maturity, a vegetation index calculated using RGB bands, and the actual visual look of the pictures of the plots. Selected entries were then bulk harvested and sent back

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to Arkansas where they were evaluated in preliminary yield trials in 3 locations with 1 replication.

Results and Discussion

The Soybean Breeding Program evaluated 569 preliminary lines a year earlier than under the standard workflow, all while maintaining a consistent inbreeding stage. This generated an increase in the proportion of MG 4 entries in testing from 46% to 52% and added 3% in MG 3 entries, which brings us closer to our goal of 75% MG 4 by 2021.

Practical Applications

It is critical to employ tools that help reduce the time needed per breeding cycle in order to meet the Arkansas soybean grower's demands of MG 4 competitive varieties that are locally adapted. Utilization of a winter nursery to grow soybeans counter-season shortens the number of years required to develop and release varieties, as it makes it possible to conduct 2 cycles of selections on a given calendar year.

Acknowledgments

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Effects of Cereal Rye Termination Date on Seedling Diseases and Soil Nutrient Content

J.C. Rupe,[1] J.A. Rojas,[1] and T.R. Roberts[2]

Abstract

In the second year of a cereal rye cover crop termination study, cereal rye (*Secale cereale*) was terminated on 17 Feb., 2 April, and at planting (13 June) in 2020. While not statistically significant, cereal rye biomass increased with delays in termination. Levels of soil phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and soil organic matter (SOM) were greater, and levels of soil iron (Fe) and manganese (Mn) were significantly lower in the terminated at planting cover crop treatment than the no cover crop treatment. Seed treatments did not significantly increase stands compared to the untreated seed, but the seed treatment containing the nematicide, Avicta®, had significantly lower stands than any of the other treatments. Plant-parasitic nematodes were not detected this year. Yields were not significantly affected by any of the treatments but were lower than last year (40.3 vs. 55.8 bu./ac respectively). The lower yields may have reflected the late planting (13 June 2020 vs. 15 May 2019). Our results indicate that in only 2 years, a cereal rye cover crop has made significant changes in the soil's chemical properties. While it is not known why the addition of Avicta to the seed treatment lead to a reduction in plant stand, this year's results indicate that only seed treatments that meet the needs of the particular field should be used.

Introduction

Soybean [*Glycine max* (L.) Merr.] growers are increasingly turning to cover crops to reduce soil erosion and build soil health. Of the many plant species used as cover crops, cereal rye (*Secale cereale*) is one of the most popular with soybean (Crowley et al., 2018; Wen et al., 2017). Not only is cereal rye effective in preventing erosion and maintaining soil moisture, but it can also suppress weeds and reduce several soilborne pathogens including the soybean cyst nematode (Bakker et al., 2016; Crowley et al., 2018; Martinez-Garcia et al. 2018; Rupe et al., 2019; Schmidt et al., 2018; Schultz et al., 2013; Timper 2017; Wen et al., 2017). Cereal rye, established in the fall, produces maximum biomass by late spring; however, growers may terminate the crop early for a variety of management considerations. Termination timing greatly affects the amount of biomass produced and the impact of the cover crop on the soil (Balcom et al., 2016). The objective of this research was to determine the effects of several seed treatments on the emergence and yield of soybean planted into a cereal rye cover crop terminated on different dates.

Procedures

This was the second year of this cereal rye cover crop termination study at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station near Marianna, Ark. (Rupe et al., 2020). Cereal rye was planted after soybean harvest on 26 Oct. 2019 with a grain drill in a randomized complete block experimental design with 4 replications. Each cover crop plot was 24 (eight rows) by 200 ft.

The cover crop treatments were fallow, early termination (17 February 2020), mid-termination (2 April 2020), and at planting termination (13 June 2020). The early and mid-treatments were terminated with glyphosate (2 pt/ac) and the planting termination with glyphosate and glufosinate (2 pt/ac, each). Biomass was determined from 10, 8-ft^2 sections of each plot at planting on 16 June 2020. In each cover crop plot, the soybean cultivar "Delta Grow DG48E49-FE-31-BB" was planted in 38-in. rows at 80,000 seed/ac.

There were 6 soybean seed treatments planted in each cover crop plot: ApronMaxx® + Vibrance®, ApronMaxx + Vibrance + Cruiser®, ApronMaxx + Vibrance + Cruiser + Avicta®, Allegiance® alone, Sedaxane alone, and an untreated control. These seed treatments controlled fungi/oomycetes, fungi/oomycetes and insects, fungi/oomycetes and insects and nematodes, or oomycetes (*Pythium* spp.), fungi (targeting mostly *Rhizoctonia solani*), or had no added control, respectively.

The soybean plots were planted no-till. Soil samples from the top 6-in. of each cover crop plot were taken at planting and sent to the University of Arkansas System Division of Agriculture's Soil Testing and Research Laboratory, Marianna, Ark. for soil nutrient and chemical analysis. The soil was also sent to the University of Arkansas System Division of Agriculture's Nematode Laboratory, Hope, Ark., for nematode analysis. Plant stands were determined from each plot 2 at weeks (30 June 2020) and 4 weeks (14 July 2020) after planting. Mid-season soil samples were collected from plots planted with untreated seed and with seed treated with ApronMaxx + Vibrance+ Cruiser + Avicta on 29 July 2020 and 8 Oct. 2020 and sent to the Nematology Laboratory for

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analysis. Yields were taken from the center 2 rows of each seed treatment plot on 10 Oct. 2020. Cover crop biomass, soil nutrient, and chemical factors, and nematode densities at planting were analyzed by cover crop as a randomized block design. All other measurements were analyzed as a split-plot design with the cover crop as the main factor and seed treatments randomized within each cover crop. All analyses used PROC GLIMMIX (SAS Institute Inc., Cary, N.C.).

Results and Discussion

There were no significant differences in biomass at planting in 2020; however, biomass increased from 906 lb/ac for the fallow and the February termination to 1526 lb/ac for the April termination, and 2242 lb/ac at planting on 16 June. The biomass levels recorded for the fallow and early termination treatments were due to winter annual weeds. The at planting biomass was much lower than in 2019, which was 4837 lb/ac. The lower biomass in 2020 may have been due to planting after the cereal rye had senesced, and 2019 may have been a more favorable year for the growth of cereal rye. The higher-than-expected biomasses for the January termination plots may have been due to weed growth in the spring.

The cover crop termination timings did have a significant effect on soil chemical properties. While only in the second year of this study, there were significant changes in concentrations of several soil chemical properties with a delay in cover crop termination (Table 1). Levels of phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and soil organic matter (SOM) were greater and levels of iron (Fe) and manganese (Mn) were lower in the cover crops terminated at planting than the no cover crop treatment. There were no differences between cover crop treatments in soil fertility factors in 2019. This shows how quickly soil chemicals can fluctuate with cover crops.

Like these changes in soil fertility, cover crops probably affected the soil-borne microorganisms including seedling pathogens. While we did not have significant increases in the soybean stand with any of the seed treatments compared to the untreated or to cover crop terminations, that may be due to the planting environment. Planting was delayed this year (13 June 2020 compared to 15 May 2019) and soybean was established under hot conditions (average soil temperature approximately 76 ºF) with adequate, but not excessive moisture. These are conditions that do not favor seedling disease, hence seed treatments would have a reduced effect. However, there was apparent phytotoxicity with the seed treatment containing the nematicide Avicta (ApronMaxx + Vibrance + Cruiser + Avicta). Seeds with this treatment had significantly lower stands than any of the other treatments including the control (Fig. 1). This apparent phytotoxicity with Avicta was not observed last year and we have not observed this in any of our other seed treatment tests (Rupe et al., 2020). It is not clear why this happened this year, but we have observed stand reductions with other seed treatments and this reduction in emergence may be due to specific combinations of seed vigor, seed treatment, and the planting environment.

Plant pathogenic nematodes (soybean cyst nematode, southern root-knot nematode, reniform nematode) were at undetectable levels at all sampling dates. All had been present in previous years (Rupe et al., 2019, Rupe et al., 2020). While the cultivar used in this study (Delta Grow DG48E49-FE-31-BB) has resistance to races 3 and 14 of soybean cyst nematode, it is susceptible to root-knot nematode. One explanation may be that the soils were very dry when samples were taken and the nematodes may have been lower in the soil profile than our sampling depth.

There were no significant differences in yield between any of the cover crop termination treatments or seed treatments. Yields averaged 40.3 bu./ac. In 2019, yields averaged 55.8 bu./ac. Lower yields may have been due to the late planting date in 2019.

Practical Applications

Previous work has suggested that introducing cover crops into a rotation and significantly increase the concentration of plant-available nutrients near the soil surface and the crop rooting zone. Our study shows that planting a cereal rye cover crop changes the soil's chemical properties in as little as 2 years. Increases in macronutrient concentrations such as P and K can decrease the need or rate of commercial fertilizer additions while still maximizing soybean yield potential. These changes were greatest when termination of the cover crop was delayed until planting. This late termination date would also give the greatest weed control. While previous studies have shown the importance of seed treatments in stand establishment with or without a cover crop, our 2020 results indicate that there may be situations where some seed treatments are detrimental or the effect is not visible. Why the inclusion of Avicta resulted in a reduction in stand in 2020 is not known, but it is prudent to select seed treatments to meet the needs of your specific fields. The overall effect of cover crops is additive after years of practice; the current study in 2021 will provide a broader view after three years of these cover crop treatments.

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Table 1. Effect of cereal rye cover crop termination on soil fertility factors in 2019 and 2020 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Ark.

Year/ Treatment	P	K	Ca	Mg	Zn	Fe	Mn	CU	B	OM
	Soil factor									
	---lb/ac---									%
2019[†]	38	125	1285	292	2.3	153	152	1.5	0.28	1.7
2020/C1[‡]	25 b[§]	103 b	1278 c	310 b	1.4 b	135 a	191 a	1.2 bc	0.48 ab	1.6 b
2020/C2	29 b	145 a	1403 b	355 a	1.6 b	131 ab	176 a	1.3 ab	0.50 a	1.8 a
2020/C3	26 b	104 b	1275 c	295 c	1.4 b	155 a	132 c	1.0 c	0.43 b	1.8 a
2020/C4	42 a	156 a	1522 a	325 a	3.7 a	127 b	149 b	1.6 a	0.53 a	1.9 a

[†]There were no significant cover crop effects on soil fertility factors in 2019.

[‡]Cover Crops were C1 = fallow; C2 = terminated in February; C2 = terminated in March; C4 = terminated at planting (16 June).

[§]Numbers within a column in 2020 with the same letter were not significantly different ($P < 0.05$). Factors that were not significantly different between cover crops in 2020 were Sulfur (5–7 lb/ac) and pH (6.9–7.0). In 2019, Sulfur (4–6 lb/ac) and pH (6.7–7.5) respectively.

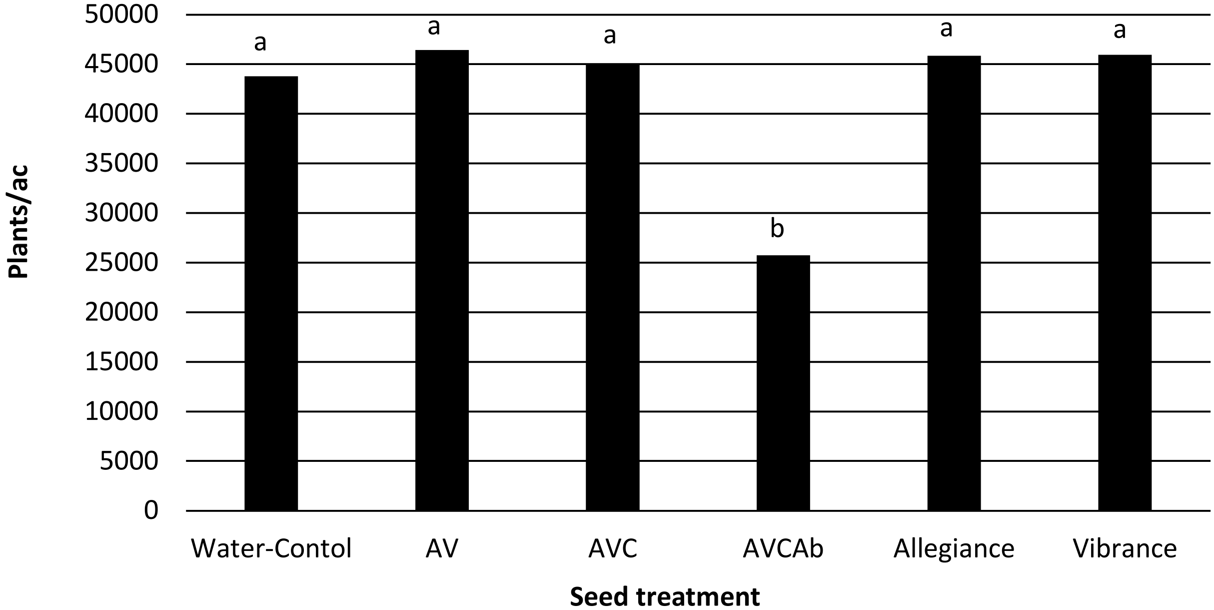

Fig. 1. Plant stands 2 weeks after planting of soybean treated with 5 seed treatments or water at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Ark. in 2020. Seed treatments were: Water-Control; ApronMaxx®+Vibrance® = AV; ApronMaxx+Vibrance+Cruiser® = AVC; ApronMaxx+Vibrance+Cruiser+Avicta® = AVCAb; Allegiance® alone; Vibrance alone. Bars with the same letter are not significantly different (*P* < 0.05).

Field Performance of 37 Maturity Group 4 and 5 Soybean Cultivars in a Southern Root-Knot Nematode Infested Field

M. Emerson[1] *and T. R. Faske*[1]

Abstract

The susceptibility of 37 soybean cultivars to the southern root-knot nematode (*Meloidogyne incognita*) was evaluated in 5 field trials. In all trials, the damage threshold was severe with an average population density of 438 second-stage juveniles/100 cm^3 of soil at harvest. Host susceptibility was based on the percent of root system galled at the R5–R6 growth stage. Cultivars were considered very resistant if the percentage of root system galled was between 0.0% to 1.0%, resistant 1.1% to 4.0%, and moderately resistant 4.1% to 9.0%. Of the maturity group 4 Roundup Ready Xtend® and Enlist E3® cultivars, Go Soy 49G16 was resistant and Credenz CZ 4810X, Delta Grow 4940, Dyna Gro S48XT40, GT Ireane, Pioneer P43A42X-SA2P, Pioneer P46A35X, and Progeny P4908 E3S were moderately resistant, while Pioneer 45A29L-SA2P was moderately resistant in the Liberty Link™ trial. In the maturity group 5 Roundup Ready/Xtend and Enlist E3 trial, Armor 55-D57, Delta Grow DG50E10, Go Soy 50G17, Go Soy 5214, and Pioneer 52A05X were resistant, Credenz CZ 5700X and Progeny P5554 RX were moderately resistant, whereas Pioneer P52A43L-SA2P was moderately resistant in the Liberty Link trial. The 6 resistant cultivars would be a preferred choice in fields with a high density of southern root-knot nematode; however, the other 10 moderately resistant cultivars would be useful at lower nematode densities.

Introduction

The southern root-knot nematode (RKN), *Meloidogyne incognita*, is one of the most important nematodes of soybean in Arkansas (Kirkpatrick et al., 2014). During the 2015 cropping season, yield losses by RKN were estimated at 8.62 million bushels (Allen et al., 2018). Based on a recent survey, more than 28% of the samples collected in soybean fields in the state were infested with RKN (Kirkpatrick, 2017), which is a dramatic increase over the last survey (Robbins et al., 1987). Factors that contributed to this increase over the past 30 years include an increase in the use of earlier maturing soybean cultivars that are susceptible to RKN and their use in monoculture soybean or soybean-corn cropping systems (Kirkpatrick, 2017).

Management strategies for root-knot nematodes include an integrated approach that utilizes resistant cultivars, crop rotation, and nematicides. Since 2006, the availability of seed-treated nematicides has increased; however, this delivery system is most effective at low nematode population densities or when paired with host plant resistance at higher population densities. Crop rotation can be an effective tool when poor hosts such as some grain sorghum hybrids or peanuts are used in a cropping sequence; however, these crops may not fit all production systems. The use of resistant soybean cultivars is the most economical and effective strategy to manage RKN (Kirkpatrick et al., 2014). Unfortunately, resistance is limited in the most common maturity groups (MG 4) grown in the state (Emerson et al., 2018) and further limited among new herbicide technology traits for soybean.

Screening soybean cultivars for susceptibility to root-knot nematode is one of the services provided by the University of Arkansas System Division of Agriculture (UADA) Cooperative Extension Service (Kirkpatrick et al., 2017) and only provides information on those cultivars that are entered into the official UADA Official Variety Testing Program (OVT). The objective of this study was to expand on the RKN susceptibility and yield response of a few MG 4 and 5 cultivars that are marketed as resistant or identified as resistant from the OVT.

Procedures

Thirty-seven soybean cultivars were evaluated in a field that was naturally infected with *Meloidogyne incognita* near Kerr, Ark. Selected cultivars were among the most common MG 4 and 5's grown in the state (Tables 1–5) and experiments were divided between MG and herbicide technologies [glyphosate-tolerant (Roundup Ready® 2 Yield), glufosinate-tolerant (Liberty Link™), dicamba-tolerant (Xtend®), and 2,4-D-tolerant (Enlist® E3)]. Fertility, irrigation, and weed management followed recommendations by the UADA Cooperative Extension Service. Plots consisted of 4 rows, 30-ft long, spaced 30-in. apart, separated by a 5-ft fallow alley. Seeds were planted using a Kincaid Precision Voltra Vacuum plot planter (Kincaid Equipment Manufacturing, Haven, Kan.) on 2 June 2020 at a seeding rate of 150,000 seeds/ac. The experimental design was a randomized complete block with 4 replications per cultivar. The population density of RKN at planting averaged 77 second-stage juveniles (J2)/100 cm^3 of soil with a final population density of 438 J2/100 cm^3 of soil.

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Nematode infection was based on root galling using a 0%–100% scale (0–1.0 = very resistant; 1.1–4.0 = resistant; 4.1–9.0 = moderately resistant; 9.1–20.0 = moderately susceptible; 20.1–40.0 = susceptible; 40.1–100.0 = very susceptible) from 8 arbitrarily sampled roots/plot at R5–R6 growth stage. The 2 center rows of each plot were harvested on 21 Oct. 2020 using an SPC-40 Almaco combine equipped with a Harvest Master weigh system (Harvest Master, Logan, Utah).

Data were subject to analysis of variance (ANOVA) using ARM 2021.0 (Gylling Data Management, Inc., Brookings, S.D.). When appropriate, mean separations were performed using Tukey's honestly significant difference (HSD) test at $P = 0.05$.

Results and Discussion

Of the maturity group 4 Roundup Ready/Xtend and Enlist E3 cultivars, there was a wide range in susceptibility with 2.8% to 45.0% of the root system galled. One cultivar, Go Soy 49G16, was resistant to the southern root-knot nematode and had a lower ($P = 0.05$) gall rating than Delta Grow DG4880, the susceptible control cultivar (Table 1 and 2). This resistant cultivar had an average grain yield of 61 bu./ac, which was 14 bu./ac greater than the average yield (47 bu./ac) of the susceptible cultivars. In both trials, there was a negative correlation (r = -0.58, $P = 0.0002$ and r = -0.46, $P = 0.0016$) between root system galled and yield.

In maturity group 4 Liberty Link cultivars, there was a wide range in susceptibility with 4.5% to 25.0% of the root system galled. One cultivar was moderately resistant, Pioneer P45A29L-SA2P, and had a lower ($P = 0.05$) gall rating than Credenz CZ 4649LL, the susceptible control cultivar (Table 4).

The moderately resistant cultivar grain yield average was 64 bu./ac, which was 18 bu./ac greater than the average yield (46 bu./ac) of the susceptible cultivars. There was a significant negative correlation (r = -0.85, $P = 0.0001$) between galling and yield. Of the maturity group 5, Roundup Ready/Xtend and Enlist E3 cultivars, 5 were resistant. Susceptibility ranged from 1.5% to 41.3% of the root system galled. Armor 55-D57, Delta Grow DG50E10, Go Soy 50G17, Go Soy 5214, and Pioneer 52A05X were resistant and all had a lower ($P = 0.05$) gall rating than Delta Grow DG5170, the susceptible control cultivar (Table 3). These resistant cultivar's grain yield average was 55 bu./ac, which was 14 bu./ac greater than the average yield (41 bu./ac) of the susceptible cultivars. There was a significant negative correlation (r = -0.69, $P = 0.0001$) between galling and yield.

In maturity group 5, Liberty Link cultivars, susceptibility ranged from 8.3% to 67.5% root system galled. None of the cultivars were resistant; however, 1 of the cultivars was moderately resistant, Pioneer P52A43L-SA7P, and had a lower ($P = 0.05$) gall rating than Credenz CZ 5150LL, the susceptible control (Table 5). The resistant cultivar grain yield average was 65 bu./ac, which was 26 bu./ac greater than the average yield (39 bu./ac) of the susceptible cultivars. There was a significant negative correlation (r = -0.75, $P = 0.0001$) between galling and yield.

Practical Applications

Root-knot nematode is an important yield-limiting pathogen that affects soybean production in Arkansas. These data provide information on a cultivar's susceptibility to the southern root-knot nematode and its impact on susceptible soybean cultivars. Cultivar selection should be based on at least two years of screening as there is variation in galling and yield between seasons.

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Table 1. Root gall ratings and yield from 10 Roundup Ready/Xtend® and Enlist E3® maturity group 4 soybean cultivars grown in a southern root-knot nematode infested field.

Cultivar	Root system galled†	Susceptibility‡	Yield
	%		bu./ac§
GT Ireane	5.3 bc¶	MR	62.6 a
GoSoy 49G16	2.8 c	R	60.8 ab
Pioneer P43A42X-SA2P	5.5 abc	MR	60.6 ab
Pioneer P49T62E-SA2P	32.0 a	S	57.5 abc
Credenz CZ 4810X	8.5 abc	MR	56.1 a-d
Dyna Gro S48XT40	8.5 abc	MR	55.8 a-d
Progeny P4908 E3S	6.8 abc	MR	53.1 a-d
Delta Grow DG4880RR (susceptible check)	36.8 a	S	47.5 bcd
Armor 44-D19	29.5 ab	S	45.8 cd
Armor 48-D03	39.0 a	S	43.2 d

† Root gall rating severity was based on a percent scale where 0 = no galling and 100 = 100% of the root system galled.

‡ Susceptibility based on percent of root system galled where 0–1.0 = very resistant (VR), 1.1–4.0 = resistant (R), 4.1–9.0 = moderately resistant (MR), 9.1–20.0 = moderately susceptible (MS), 20.1–40.0 = susceptible (S), 40.1–100.0 = very susceptible (VS).

§ Adjusted to 13% moisture.

¶ Numbers within the same column followed by the same letter are not significantly different (P = 0.05) according to Tukey's honestly significant difference test.

Table 2. Root gall ratings and yield from 11 Roundup Ready Xtend® and Enlist E3® maturity group 4 soybean cultivars grown in a southern root-knot nematode infested field.

Cultivar	Root system galled	Susceptibility‡	Yield
	%		bu./ac§
Delta Grow DG48E28	12.0 ab¶	MS	56.1 a
Pioneer P46A35X	9.0 ab	MR	55.8 a
Delta Grow DG4940	4.5 b	MR	54.5 ab
Progeny P4444 RXS	13.8 ab	MS	53.9 ab
Pioneer P48A60X	27.0 ab	S	49.8 abc
NK S45-J3X	20.0 ab	MS	49.5 abc
Pioneer P41T07E-SA2P	28.8 ab	S	47.9 abc
Pioneer P39T73E-SA2P	33.0 a	S	45.8 abc
Pioneer P48T22-SA2P	31.3 a	S	38.3 abc
Delta Grow DG4880RR (susceptible check)	45.0 a	HS	37.5 bc
USG 7461XTS	33.8 a	S	35.9 c

† Root gall rating severity was based on a percent scale where 0 = no galling and 100 = 100% of the root system galled.
‡ Susceptibility based on percent of root system galled where 0–1.0 = very resistant (VR), 1.1–4.0 = resistant (R), 4.1–9.0 = moderately resistant (MR), 9.1–20.0 = moderately susceptible (MS), 20.1–40.0 = susceptible (S), 40.1–100.0 = very susceptible (VS).
§ Adjusted to 13% moisture.
¶ Numbers within the same column followed by the same letter are not significantly different (P = 0.05) according to Tukey's honestly significant difference test.

Table 3. Root gall ratings and yield from 11 Roundup Ready/Xtend® and Enlist E3® maturity group 5 soybean cultivars grown in a southern root-knot nematode infested field.

Cultivar	Root system galled †	Susceptibility‡	Yield
	%		bu./ac§
GoSoy 50G17	3.8 d¶	R	60.7 a
Pioneer P52A05X	3.5 d	R	60.6 a
Armor 55-D57	3.0 d	R	54.8 ab
Progeny P5554 RX	6.3 a-d	MR	52.1 abc
Credenz CZ 5700X	4.8 bcd	MR	50.3 abc
GoSoy 5214	1.5 d	R	49.1 abc
Delta Grow DG50E10	4.0 cd	R	47.7 a-d
Local Seed LS5009XS	35.5 abc	S	44.4 bcd
Delta Grow DG5170 (susceptible check)	33.8 ab	S	44.2 bcd
Progeny P5016 RXS	41.3 a	HS	40.3 cd
NK S52-47X	31.3 ab	S	34.2 d

† Root gall rating severity was based on a percent scale where 0 = no galling and 100 = 100% of the root system galled.
‡ Susceptibility based on percent of root system galled where 0–1.0 = very resistant (VR), 1.1–4.0 = resistant (R), 4.1–9.0 = moderately resistant (MR), 9.1–20.0 = moderately susceptible (MS), 20.1–40.0 = susceptible (S), 40.1–100.0 = very susceptible (VS).
§ Adjusted to 13% moisture.
¶ Numbers within the same column followed by the same letter are not significantly different (P = 0.05) according to Tukey's honestly significant difference test.

Table 4. Root gall ratings and yield from 3 maturity group 4 Liberty Link™ soybean cultivars grown in a southern root-knot nematode infested field.

Cultivar	Root system galled†	Susceptibility‡	Yield
	%		bu./ac§
Pioneer P45A29L-SA2P	4.5 b¶	MR	63.8 a
Credenz CZ 4649LL (susceptible check)	17.5 ab	MS	51.4 b
Pioneer P38A49L-SA2P	25.0 a	S	40.3 c

† Root gall rating severity was based on a percent scale where 0 = no galling and 100 = 100% of the root system galled.

‡ Susceptibility based on percent of root system galled where 0–1.0 = very resistant (VR), 1.1–4.0 = resistant (R), 4.1–9.0 = moderately resistant (MR), 9.1–20.0 = moderately susceptible (MS), 20.1–40.0 = susceptible (S), 40.1–100.0 = very susceptible (VS).

§ Adjusted to 13% moisture.

¶ Numbers within the same column followed by the same letter are not significantly different (P = 0.05) according to Tukey's honestly significant difference test.

Table 5. Root gall ratings and yield from four maturity group 5 Liberty Link™ soybean cultivars grown in a root-knot nematode infested field.

Cultivar	Root system galled†	Susceptibility‡	Yield
	%		bu./ac§
Pioneer P52A43L-SA7P	8.3 b¶	MR	65.4 a
Progeny P5414 LLS	38.8 ab	S	42.2 b
Credenz CZ 5150LL (susceptible check with ILeVo)	67.5 a	HS	38.0 b
Credenz CZ 5150LL (susceptible check untreated)	63.8 a	HS	37.3 b

† Root gall rating severity was based on a percent scale where 0 = no galling and 100 = 100% of the root system galled.

‡ Susceptibility based on percent of root system galled where 0–1.0 = very resistant (VR), 1.1–4.0 = resistant (R), 4.1–9.0 = moderately resistant (MR), 9.1–20.0 = moderately susceptible (MS), 20.1–40.0 = susceptible (S), 40.1–100.0 = very susceptible (VS).

§ Adjusted to 13% moisture.

¶ Numbers within the same column followed by the same letter are not significantly different (P = 0.05) according to Tukey's honestly significant difference test.

Comprehensive Disease Screening Summary of 2017 to 2019 Official Variety Testing Soybean Varieties in Arkansas

M. Emerson,[1] T.R. Faske,[1] and T. Spurlock[1]

Abstract

The Arkansas Soybean Promotion Board has supported a comprehensive disease screening program since 1990 in Arkansas. Based on a three-year summary of the disease screening program from 2017–2019, resistance and moderately resistant entries to stem canker (*Diaporthe phaseolorum* var. *meridionalis*) have increased from 76% to 94%. While resistance and moderately resistant entries to frogeye leaf spot (Cercospora sojina) were 64% of the entries in 2018, this was the only year frogeye leaf spot developed in the screening plots between 2017 to 2019. As with previous years, most of the entries are at least susceptible (average of 85% of entries) to the southern root-knot nematode (*Meloidogyne incognita*) in both greenhouse and field screens. The difference between the nematode screenings could be attributed to the different environmental conditions, artificial versus natural inoculum, and soil texture; however, both screenings can provide useful data to farmers picking cultivars for fields with a history of southern root-knot nematodes to avoid yield losses. The results of the disease screening are summarized each year for the annual Soybean Update and the Arkansas Variety Testing Website.

Introduction

Host plant resistance is the most practical tactic of the options to manage soybean diseases (Mayhew et al., 2000). In Arkansas, the southern root-knot nematode (*Meloidogyne incognita*), southern stem canker (caused by D*iaporthe phaseolorum* var. *meridionalis*), and frogeye leaf spot (caused by *Cercospora sojina*) are among the most common diseases observed in the state and have been the focus of this comprehensive disease screening. The screening was conducted from 2017 to 2019, and data were provided to the Arkansas Variety Testing, but a summary has yet to be reported. The objective of this report was to summarize the susceptibility of the entries of the 2017 to 2019 University of Arkansas System Division of Agriculture's Official Variety Testing Program (OVT) for the 2 diseases and one soybean nematode.

Procedures

Over the past 3 years, approximately 207 varieties were screened each year for southern root-knot nematode, frogeye leaf spot, and stem canker.

Southern Root-Knot Nematode (RKN). The RKN greenhouse screen was conducted at the University of Arkansas System Division of Agriculture's Southwest Research and Extension Center near Hope, Ark. by John Barham. All entries were planted with three replications in clay pots and inoculated with 5000 eggs of *Meloidogyne incognita* per pot at the V1 growth stage. Root systems were visually inspected at approximately 56 days after planting (DAP) for root system galled using a 0–10 index scale with 0 being no root galling and 10 being 90%–100% of the root system galled.

The RKN field screening was duplicated in a soybean field near Kerr, Ark., with a history of the southern root-knot nematode. Plots consisted of a single row 11-ft long with 30-in. row spacings and separated by a 4-ft fallow alley. Plots were arranged in a randomized complete block design with 3 replications. The percent of root system galling was estimated for at least 8 root systems from each replication at the R5–R6 growth stage.

Frogeye Leaf Spot (FLS). The screening was conducted at the University of Arkansas System Division of Agriculture's Jackson County Extension Center (JCEC), near Newport, Ark. Plots consisted of a single row; 11-ft long rows spaced 30-in. apart separated by a 4-ft fallow alley. Plots were arranged in a randomized complete block design with 3 replications. *Cercospora sojina* spores were mixed in a water solution and applied once to twice depending on weather conditions using a broadcast sprayer at the R1–R2 growth stage. Plots were heavily irrigated using overhead irrigation to promote disease development. The severity of FLS was rated at approximately 12 weeks after planting based on leaf area infected in the upper canopy using a 0–9 index scale with 0 being no disease and 9 expressing severe symptoms of FLS.

Stem Canker. The 2017 and 2018 screening for stem canker was conducted at the JCEC. Starting in 2019, the screening was conducted at the University of Arkansas System Division of Agriculture's Southeast Research and Extension Center, near Rohwer, Ark. Plots consisted of a single row

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11-ft long spaced 30-in. apart and separated by a 4-ft fallow alley. Plots were arranged in a randomized complete block design with three replications. In each plot, the stems of 10 soybean plants were artificially inoculated at the V5 growth stage with toothpicks infested with *Diaporthe phaseolorum* var. *meridionalis* fungus. The severity of stem canker was rated at the late R5–R6 growth stage using a 0–9 index scale with 0 being no disease and 9 expressing severe symptoms of stem canker.

Results and Discussion

Each year, all soybean varieties entered in the University of Arkansas System Division of Agriculture's Soybean Performance Trials are screened to determine reactions to several pests. The stem canker screenings showed that there was approximately a 10% decrease in the amount of very susceptible cultivars from 2017 to 2019 (Fig. 1). Environmental conditions did not favor FLS in 2017 and 2019; however, disease ratings in 2019 indicated that 38% of the soybean entries tested were susceptible (Fig. 2). Soybean producers could potentially be required to make fungicide applications to manage FLS if a susceptible variety is chosen. On average during 2018 and 2019, the RKN greenhouse screenings showed that 71% of the cultivars screened were rated very susceptible, and the percentage of moderately resistant and resistant cultivars decreased between 2018 and 2019 (Fig. 3). In contrast, the RKN field screening showed that in comparison to the greenhouse screen, more entries were characterized as susceptible as very susceptible than those in the greenhouse (Fig. 4). The difference between the 2 nematode screenings could be attributed to the different environmental conditions, artificial versus natural inoculum, and soil texture; however, both screenings can provide useful data to farmer's selection soybean cultivars for fields with a history of southern root-knot nematodes to avoid yield losses. A copy of disease screening data can be found each year in the Arkansas Soybean Update and on the Arkansas Soybean Variety Testing Website.

Practical Applications

Southern root-knot nematode, frogeye leaf spot, and stem canker are all important yield-limiting pathogens that affect soybean production in Arkansas. The data from the comprehensive disease screening program provides information on cultivar's susceptibility to the southern root-knot, stem canker, and frogeye leaf spot and its impact on susceptible soybean cultivars. Cultivar selection should be based on at least two years of screening as there is variation in disease severity and yield between seasons.

Acknowledgments

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

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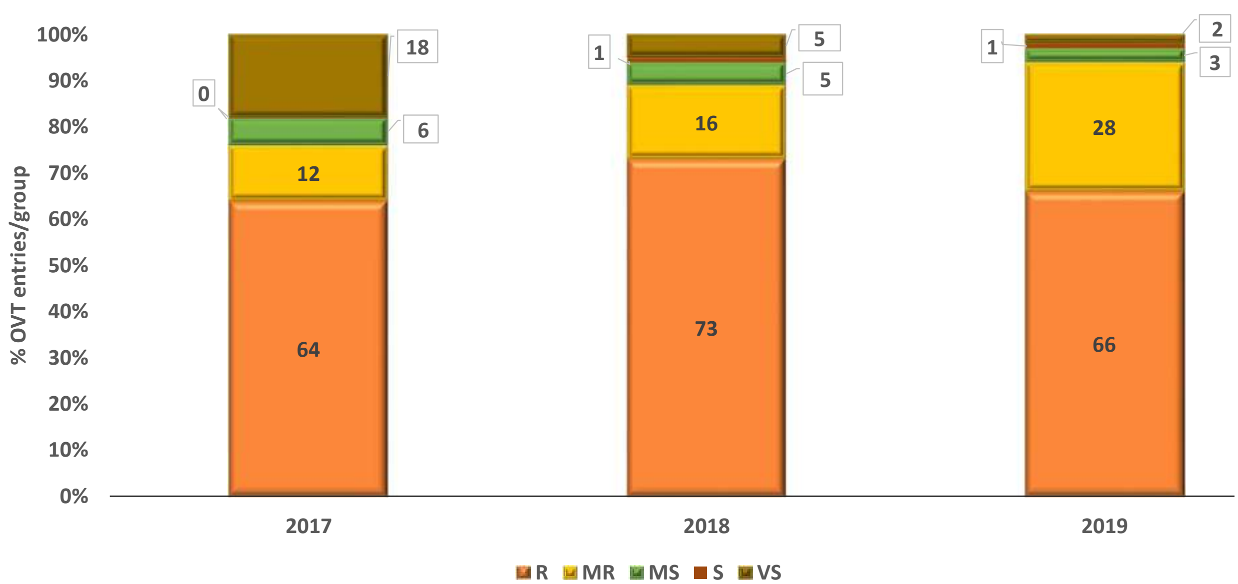

Fig. 1. Percent of soybean cultivars screened (2017–2019) that were resistant (R), moderately resistant (MR), moderately susceptible (MS), susceptible (S), and very susceptible (VS) to stem canker (caused by *Diaporthe phaseolorum var. meridionalis*).

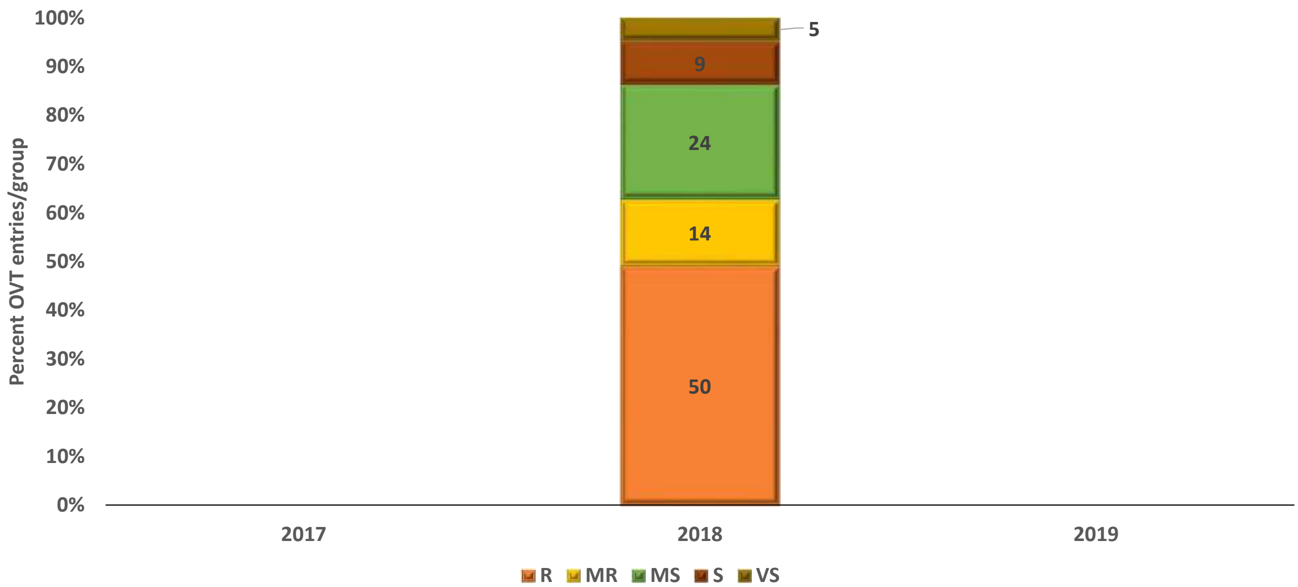

Fig. 2. Percent of soybean cultivars screened (2018) that were resistant (R), moderately resistant (MR), moderately susceptible (MS), susceptible (S), and very susceptible (VS) to frogeye leaf spot (caused by *Cercospora sojina*).

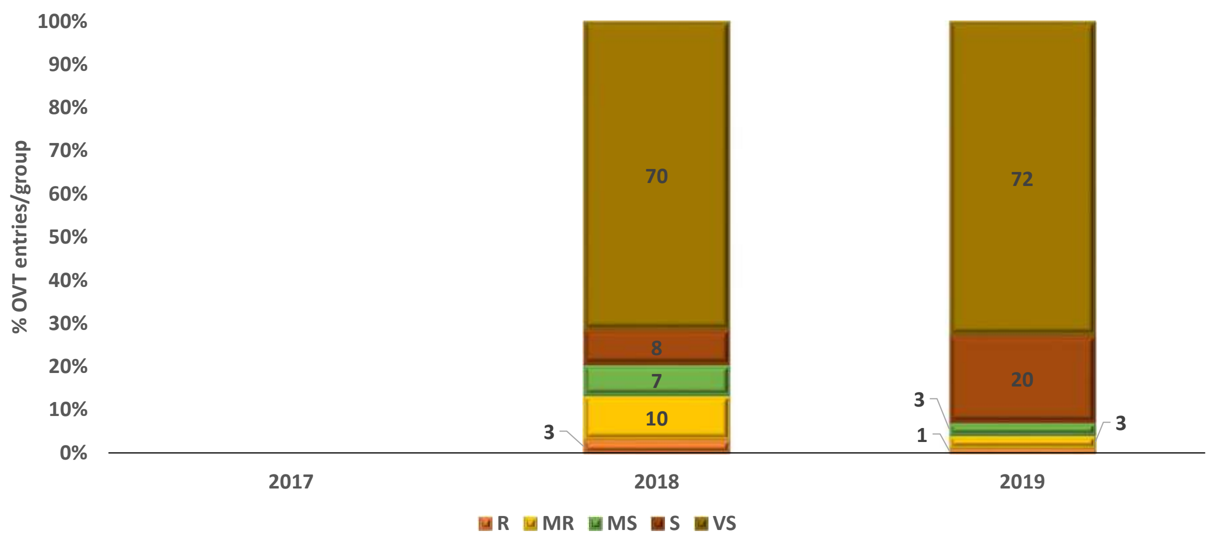

Fig. 3. Percent of soybean cultivars screened (2018–2019) that were resistant (R), moderately resistant (MR), moderately susceptible (MS), susceptible (S), and very susceptible (VS) to root-knot nematode *(Meloidogyne incognita)* in a greenhouse trial.

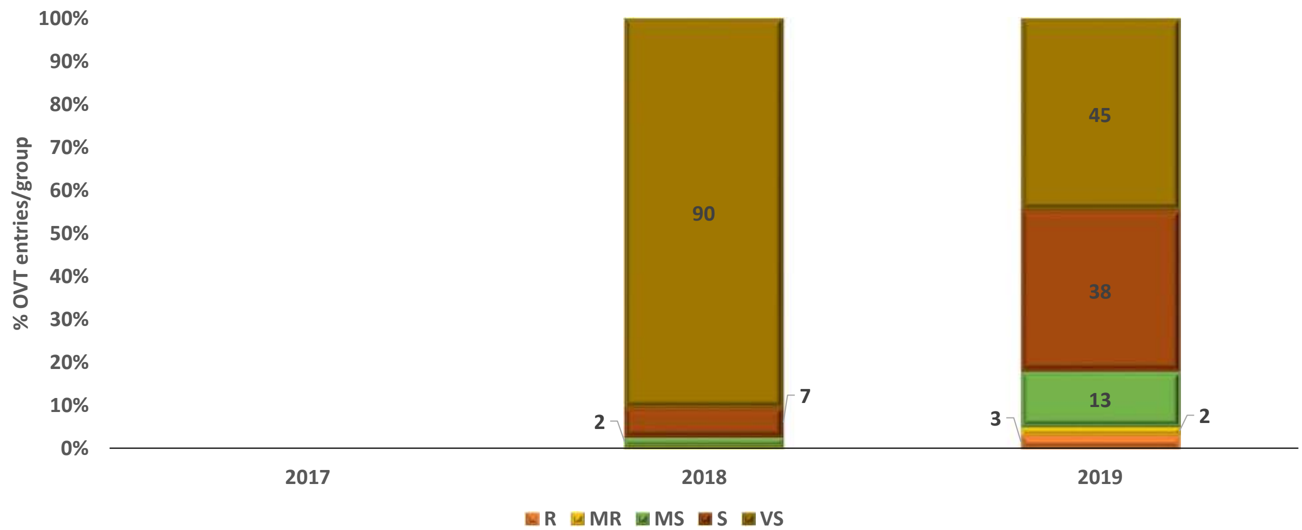

Fig. 4. Percent of soybean cultivars screened (2018–2019) that were resistant (R), moderately resistant (MR), moderately susceptible (MS), susceptible (S), and very susceptible (VS) to southern root-knot nematode (*Meloidogyne incognita)* in a field trial.

Field Efficacy of Low and High Rates of ILEVO® and NemaStrike® ST to Manage the Southern Root-Knot Nematode in Arkansas

T. R. Faske[1] and M. Emerson[1]

Abstract

Two seed-applied nematicides, ILEVO® (fluopyram) and NemaStrike® ST (tioxazafen), were evaluated at low and high labeled rates in 2019 and 2020 in a sandy loam field with a history of the southern root-knot nematode (*Meloidogyne incognita*). Based on soil samples collected at harvest, the nematode damage threshold was high in 2019 (1012 J2/100 cm^3 soil) and 2020 (480 J2/100 cm^3 soil). Nematicide rates for fluopyram were 0.15 and 0.25 mg/seed, whereas tioxazafen were 0.25 and 0.50 mg/seed. The southern root-knot nematode susceptible soybean cultivar, 'Delta Grow DG 4880 RR', was used. Ten roots were sampled from each plot and estimated for percent root system galled at 62 and 34 days after planting in 2019 and 2020, respectively. Though there were slight differences between years, overall, a numerically lower root system galled was observed at the high rate of NemaStrike ST compared to the low rate, but the reverse was true for ILEVO. A greater numeric yield was observed across years at low rates for both nematicides compared to high rates. These data indicate that low rates of ILEVO and NemaStrike ST provide a similar degree of root and yield protection when the southern root-knot nematode damage threshold is high in a sandy loam field.

Introduction

The southern root-knot nematode, *Meloidogyne incognita* (Kofoid and White) Chitwood, is among the most important plant-pathogenic nematode that affects soybean production in the southern United States (U.S.). This nematode species has been reported in 86% of soybean-producing counties in Arkansas, and yield losses > 75% have been reported on susceptible soybean cultivars (Emerson et al., 2018; Kirkpatrick and Sullivan, 2018).

According to the Southern Soybean Disease Workers, the average yield loss estimates due to the southern root-knot nematode in 2019 was 4.0% or 5.6 million bushels of grain in Arkansas and 1.0% or 8.6 million bushels of grain across the Southern U.S. (Allen et al., 2020).

Management of the southern root-knot nematode is difficult due to its wide host range that includes corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), and grain sorghum [*Sorghum bicolor* (L.) Moench], which are grown in rotation with soybean in Arkansas. A few soybean cultivars are characterized as moderately resistant against the southern root-knot nematode (Emerson et al., 2018; Emerson et al., 2019); however, they are often underutilized because resistance may not exist for a specific herbicide technology or maturity group. Furthermore, resistance to the southern root-knot nematodes does not imply resistance to other soybean nematodes such as the soybean cyst nematode (*Hederodera glycines Ichinohe*) or reniform nematode (*Rotylenchulus reniformis* Linford & Oliveira). Given these limitations in resistant cultivars and crop rotation, farmers often use nematicides to manage the southern root-knot nematode.

Seed-applied nematicides are the most common application method in soybean because of availability, adaptability to existing equipment, and no requirement of additional inputs that can potentially slow planting speed, such as with in-furrow applied granular or liquid nematicides.

ILEVO® (fluopyram) and NemaStrike® ST (tioxazafen) were among the most widely marketed seed-applied chemical nematicides from 2017 to 2019 for use in soybean. Typically, low rates of seed-applied nematicides are used because of cost, but there is limited information on high rates of seed-applied nematicides in soybean production. In greenhouse studies, high seed treatment rates of ILEVO provided better southern root-knot nematode control, and greater yield trends were reported in single-year field trials (Hurd et al., 2015, 2017a, 2017b). However, there is little information on the efficacy of NemaStrike ST in greenhouse or field studies. The objective of this multi-year study is to evaluate the field efficacy of ILEVO and NemaStrike ST at low and high labeled rates for suppression of southern root-knot nematode on a susceptible soybean cultivar.

Procedures

The field efficacy of 2 seed-applied nematicides at low and high labeled rates was evaluated in a soybean field with a history of southern root-knot nematode near Kerr, Ark. The site had a moderate and low population density of root-knot

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nematode in 2019 [175 J2/pt soil (37/100 cm^3 soil)] and 2020 [90 J2/pt soil (19/100 cm^3 soil)] at planting, respectively. However, the damage threshold was high in both years based on soil samples at harvest with 1,012 J2/100 cm^3 soil in 2019 and 480 J2/100 cm^3 soil in 2020. The previous crop was corn in 2019 and soybean in 2020. Based on the USDA-NRCS Web Soil Survey website, the 2019 soil series was a Rilla silt loam; but based on a soil texture test, it was a sandy loam (47% sand, 47% silt, 6% clay, and < 1% OM). The 2020 site soil series was a Perry clay, but a soil texture test classified it as a sandy loam (56% sand, 43% silt, and 1% clay, and < 1% OM).

The southern root-knot nematode-susceptible soybean cultivar Delta Grow DG 4880 RR (Delta Grow Seed Co. Inc., England, Ark.) was used (Emerson and Faske, 2020).

All insecticides and nematicides were applied using a rotary seed treating system (UNICOAT 1200 CCS, Universal Coating Systems, Inc., Independence, Oreg.).

No seed-applied fungicide was used in this study. An insecticide treatment of Gaucho 600 F (imidacloprid, Bayer CropScience) at 1.7 fl oz/cwt (0.12 mg ai/seed) was used as the nontreated control. Nematicide treatments included: Avicta® 500 FS (abamectin, Syngenta Crop Protection, Greensboro, N.C.) at 2.6 fl oz/cwt (0.15 mg ai/seed) + Cruiser® 5FS (thiamethoxam, Syngenta Crop Protection) at 1.28 fl oz/cwt (0.0756 mg ai/seed); ILEVO 600 FS (fluopyram; BASF Corporation, Florham Park, N.J.) at 1.2 and 2.0 fl oz/cwt (0.15 and 0.25 mg ai/seed, respectively) + Gaucho® 600 F; and NemaStrike ST (tioxazafen, Bayer CropScience, Research Triangle park, N.C.) at 2.2 and 4.4 fl oz/140,000 seed (0.25 and 0.5 mg ai/seed, respectively) + Gaucho 600 F.

Seeds were planted on 28 May 2019 and 2 June 2020 at a seeding rate of 150,000 seed/ac. Weeds were controlled in plots based on recommendations by the University of Arkansas System Division of Agriculture Cooperative Extension Service (Barber et al., 2020). This study was furrow irrigated. The experimental design consisted of 4 rows, 30-ft long plots, with 30-in. row spacing, separated by a 5-ft fallow alley. Treatments were arranged in a randomized complete block design with four replications per treatment. Seedling vigor and phytotoxicity counts were assessed on 13 June, 10 days after planting (DAP) in 2019, and June 17, 15 DAP in 2020. Vigor was based on a 1–5 scale with 5 = best plant vigor. Soil samples were collected within each block at planting and harvest.

Soil samples were a composite of a minimum of 10 soil cores taken 8 to 10 in. deep with a 0.75-in.-diam soil probe. Nematodes were collected with a modified Baermann ring system and enumerated using a stereoscope. In order to determine nematode infection, 10 roots were arbitrarily sampled from rows 1 and 4 (non-harvest rows) on 29 July (62 DAP) in 2019 and on July 6 (34 DAP) in 2020 from each plot. Gall ratings were based on the percent of root system galled. The center 2 rows of each plot were harvested on 4 Nov. 2019 using a K Gleaner combine (Allis-Chalmers Manufacturing Company (1969-1976), West Allis, Wisc.) equipped with a HarvestMaster Single BDS HiCap HM800 Weigh System (HarvestMaster Logan, Utah), and on 21 Oct. 2020 using an ALMACO SPC40 plot combine (ALMACO Nevada, Iowa) equipped with a HarvestMaster Single BDS HiCap HM800 Weigh System (HarvestMaster Logan, Utah).

Data were subjected to analysis of variance (ANOVA) using IBM SPSS 27.0 (International Business Machines Corp., Armonk, N.Y.). Percent root system galled data were log-transformed [$\log_{10}$ (x+1)] to normalize for analysis and non-transformed data are presented. Means, when appropriate, were separated according to Tukey's honestly significant difference (HSD) test at $\alpha = 0.10$.

Results and Discussion

There was no effect of nematicide on seedling vigor or population density. Only those seeds treated with ILEVO expressed any phytotoxicity. Phytotoxicity was a narrow to a wide necrotic ring along the edge of the cotyledonary leaves on 80%–90% of seedlings.

There was an interaction ($P = 0.001$) between year and nematicide for the percent of root system galled, but not for grain yield (Table 1). The interaction was inconsistent root protection among nematicide treatment in 2019 and 2020. In 2019, the percent root system galled was similar among nematicide treatments; while in 2020, a lower ($P \leq 0.05$) percent root galled was observed for the nontreated control compared to all nematicide treatments, except ILEVO at 0.15 mg ai/seed. For the main effects, there was a lower percentage of roots galled, across treatments; in 2020, compared to 2019, which was due to differences in nematode population densities between field sites. Percent root system galled was similar, across years, between high and low rates of ILEVO and NemaStrike ST, which suggest low rates provide a similar degree of root protection.

Grain yield, across treatments, was similar between years (Table 1). While, across years, Avicta had a numerically lower grain yield compared to low rates of ILEVO and NemaStrike ST. There was no significant difference in yield between low and high seed treatment rates of ILEVO or NemaStrike ST, which suggests low rates provide similar yield protection when nematode population densities are high in a sandy loam field.

These data suggest low and high nematicide rates of ILEVO and NemaStrike ST have a similar effect on protecting soybean root systems from the southern root-knot nematode and protecting soybean yield potential when nematode damage threshold is high. In this study, the lower rate of ILEVO had a numerically greater yield than the high rate, which contradicts that of earlier reports (Hurd et al., 2017a, 2017b). Thus, high nematicide rates may not always provide the greatest yield protection.

Since 2020, NemaStrike ST has not been available as a nematicide in row crops. The manufacturer (Bayer CropScience) voluntarily removed it from commercial use. Thus, these data serve as a reference for field efficacy if the nematicide becomes commercially available in the future for use in soybean.

Practical Applications

Seed-applied nematicides are the most commonly used method to deliver nematicides against soybean nematodes in Arkansas and the mid-South. In this study, low nematicide rates provided similar root and yield protection as high rates of ILEVO and NemaStrike ST. Thus, despite a greater concentration of nematicide on the seed coat, there was no yield benefit.

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Table 1. Field efficacy of two seed-applied nematicides at two rates on a susceptible soybean cultivar in a southern root-knot nematode infested field.

Experiments	% root galling[‡]	Yield [§]
		bu./ac
2019	9.1 b[¶]	39.4
2020	2.3 a	43.9
Nematicide treatment and rate		
Nontreated control	5.7	40.8 ab
Avicta 500 FS (0.15 mg ai/seed)	6.5	37.5 a
ILEVO 600 FS (0.15 mg ai/seed)	4.4	43.2 b
ILEVO 600 FS (0.25 mg ai/seed)	5.3	41.6 ab
NemaStrike ST (0.25 mg ai/seed)	6.6	45.7 b
NemaStrike ST (0.50 mg ai/seed)	5.3	41.2 ab
Experiment x Nematicide		
2019, nontreated control	9.6 e	40.4
2019, Avicta	11.2 de	33.6
2019, ILEVO (0.15 mg)	6.8 de	41.4
2019, ILEVO (0.25 mg)	8.0 de	38.4
2019, NemaStrike ST (0.25 mg)	10.7 de	43.6
2019, NemaStrike ST (0.50 mg)	7.6 de	38.9
2020, nontreated control	1.7 a	41.2
2020, Avicta	2.2 bc	41.5
2020, ILEVO (0.15 mg)	2.1 ab	44.9
2020, ILEVO (0.25 mg)	2.7 cde	44.9
2020, NemaStrike ST (0.25 mg)	2.6 bcd	47.8
2020, NemaStrike ST (0.50 mg)	2.6 bcd	43.5
Statistics: *P* > F		
Experiment	0.01	0.14
Nematicide	0.61	0.06
Experiment x Nematicide	0.001	0.51

[‡] Percent of root system galled by southern root-knot nematode 62 and 34 days after planting in 2019 and 2020, respectively.

[§] Adjusted to 13% moisture.

[¶] Numbers within the same column followed by the same letter are not significantly different ($P = 0.10$) according to Tukey's honestly significant difference test.

Effect of Foliar Fungicides in the Absence of Disease on Soybean Yield

T. R. Faske[1] and M. Emerson[1]

Abstract

The impact on grain yield by 21 foliar fungicides applied in the absence of a yield-limiting disease was evaluated across 18 individual experiments in 2019 and 2020 in a pivot irrigated field at the University of Arkansas System Division of Agriculture's Jackson County Extension Center. The soybean cultivar 'Terral REV49L88' and 'Armor 42D27' were used in 2019 and 2020, respectively. Fungicides were applied at R4 in 2019 and R3 in 2020 in 30-ft replicated plots. The fungicides tested provided a grain yield benefit of >2 bu./ac 76% and 50% in 2019 and 2020, respectively, and >4 bu./ac 51% and 10% in 2019 and 2020, respectively. Only one fungicide, Miravis Top, provided a >4 bu./ac yield benefit in both years, while the other 20 fungicides were inconsistent. These data support the inconsistency among fungicides to provide a yield benefit in the absence of a yield-limiting disease.

Introduction

Frogeye leaf spot (FLS) of soybean, caused by *Cercospora sojina* K Hara, is one of the most important foliar diseases in the mid-South (Faske et al., 2014). Generally, yield losses range from 12% to 15% but can reach as high as 30% on susceptible soybean cultivars (Phillips, 1999). Yield loss to FLS in 2019 was estimated at 2.7 million bu. in the mid-southern United States (U.S.) (Allen et al., 2020). Though host plant resistance is more common in soybean cultivars marketed in Arkansas and the mid-South (Kirkpatrick et al., 2017), fungicides continue to be used to manage FLS and other foliar fungal diseases. Since 2005, fungicide use in soybean has increased across the U.S. (Mueller et al., 2013). Several factors contribute to increased fungicide use, such as increased awareness of disease identification, increase in soybean prices, and promotion of fungicides by manufacturers for their potential physiological benefits that may increase grain yield (Bandara et al., 2020; Bartlett et al., 2002; Mahoney et al., 2015).

Fungicide groups marketed for use on soybean include quinone outside inhibitors (QoI; also known as strobilurin), demethylation inhibitors (DMI; also known as triazole), methyl benzimidazole carbamates (MBC; or benzimidazole), and succinate dehydrogenase inhibitor (SDHI) fungicides (Faske, 2020). Frogeye leaf spot resistance to QoI fungicides is widespread across soybean-producing states in the U.S. (Zhang et al., 2018); thus most fungicides are marketed as a premix with a DMI or DMI + SDHI and a QoI fungicide. During the past few (2018 to 2020) cropping seasons, foliar disease severity including FLS has been low, which is likely due to the availability of FLS-resistant cultivars and climatic conditions that do not favor fungal diseases. However, fungicides, especially those with a QoI fungicide, continue to be recommended for physiological benefits (Bartlett et al., 2002; Mahoney et al., 2015). The objective of this study was to evaluate the yield benefit of 21 fungicides over 2 years applied at R3 or R4 growth stage in the absence of disease.

Procedures

The impact on grain yield of 21 commercially available foliar fungicides was evaluated across 10 experiments in 2019 and 8 experiments in 2020 at the University of Arkansas System Division of Agriculture's Jackson County Extension Center near Newport, Ark. The FLS-susceptible soybean cultivar 'Terral REV 49L88' was planted on 11 Juen in 2019 and 'Armor 42D27' was planted on 5 June in 2020 at a seeding rate of 150,000 seed/ac. Weeds were controlled in 2019 using Valor® (2 oz/ac) applied pre-plant, followed by Liberty® + Prefix® + Ele-Max Nutrient Concentrate (1 qt/ac + 2.33 pt/ac + 1 qt/ac) applied 27 days after planting (DAP). The weed control program in 2020 was similar with the addition of Liberty® (1 qt/ac) at planting followed by Roundup® + Prefix® (1 qt/ac + 2.0 pt/ac) applied post-plant on 29 June. Plots consisted of 4, 30-ft long rows spaced 30 in. apart. The experiments were watered with an overhead pivot irrigation system. The experimental design was a randomized complete block with 4 replications separated by a 5-ft fallow alley. Fungicides were broadcast through flat-fan nozzles (TeeJet XR110015VS) spaced 20-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 used and rates are listed in Table 1. Fungicides were applied in the absence of disease at the mid-R4 growth stage on 16 Aug. 2019 and at the R3 growth stage on 3 Aug. 2020. Plots were harvested on 14 Oct. in 2019 using a K Gleaner combine (Allis-Chalmers Manufacturing Company (1969-

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76), West Allis, Wisc.) equipped with a HarvestMaster Single BDS HiCap HM800 Weigh System (HarvestMaster Logan, Utah) and 14 Oct. in 2020 using an ALMACO SPC40 plot combine (ALMACO Nevada, Iowa) equipped with a HarvestMaster Single BDS HiCap HM800 Weigh System (HarvestMaster Logan, Utah). Data from individual experiments were analyzed according to a general linear model using ARM software (Version 2020, Gylling Data Management, Inc., Brookings, S.D.). Mean separation ($P = 0.05$) was established by Tukey's honestly significant difference test.

Results and Discussion

No foliar disease was observed in the upper canopy in 2019, but low levels of Septoria brown spot (caused by *Septoria glycines* Hemmi) were observed in the lower canopy. A greater grain yield was observed 81% of the time with a range of -4.5–13.8 bu./ac compared to the non-treated control across experiments (Table 2). A yield benefit of >2 bu./ac was observed 76% of the time with a range of 2.1–13.8 bu./ac, and >4 bu./ac was observed 51% of the time and ranged from 4.8–13.8 bu./ac. Of the fungicides tested in at least four experiments Lucento® 4.17 SC, Miravis® Top 1.28 SC, Quadris® Top SBX 3.76 SC, and Priaxor® 4.17 SC had an average yield benefit of >4 bu./ac, at least 75% of the time.

No foliar disease was observed in 2020, except low levels of Septoria brown spot in the lower canopy. A greater grain yield was observed 50% of the time with a range of -7.3–4.8 bu./ac compared to the nontreated control across experiments (Table 3). A yield benefit of >2 bu./ac was observed 36% of the time with a range of 2.2–4.8 bu./ac and >4 bu./ac was observed 10% of the time and ranged from 4.1–4.8 bu./ac. Of the three fungicides that were in at least four experiments, Miravis Top 1.82 SC had an average yield >4 bu./ac, 20% of the time.

These data support the inconsistency among fungicides to provide a yield benefit in the absence of a yield-limiting foliar fungal disease. Grain yield response to fungicides varied among years/cultivars, and fungicides, thus utilizing a fungicide to increase grain yield is unlikely to provide a consistent yield benefit that exceeds the break-even cost (fungicide and application).

Practical Applications

Fungicides do not consistently provide a yield benefit when used to increase grain yield in the absence of a yield-limiting foliar fungal disease. Furthermore, this misuse of fungicides increases production cost and contribute to the development of diseases that are resistant to soybean fungicides.

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Table 1. Trade names, rates, active ingredient, and FRAC codes for fungicides used in trials conducted in 2019 and 2020 at the University of Arkansas System Division of Agriculture's Jackson County Extension Center at Newport.

Trade name and formulation	Rate	Active ingredient	FRAC code
	fl oz/ac		
Nontreated control			
Topsin 4.5 FL	20	thiophanate-methyl	1
Tilt 41.8 EC	4	propiconazole	3
Domark or Andiamo 230 ME	4	tetraconazole	3
Quadris 2.08 SC	6	azoxystrobin	11
Headline 2.09 SC	6	pyraclostrobin	11
Froghorn 4.3 SC	20	thiophanate-methyl + tebu.conazole	1 + 3
Acropolis 2.38 F	23	thiophanate-methyl + tetraconazole	1 + 3
Lucento 4.17 SC	5	flutriafol + bixafen	3 + 7
Miravis Top 1.82 SC	13.7	difenconazole + pydiflumetofen	3 + 7
Topguard EQ 4.29 SC	5	flutriafol + azoxystrobin	3 + 11
Brixen 1.85 SC	16	tetraconazole + azoxystrobin	3 + 11
Zolera FX 3.34 SC	5	tetraconazole + fluoxastrobin	3 + 11
Quadris Top SBX 3.76 SC	7	difenconazole + azoxystrobin	3 + 11
Aproach Prima 2.34 SC	6.8	cyproconazole + picoxystrobin	3 + 11
Stratego YLD 4.18 SC	4	prothioconazole + trifloxystrobin	3 + 11
Delaro 2.78 SC	8	prothioconazole + trifloxystrobin	3 + 11
Priaxor 4.17 SC	4	fluxapyroxad + pyraclostrobin	7 + 11
Priaxor 4.17 SC + Tilt 41.8 SC	4 + 4	fluxapyroxad + pyraclostrobin + propiconazole	7 + 11 + 3
Veltyma 3.34 SC	7	mefentrifluconazole + pyraclostrobin	3 + 11
Trivapro 2.21 SE	13.7	propiconazole + benzovindiflupyr + azoxystrobin	3 + 7 + 11
Revytek 3.33 SC	8	mefentrifluconazole + fluxapyroxad + pyraclostrobin	3 + 7 + 11

Table 2. Yield response of Terral REV 49L88 to 19 fungicides applied at R4 growth stage in 10 foliar fungicide trials in 2019 in the absence of disease at the University of Arkansas System Division of Agriculture's Jackson County Extension Center at Newport.

		Trial number									
Fungicide	**Rate**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	fl oz/ac	**bu./ac**									
Nontreated control		59.3 ab[†]	65.2	60.1	55.6	58.2	63.6	31.7	63.3	55.6	67.0
Tilt 41.8 EC	4	65.7 ab	...	...	...	...	...	...	...	...	...
Domark or Andiamo 230 ME	4	61.9 ab	...	...	...	...	...	...	...	...	67.1
Quadris 2.08 SC	6	...	...	61.9	...	...	62.3	...	...	...	...
Headline 2.09 SC	6	54.8 b	...	63.6	...	...	...	...	...	...	...
Froghorn 4.3 SC	20	69.6 a	...	...	...	...	...	...	63.3	...	...
Acropolis 2.38 F	23	67.2 ab	...	65.8	...	...	68.6	...	67.1	...	...
Lucento 4.17 SC	5	69.0 ab	72.7	...	63.6	61.2	68.9	36.5	...	...	...
Miravis Top 1.82 SC	13.7	68.0 ab	71.5	59.6	63.5	64.3	69.3	36.2	...	54.7	...
Topguard EQ 4.29 SC	5	...	68.3	66.8	60.8	...	...	32.5	...	...	...
Brixen 1.85 SC	16	...		61.7	...	...	...	...	...	...	68.8
Quadris Top SBX 3.76 SC	7	67.6 ab	73.6	73.4	64.3	71.2	72.1	34.6	70.3	...	...
Aproach Prima 2.34 SC	6.8	...	...	69.1	...	...	...	...	...	...	...
Stratego YLD 4.18 SC	4	60.4 ab	...	...	...	63.7	...	...	...	...	...
Delaro 2.78 SC	8	66.8 ab	...	...	61.7	...	65.6	...	...	...	...
Priaxor 4.17 SC	4	...	71.0	...		63.7	...	33.8	...	...	70.2
Priaxor 4.17 SC + Tilt 41.8 SC	4 + 4	64.1 ab	...	65.4	64.2	...	68.7	...	69.2	54.5	...
Veltyma 3.34 SC	7	...	...	...	...	65.9	...	...	...	...	...
Trivapro 2.21 SE	13.7	66.3 ab	...	...	...	...	70.2	...	...	...	...
Revytek 3.33 SC	8	73.1 a	...	...	...	67.1	68.7	...	...	...	...
P >F		0.004	0.09	0.15	0.26	0.32	0.81	0.69	0.34	0.26	0.26

[†] Means in each column followed by the same letter are not different at $\alpha = 0.05$ according to Tukey's honestly significant difference test.

Table 3. Yield response of Armor 42D27 to 20 fungicides applied at R3 growth stage in 8 foliar fungicide trials in 2020 in the absence of disease at the University of Arkansas System Division of Agriculture's Jackson County Extension Center at Newport.

		Trial number							
Fungicide	**Rate**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	fl oz/ac	------------------------------**bu./ac**------------------------------							
Nontreated control		45.7	50.3	51.4	44.1	45.3	42.7	48.8	43.6
Tilt 41.8 EC	4	…	49.2	…	…	…	…	…	…
Domark or Andiamo 230 ME	4	…	49.2	…	…	40.0	…	…	…
Quadris 2.08 SC	6	47.3	…	51.6	…	…	…	…	…
Headline 2.09 SC	6	…	45.9	…	…	…	…	…	…
Froghorn 4.3 SC	20	47.2	…	…	…	…	…	49.9	…
Acropolis 2.38 F	23	49.4	…	47.5	…	…	…	…	…
Lucento 4.17 SC	5	…	51.5	52.4	42.6	…	…	…	…
Miravis Top 1.82 SC	13.7	46.6	52.0	52.2	46.8	…	…	…	47.7
Topguard EQ 4.29 SC	5	48.7	…	…	48.9	…	…	…	…
Brixen 1.85 SC	16	48.3	…	…	…	41.2	…	…	…
Zolera FX 3.34 SC	5	…	…	…	…	…	…	48.4	45.9
Quadris Top SBX 3.76 SC	7	47.9	…	…	…	…	45.8	…	…
Aproach Prima 2.34 SC	6.8	50.1	…	…	…	…	43.9	…	…
Stratego YLD 4.18 SC	4	…	…	…	…	…	…	…	…
Delaro 2.78 SC	8	…	43.5	48.2	48.4	…	…	…	…
Priaxor 4.17 SC	4	…	…	…	…	…	…	…	…
Priaxor 4.17 SC + Tilt 41.8 SC	4 + 4	43.9	45.2	45.8	…	37.8	…	50.2	…
Veltyma 3.34 SC	7	…	…	…	…	…	…	…	…
Trivapro 2.21 SE	13.7	…	43.0	48.9	…	…	…	…	…
Revytek 3.33 SC	8	…	48.5	48.7	47.9	…	…	52.0	…
P >F		0.21	0.14	0.18	0.74	0.15	0.13	0.66	0.08

Effect of Foliar Fungicides on Frogeye Leaf Spot Resistant Soybean Varieties

T. R. Faske[1] *and M. Emerson*[1]

Abstract

Two fungicide treatments, Priaxor® + Domark® and Quadris® Top SBX, were applied at the R3 growth stage on six and 5 soybean varieties, respectively, in 2 experiments that were conducted in 2016 and 2017 in replicated plots. Frogeye leaf spot (caused by *Cercospora sojina*) severity was greatest on 'Armor DK 4744', a very susceptible variety, with an average severity of 10.7% in 2016 and 3.1% in 2017 on the nontreated plots across both experiments. A lower disease severity (<1%) was observed on other varieties tested ('Asgrow AG 4632', 'AG 4730', 'Pioneer P47T36R', 'P46T59R', and 'Delta Grow DG 4940') across years and experiments. Both fungicides were similar in efficacy to control frogeye leaf spot. Overall, across years and experiments, the greatest benefit from a fungicide (10.7 bu./ac) was observed on the susceptible variety when disease severity was > 4% on the nontreated control. In contrast, the benefit of a fungicide on grain yield was inconsistent on the other varieties, with an average yield difference of 3.8 bu./ac between fungicide treated and nontreated plots. These data support the use of fungicides on susceptible varieties when disease severity is > 4% but not on frogeye leaf spot-resistant varieties when disease pressure is < 1%.

Introduction

Frogeye leaf spot (FLS) of soybean, caused by *Cercospora sojina* K. Hara, is one of the most common and important foliar diseases in the mid-South (Faske et al., 2014). Generally, yield losses range from 12% to 15% but can reach as high as 30% on susceptible soybean varieties (Phillips, 1999). Yield losses to frogeye leaf spot in 2019 were estimated at 2.7 million bushels in the mid-South (Allen et al., 2020). Management of frogeye leaf spot consists of utilizing resistant varieties, crop rotation, and foliar fungicides.

Fungicide groups marketed and registered for use to control FLS include quinone outside inhibitors (QoI; also known as strobilurin), demethylation inhibitors (DMI; also known as triazole), methyl benzimidazole carbamates (MBC; or benzimidazole), and succinate dehydrogenase inhibitor (SDHI) fungicides (Faske, 2020). Frogeye leaf spot resistance to QoI fungicides is widespread across soybean-producing states in the United States. (Zhang et al., 2018), thus most fungicides are marketed as a premix, such as DMI + QoI, DMI + SDHI, or DMI + SDHI + QoI fungicide. A few studies have reported on the efficacy of premix fungicides against QoI-resistant FLS (Emerson et al., 2016a, 2016b; Price et al., 2014; Price et al., 2016a); however, none have evaluated the impact of a fungicide on frogeye leaf spot-resistant varieties. Soybean varieties with resistance to frogeye leaf spot are available in the mid-South (Kirkpatrick et al., 2017), but studies on the impact of fungicides on moderately resistant to resistant varieties are lacking. The objective of this study was to evaluate two fungicides (DMI + QoI and DMI + SDHI + QoI) to control QoI-resistant frogeye leaf spot and evaluate the yield benefit of these fungicides on frogeye leaf spot-resistant varieties.

Procedures

Two experiments were conducted to evaluate the effect of a foliar fungicide on several frogeye leaf spot-resistant soybean varieties at the University of Arkansas System Division of Agriculture's Jackson County Extension Center near Newport, Ark. Experiment 1: Priaxor® 4.17 SC (pyraclostrobin + fluxapyroxad) + Domark® 230 ME (tetraconazole) at 4 oz/ac + 4 oz/ac was evaluated on 6 varieties: 'Asgrow AG 4632', 'Asgrow AG 4730', 'Armor DK 4744', 'Delta Grow DG4990 RR', 'Pioneer P46T59R', 'Pioneer P47T36R'. Varieties marketed as resistant are 'AG 4632', 'P47T36R', and 'DG 4940', while 'P46T59R' and 'AG 4730' are moderately resistant, and 'DK 4744' is very susceptible to frogeye leaf spot. Experiment 2: Quadris® Top SBX 3.76 SC (azoxystrobin + difenoconazole) at 7 oz/ac was evaluated on 4 varieties: 'Asgrow AG 4632', 'Armor DK 4744', 'Pioneer P46T59R', and 'Pioneer P47T36R'. The soybean varieties were planted on 9 June 2016 and on 12 June 2017 at a seeding rate of 150,000 seed/ac. Weeds were controlled based on recommendations by the University of Arkansas System Division of Agriculture Cooperative Extension Service (Barber et al., 2021). Plots consisted of 4, 30-ft long rows spaced 30 in. apart. The experimental design was a randomized complete block with 4

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replications separated by a 3-ft fallow alley. Fungicides were broadcast through flat-fan nozzles (Tee-Jet XR110015VS) spaced 20-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 were applied at the R3 growth stage on 4 Aug. 2016 and 8 Aug. 2017. Frogeye leaf spot severity was assessed at 21 days after treatment based on percent severity in the upper 1/3 of the plant canopy (Price et al., 2016b). Plots were harvested on 24 Oct. in 2016 and 24 Oct. in 2017 using a modified K Gleaner combine [Allis-Chalmers Manufacturing Company (1969-76), West Allis, Wisc.] equipped with a Master Scales Weigh System (HarvestMaster Logan, Utah).

Data were analyzed according to general linear mixed models with years and treatment repetitions modeled as a random variable using SPSS 27.0 (International Business Machines Corp., Armonk, N.Y.). Percent severity data were log-transformed [$\log_{10}(x + 1)$] to normalize for analysis and non-transformed data were reported. Mean separation (P = 0.05) was established by Tukey's honestly significant difference test.

Results and Discussion

There was no ($P > 0.30$) variety by fungicide by year interaction in experiment 1 for disease severity or grain yield. Disease severity was greater in 2016 than in 2017, which was associated with the frequency of precipitation and total rainfall in August, which was the 3rd wettest on record according to the National Weather Service (Table 1). Both frogeye leaf spot and target spot (caused by *Corynespora cassicola*) were observed in 2016, but only data from frogeye leaf spot are presented (Fig. 1). Target spot caused an average defoliation rate of 45% in the lower canopy across varieties and fungicide treatments. The frequency of days greater than 90 °F may have contributed to greater target spot severity in 2016 than in 2017 (Table 1) as target spot is more aggressive at warm temperatures. The greatest ($P \leq 0.05$) severity of frogeye leaf spot was observed on 'Armor DK 4744', which averaged 6.6% across years (Fig. 1). Priaxor + Domark lowered ($P \leq 0.05$) frogeye leaf spot on 'DK 4744' compared to the nontreated control with an average of 4.3% disease severity across years. Low disease severity was observed on the moderately resistant varieties: 'Pioneer P46T59R' and 'Asgrow AG 4730' with an average severity of 1.2% across years. Priaxor + Domark provided a numeric suppression of frogeye leaf spot severity on these varieties with an average of 0.8% across years.

Though a positive yield trend was observed across all varieties in 2016 and 2017, there were some inconsistencies (Fig. 2 and 3). For example, a greater ($P \leq 0.05$) grain yield was observed by Priaxor + Domark on 'Armor DK 4744' when frogeye leaf spot severity was 9.2% in 2016, whereas there was no significant impact on yield in 2017 when severity was 4.0% on the nontreated control. These data suggest more than 4% disease severity is needed to provide a significant impact in yield protection on a susceptible variety. Furthermore, a low severity of frogeye leaf spot was observed on 'Pioneer P46T59R' and 'Asgrow AG 4730', while greater ($P \leq 0.05$) grain yield protection was observed in 2016 on 'AG 4730'. This trend may have been due to the severity of target spot on 'AG 4730' (57%) compared to 'Pioneer P46T59R' (41%).

Overall, a slightly greater numeric trend in grain yield protection was observed each year on the susceptible (+9.5 and +5.3 bu./ac in 2016 and 2017, respectively) compared to the resistant varieties (+5.7 and +3.9 bu./ac in 2016 and 2017, respectively) (Figs. 2 and 3). Overall, the fungicides did provide a greater ($P \leq 0.05$) grain yield across years and varieties (63.3 bu./ac) compared to the nontreated control (58.0 bu./ac). Of the varieties evaluated, across years and fungicide treatments, 'P46T59R' had a greater ($P \leq 0.05$) yield average (69.2 bu./ac) compared to all other varieties, while 'Pioneer P47T36R' (63.2 bu./ac) and 'Asgrow AG 4632' (62.4 bu./ac) had a greater ($P \leq 0.05$) grain yield compared to 'Delta Grow DG 4940' (56.0 bu./ac) and 'Asgrow AG 4730' (55.8 bu./ac).

There was a variety by fungicide by year interaction ($P \leq 0.05$) in experiment 2 for grain yield, but not for disease severity. Frogeye leaf spot was observed in both years, while target spot was only observed in 2016 and averaged 17% defoliation across varieties (Fig. 4). Only frogeye leaf spot data is presented. The greatest ($P \leq 0.05$) severity of frogeye leaf spot was observed on 'Armor DK 4744', which averaged 7.2% across years (Fig. 4). Quadris Top SBX treatment lowered ($P \leq 0.05$) frogeye leaf spot severity on 'DK 4744' compared to the nontreated control with an average of 2.9% disease severity across years. Lower disease severity was observed on the moderately resistant variety 'Pioneer P46T59R,' with an average severity of 1.3% across years. No frogeye leaf spot was observed on 'Asgrow AG 4632' or 'Pioneer P47T36R'.

There was a positive trend in grain yield with a fungicide in 2016 and 2017 across all varieties, with the greatest ($P \leq 0.05$) in 2016 on 'Armor DK 4744' (Figs. 5 and 6). Disease severity on 'DK 4744' was 12.2% on the nontreated control in 2016 compared to 2.2% in 2017. A significant benefit from a fungicide was observed in 2016 but not in 2017 on 'DK 4744', thus supporting the need for more than 4% disease severity to contribute to a significant yield impact by a fungicide.

Overall, a slightly greater numeric trend in grain yield protection was observed each year on the susceptible (+12.0 and +2.0 bu./ac in 2016 and 2017, respectively) compared to the resistant varieties (+5.0 and +2.0 bu./ac in 2016 and 2017, respectively) (Figs. 5 and 6). Overall, the fungicide provided a greater ($P \leq 0.05$) average grain yield across years and varieties (60.0 bu./ac) compared to the non-treated control (55.6 bu./ac). Further, of the varieties tested, 'P47T36R' had a greater ($P \leq 0.05$) yield average (61.7 bu./ac) across years and fungicide treatments compared to 'Armor DK 4744' (53.9 bu./ac).

Practical Applications

Fungicides were consistently effective at protecting soybean grain yield on the frogeye leaf spot-susceptible variety when disease severity was > 4% compared to those that were moderately resistant or resistant varieties where disease severity was often < 1%. The average yield benefits from a fungicide on the susceptible variety was 7.2 bu./ac (range 2.0–12.0 bu./ac), while an average of 3.8 bu./ac (range of 1.2–9.8 bu./ac) was observed on the resistant varieties. These data support the use of a fungicide to manage foliar diseases and protect yield potential on susceptible but not moderately resistant or resistant varieties.

Acknowledgments

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Table 1. Monthly average temperature and precipitation in 2016 to 2017 from a weather station near Newport, Arkansas.

Year	Month	Temperature Mean Max	Temperature Mean Min	Temperature Days > 90°F	Precipitation Total	Precipitation Days ≥ 0.01 in.
		-----°F-----			-----in.-----	
2016	June	87.6	71.3	13	1.43	7
	July	90.8	73.0	19	1.79	8
	August	86.8	72.3	14	4.41	15
	September	86.7	64.7	15	1.70	3
2017	June	85.2	67.1	0	2.80	8
	July	89.1	72.2	16	2.25	10
	August	84.1	68.4	5	3.85	11
	September	82.7	62.3	2	1.14	3

Source: https://www.ncdc.noaa.gov/cdo-web/search

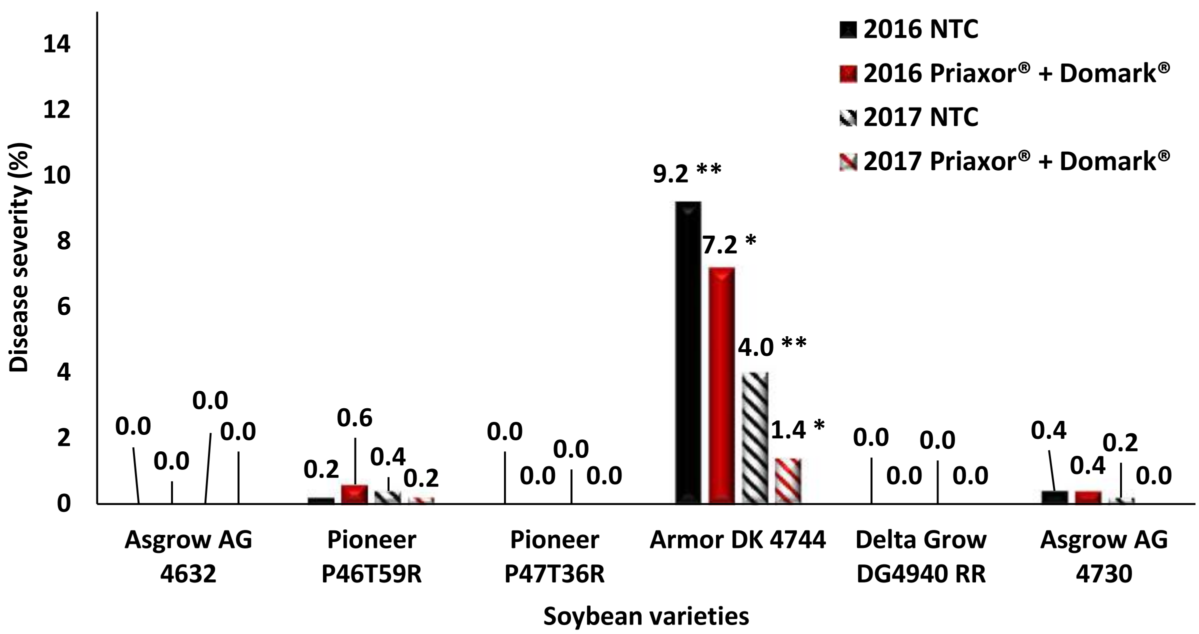

Fig. 1. Experiment 1: Frogeye leaf spot (*Cercospora sojina*) severity on six varieties treated with a fungicide in 2016 and 2017 at the University of Arkansas System Division of Agriculture's Jackson County Extension Center. Disease severity that was significantly (P = 0.05) different between fungicide and nontreated control are indicated by different number of "*" per year according to Tukey's honestly significant difference. NTC = non-treated control.

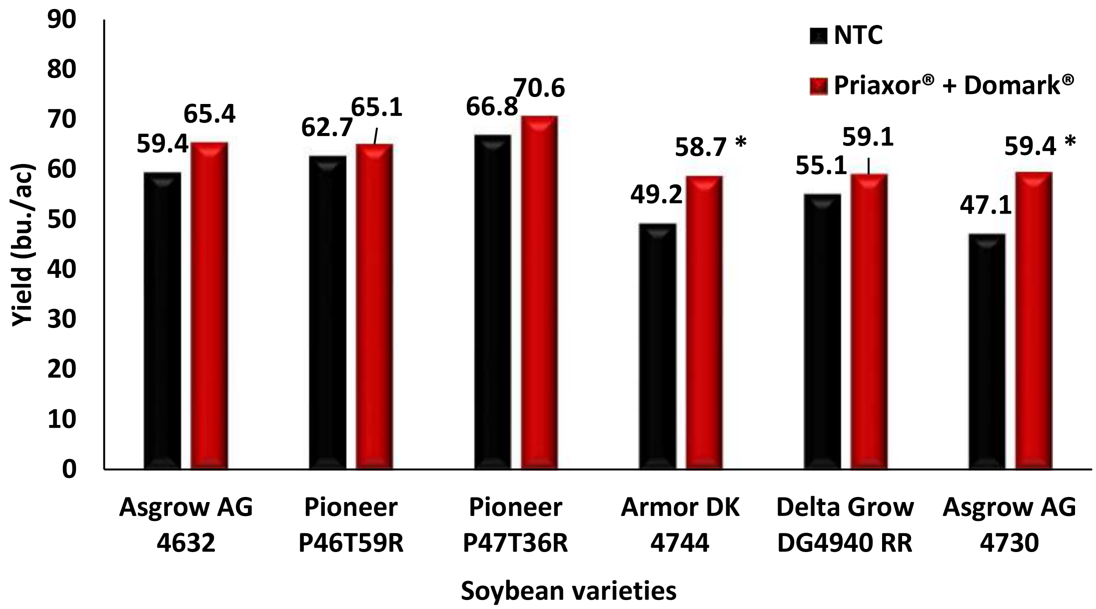

Fig. 2. Experiment 1: Grain yield of six soybean varieties treated with a fungicide in 2016 at the University of Arkansas System Division of Agriculture's Jackson County Extension Center. Fungicide was applied at R3 growth stage. Yields that are significantly (*P* = 0.05) different between fungicide and nontreated control are indicated by a "*" according to Tukey's honestly significant difference. NTC = non-treated control.

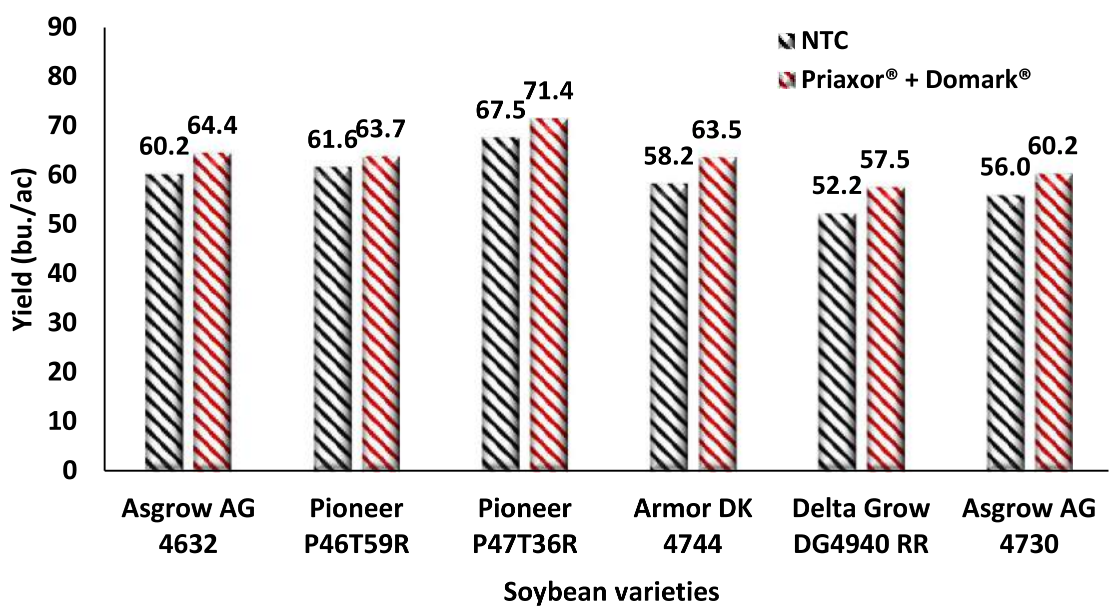

Fig. 3. Experiment 1: Grain yield of six soybean varieties treated with a fungicide in 2017 at the University of Arkansas System Division of Agriculture's Jackson County Extension Center. Fungicide was applied at R3 growth stage. NTC = non-treated control.

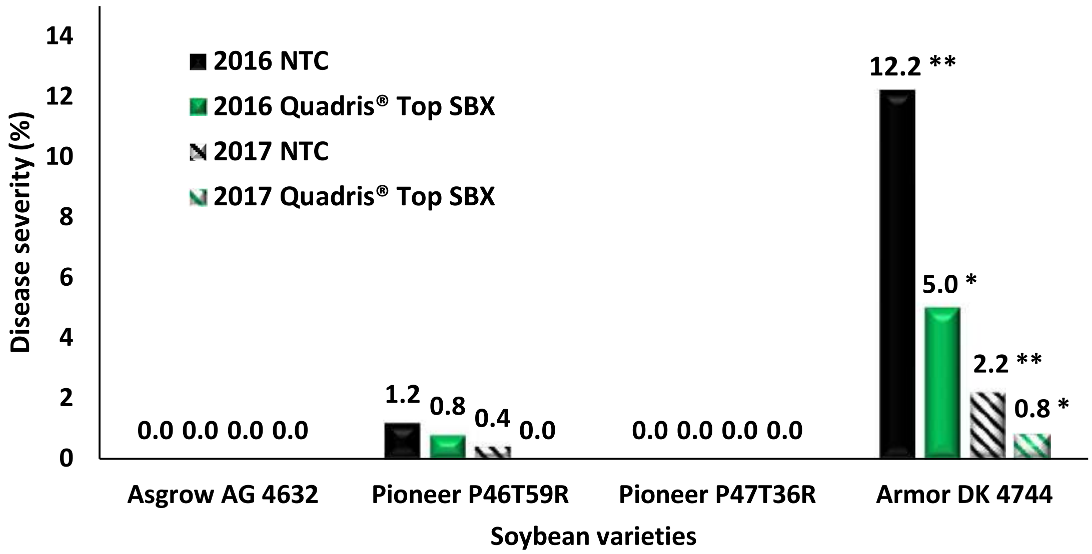

Fig. 4. Experiment 2: Frogeye leaf spot (*Cercospora sojina*) severity on four varieties treated with a fungicide in 2016 and 2017 at the Jackson County Extension Center. Disease severity that was significantly (*P* = 0.05) different between fungicide and nontreated control is indicated by different number of "*" per year according to Tukey's honestly significant difference. NTC = non-treated control.

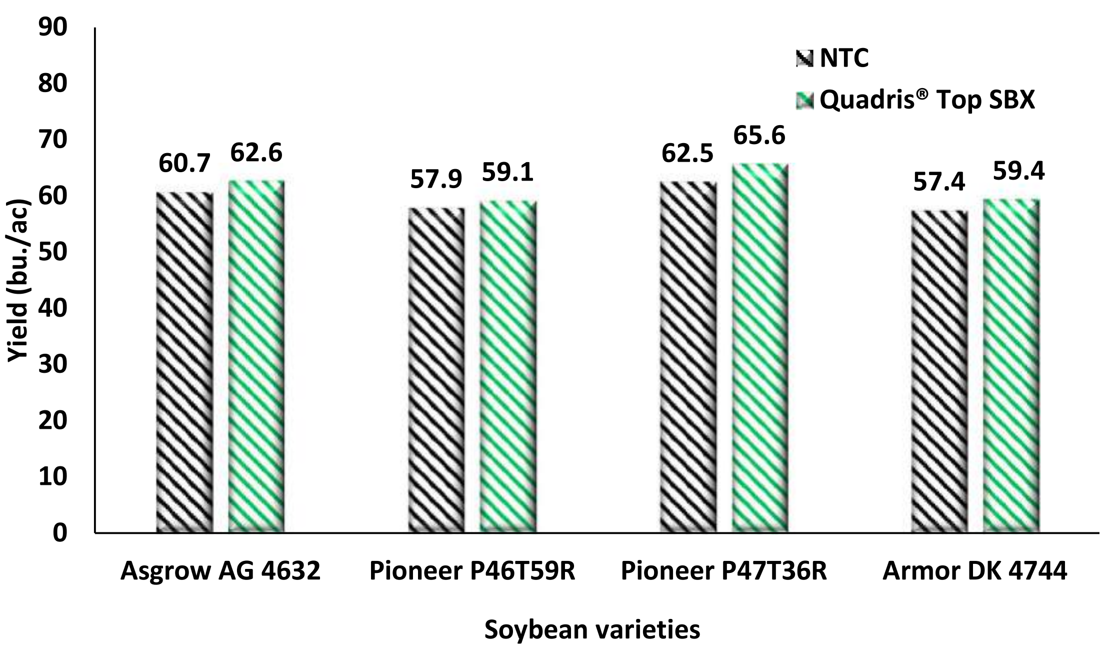

Fig. 5. Experiment 2: Grain yield of four soybean varieties treated with a fungicide in 2016 at the University of Arkansas System Division of Agriculture's Jackson County Extension Center. Fungicide was applied at R3 growth stage. Yields that are significantly (*P* = 0.05) different between fungicide and non-treated control are indicated by a "*" according to Tukey's honestly significant difference. NTC = non-treated control.

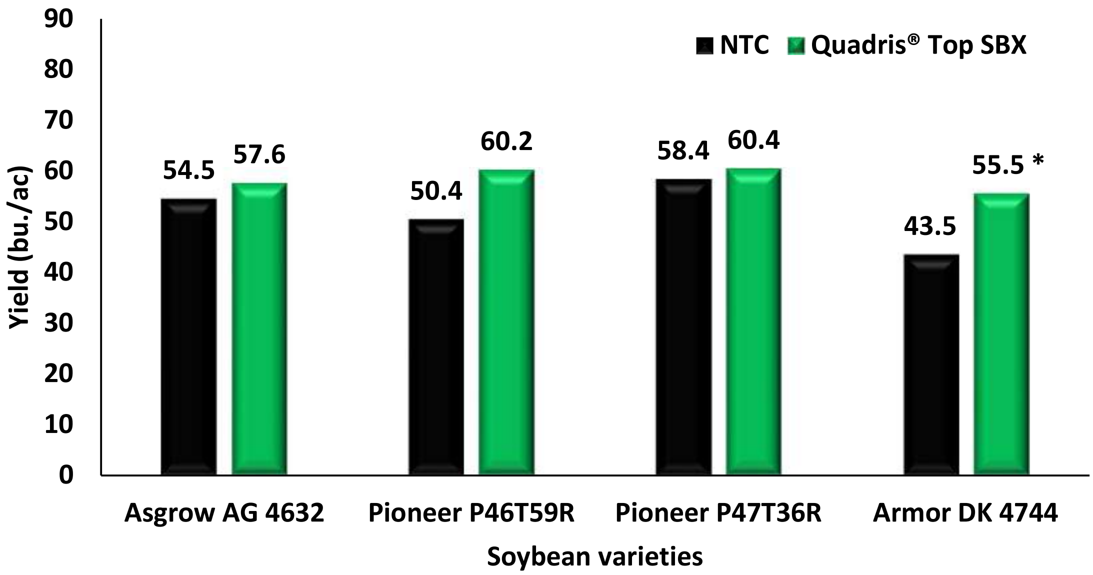

Fig. 6. Experiment 2: Grain yield of four soybean varieties treated with a fungicide in 2017 at the University of Arkansas System Division of Agriculture's Jackson County Extension Center. Fungicide was applied at R3 growth stage. NTC = non-treated control.

Determining the Impact of Disease and Stinkbug Feeding on Soybean Seed Quality, 2020

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Abstract

Soybean [*Glycine max* (L.) Merr.] seed quality has become of increasing concern in recent years. Diseases and stink bug feeding sites are among the most common visual abnormalities found on soybean seeds. To determine the impact of disease and stinkbug feeding on soybean seed quality, replicated fungicide and variety trials were placed at the University of Arkansas System Division of Agriculture's Rohwer Research Station near Rohwer, Ark. The fungicide trial consisted of 16 fungicides applied at R3 with and without insecticide applications at R3 and R5. The variety trial has 175 varieties with maturity groups ranging from MG 3 to MG 5 and multiple herbicide traits. The grain from both trials was taken from the combine and evaluated for Phomopsis seed decay (*Phomopsis longicolla*), purple seed stain (*Cercospora spp*.), soybean mosaic virus (caused by *Potyvirus*), stink bug (*Pentatomidae* spp.) damage, and overall seed quality. Few differences were seen in either trial. The data collected from the 2020 seed quality trials show the importance of timely harvest on seed quality. These results also point to varieties that may be more susceptible to various diseases that impact seed quality as well as how fungicides and insecticides may impact seed quality.

Introduction

Soybean [*Glycine max* (L.) Merr.] seed quality can be impacted significantly by insect damage or by diseases caused by fungal, bacterial, or viral plant pathogens (Rupe and Luttrell 2008, Ross, 2017). Multiple stink bug species (*Pentatomidae*) are commonly observed in Arkansas soybean production, where both adults and nymphs feed on soybean pods and grain. These insects feeding on premature grain can cause yield loss by initiating pod and/or seed abortions or seed size reduction. Quality reduction is also caused by digestive fluids entering the seed during feeding leading to deterioration and discoloration of the seed. (Lorenz, G. et al., 2000) These wounds created by actively feeding stink bugs can also create opportunities for pathogens to colonize and reproduce.

Common soybean seed fungal diseases include purple seed stain and *Phomopsis* seed decay. Purple seed stain (PSS) is caused by multiple species of *Cercospora* that stain the seed coat purple. This disease has not been associated with yield loss but can cause a significant reduction in grain quality by causing reduced vigor and increased seed decay and discoloration (Alloatti et al., 2015). *Phomopsis* seed decay (PSD) caused by *Phomopsis longicolla* can cause deformed, split, or moldy grain, altering seed viability and oil composition (Li et al., 2010). Also found in this study were symptoms similar to soybean mosaic virus (SMV) caused by a *Potyvirus*, which is associated with reduced yield and seed quality. The virus is seed-borne but can be transmitted to other plants during the growing season by aphids. Soybean mosaic virus has also been associated with higher incidences of seed infection by *Phomopsis spp*. (Koning et al., 2001)

Procedures

A fungicide by insecticide trial and a variety trial was established at the University of Arkansas System Division of Agriculture's Rohwer Research Station near Rohwer, Ark. on 20 May and 2 June 2020, respectively. Plots for both trials were 2-rows wide and 10-ft long on 38-in. row-spacings planted at 150,000 seed/ac. Sixteen fungicides plus an insecticide targeting stink bugs were used in the fungicide/insecticide trial and it was planted with DG4967LL. Applications were made at R3 on 23 July and insecticide was applied again at R5 on 11 August using TeeJet XR11002VS spray tips with a ground-driven compressed air sprayer at 10 gal/ac. Pesticides used are identified in Table 1.

Grain samples from each plot of both trials were collected from the combine elevator in paper bags, labeled appropriately, and transported to the laboratory in Monticello, Ark., and stored under ambient laboratory conditions until assessments could be made. Samples were placed into a standard-sized Petri dish filling the dish with as many grains as possible, one layer deep. Grain was observed for PSD, PSS, SMV, and stink bug damage (SBD) by estimating the percentage of pest incidence in each dish. Overall seed quality (SDQ) was estimated as the percentage of grain per sample without no-

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ticeable defects. Plots were harvested on 19 Oct. (fungicide/insecticide) and 3 Nov (variety) with a plot combine using an onboard weighing system at an average of 10% moisture content. Yield data were adjusted to 13% moisture content for comparison. All data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Tukey's honestly significant difference (HSD) using a log transformation where appropriate at $P = 0.10$ (fungicide/insecticide trial) and $P = 0.05$ (variety trial). Untransformed data are presented.

Results and Discussion

In the fungicide/insecticide trial, stink bug damage averaged 2.1% (1.0%–4.3%) with no differences among treatments. Phomopsis seed decay averaged 4.6% (2.8%–7.8%) across samples, PSS 4.0% (1.5%–6.3%), and SMV 4.0% (0.0%–6.5%). Overall SDQ averaged 30.4% (22.5%–38.8%). Treatments had no effect on yield except for Topsin XTR + Endigo. Yields averaged 31.9 (24.6–47.4) bu./ac (Table 1). Earlier in the year, damage consistent with dicamba drift was evident in the trial, which could have impacted yield and disease incidence.

The variety trial was broken down into maturity groups (MG) and sometimes by herbicide technology depending on the number of varieties included in an MG. Individual data for these groups are shown in Tables 2–13. Purple seed stain trends indicate a higher incidence for the early MG 4 soybeans (Fig. 1). Data indicated some susceptible Round-up Ready® and Xtend® varieties in the later maturing groups to PSS. Most of the damage to the earlier maturing soybeans was likely due to delayed harvest as the entire test was harvested on the same day and after the latest maturing varieties had dried down. A similar trend was observed with Phomopsis seed decay incidence and soybean mosaic virus (Figs. 2 and 3, respectively); however, Round-up Ready and Xtend varieties in the later maturity groups were not susceptible to *Phomopsis* seed decay and soybean mosaic virus. The later maturing varieties had more stink bug damage than the earlier varieties as the insects moved from more mature soybeans to feed on grain that had not fully matured (Fig. 4). Overall seed quality increased in the later maturing varieties when compared to the earlier maturing varieties indicating diseases were more likely the cause of decreased seed quality.

Practical Applications

The data collected from the 2020 seed quality trials show the importance of timely harvest on seed quality. These results also point to varieties that may be more susceptible to various diseases that impact seed quality as well as how fungicides and insecticides may impact seed quality.

Acknowledgments

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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Table 1. Seed pathogen and stink bug damage incidence percentage, seed quality, and yield data from a seed quality trial located at the University of Arkansas System Division of Agriculture's Rohwer Research Station, near Rohwer, Ark., 2020. Post-harvest pathogen and stink bug damage incidence are expressed as percentages where 0 = not found and 100 = found on all seed. Seed quality is expressed as the percentage of seed without visible defects. Yield is reported for comparison and is not representative due to herbicide drift. Fungicides were applied at R3, and insecticide was applied at R3 and R5.

Treatment and rate/ac	PSD†	PSS†	SMV†‡	SBD†	SDQ†	Yield§
Alto® 100 SL 5.5 fl oz	3.5	4.8	3.0 ab	1.5	33.8	33.9 ab
Alto 100 SL 5.5 fl oz + Endigo®	5.3	4.0	5.8 ab	3.5	28.8	36.0 ab
Domark® 230 ME 5 fl oz	4.8	5.0	2.0 ab	2.0	28.8	26.0 b
Domark 230 ME 5 fl oz + Endigo	2.8	5.5	3.8 ab	1.5	21.3	25.0 b
Headline® 2.08 SC 12 fl oz	2.8	5.0	5.0 ab	2.0	35.0	36.9 ab
Headline 2.08 SC 12 fl oz + Endigo 2.06 ZC 4 fl oz	3.0	3.0	4.0 ab	3.0	27.5	30.7 ab
Miravis Top® 1.67 SC 13.7 fl oz	3.8	3.5	3.0 ab	1.5	35.0	39.3 ab
Miravis Top 1.67 SC 13.7 fl oz + Endigo 2.06 ZC 4 fl oz	4.0	4.0	3.0 ab	1.0	33.8	36.6 ab
Priaxor® 4.17 SC 4 fl oz + Tilt® 3.6 EC 4 fl oz	4.8	6.0	4.0 ab	2.5	33.8	28.3 ab
Priaxor 4.17 SC 4 fl oz + Tilt 3.6 EC 4 fl oz + Endigo	5.3	3.5	3.0 ab	1.0	32.5	33.4 ab
Priaxor 4.17 SC 6 fl oz	6.3	4.0	3.0 ab	3.0	22.5	33.6 ab
Priaxor 4.17 SC 6 fl oz + Endigo	4.5	4.0	3.5 ab	1.8	25.0	27.7 ab
Priaxor 4.17 SC 8 fl oz	7.8	6.3	8.0 a	2.0	31.3	26.1 b
Priaxor 4.17 SC 8 fl oz + Endigo	3.0	3.0	4.5 ab	2.0	27.5	37.9 ab
Quadris® 2.08 FL 15.5 fl oz	4.3	4.5	6.5 ab	2.5	32.5	28.7 ab
Quadris 2.08 FL 15.5 fl oz + Endigo 2.06 ZC 4 fl oz	4.3	2.0	3.0 ab	1.5	31.1	31.1 ab
Quadris Top® SBX 3.76 SC 7 oz	7.5	5.8	3.5 ab	2.0	26.3	31.2 ab
Quadris Top SBX 3.76 SC 7 oz +	3.3	2.0	2.5 ab	2.0	28.8	32.4 ab
Quilt® Xcel 2.2 SE 14 fl oz	5.5	4.0	4.5 ab	2.3	28.8	32.9 ab
Quilt Xcel 2.2 SE 14 fl oz + Endigo 2.06 ZC 4 fl oz	7.3	3.5	3.0 ab	1.5	26.3	31.8 ab
Revytek® 400 SC 8 fl oz	5.3	5.0	4.0 ab	0.8	37.5	31.4 ab
Revytek 400 SC 8 fl oz + Endigo	3.5	3.5	5.0 ab	1.0	30.0	37.0 ab
Stratego® YLD 4.18 SC fl oz	3.8	3.3	4.5 ab	4.3	32.5	30.7 ab
Stratego YLD 4.18 SC fl oz + Endigo 2.06 ZC 4 fl oz	6.8	4.0	7.0 ab	2.0	22.5	28.7 ab
Tilt® 3.6 EC 4 fl oz	4.8	4.0	4.5 ab	3.0	35.0	32.7 ab
Tilt 3.6 EC 4 fl oz + Endigo	4.5	4.0	7.0 ab	2.0	25.0	32.2 ab
TKO Phosphite 6.875 SC 3.2 fl oz	5.8	2.5	3.5 ab	2.5	26.3	30.3 ab
TKO Phosphite 6.875 SC 3.2 fl oz + Endigo 2.06 ZC 4 fl oz	3.5	3.5	4.5 ab	1.0	35.0	24.6 ab
Topsin® XTR 4.3 F 20 fl oz	5.0	4.5	4.0 ab	1.5	28.8	28.6 ab
Topsin XTR 4.3 F 20 fl oz + Endigo 2.06 ZC 4 fl oz	2.8	4.0	1.5 b	2.5	31.3	47.4 a

Continued

Table 1. Continued.

Treatment and rate/ac	PSD†	PSS†	SMV†‡	SBD†	SDQ†	Yield§
Trivapro® 2.21 SE 13.7 fl oz	3.5	5.0	3.5 ab	2.0	37.5	25.2 b
Trivapro 2.21 SE 13.7 fl oz + Endigo 2.06 ZC 4 fl oz	5.5	3.0	3.5 ab	3.5	26.3	32.3 ab
Untreated	4.3	5.0	3.0 ab	2.5	37.5	26.5 b
Untreated + Endigo	4.3	1.5	3.5 ab	2.0	38.8	39.1 ab
Tukey's HSD *P* = 0.10	6.05–10.44	4.83–5.89	3.00–3.79	5.56–5.77	22.76–28.29	20.34
MSE	0.06	0.04	0.04	0.04	0.02	60.87
Treatment (F)	0.87	0.23	0.10	0.60	0.32	0.04

† PSD = Phomopsis seed decay, PSS = purple seed stain, SMV = soybean mosaic virus, SBD stink bug (*Pentatomidae*) damage, and SDQ = overall seed quality.

‡ Columns followed by the same letter are not statistically significant at *P* = 0.10 as determined by Tukey's honestly significant difference (HSD) test using a log transformation where appropriate. Means shown are untransformed. MSE = Mean square error.

§ Yield (bu./ac) adjusted to 13% moisture content for comparison. Yields are included for comparison only, due to herbicide drift in the vegetative stages.

Table 2. Seed pathogen and stink bug damage incidence percentage, seed quality, and yield data from a seed quality trial located at the University of Arkansas System Division of Agriculture's Rohwer Research Station, near Rohwer, Ark., 2020 within MGs† 3.9–4.4. Post-harvest pathogen incidence and stink bug damage incidence are expressed as percentages where 0 = not found and 100 = found on all seed. Seed quality is expressed as the percentage of seed without visible defects. Data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Tukey's honestly significant difference (HSD) using a log transformation where appropriate at *P* = 0.05. Means shown are untransformed.

Variety	MG†	PSD†	PSS†	SMV†	SBD†	SDQ†	Yield‡
Credenz CZ 3930GTLL	3.9	2.2	3.8	4.0	5.1	23.3	79.7
Local LS3976X	3.9	2.0	9.1	3.1	4.4	20.0	73.2
Local LSX3911GL	3.9	2.2	7.1	3.3	7.6	18.3	73.6
Credenz CZ 4280X	4.2	2.9	7.8	4.0	3.8	13.3	72.3
Local LS4299XS	4.2	2.2	15.1	2.4	4.9	16.7	91.0
Progeny 4241E3	4.2	1.3	8.9	2.7	3.8	23.3	64.2
Progeny 4265RXS	4.2	1.6	10.4	3.8	4.9	18.3	88.5
Asgrow AG 43X0	4.3	3.1	10.2	3.3	6.4	20.0	82.5
Credenz CZ 4341X	4.3	2.0	8.2	4.9	2.4	20.0	72.3
Dyna-Gro S43EN61	4.3	2.0	10.4	3.8	3.6	18.3	73.9
Dyna-Gro S43XS70	4.3	2.0	10.2	2.9	3.1	13.3	80.7
REV 4311X	4.3	2.2	8.0	2.7	4.2	20.0	81.3
Armor 44-D49	4.4	0.7	11.8	4.2	3.6	15.0	75.3
Armor 44-D92	4.4	2.0	8.7	2.4	4.9	26.7	78.1
Armor 44-E44	4.4	1.8	7.6	4.0	5.3	18.3	76.3
Credenz CZ 4410GTLL	4.4	0.9	7.3	2.7	3.3	21.7	92.6
DM 44X31	4.4	0.9	8.4	5.1	4.4	21.7	90.4
LGS4464RX	4.4	1.1	6.0	3.3	3.6	21.7	81.6
Local LS4407X	4.4	2.7	10.4	3.3	3.6	26.7	87.7
Mission A4448X	4.4	1.6	9.1	5.3	4.0	25.0	83.1
USG 7447XTS	4.4	0.7	3.1	2.4	6.9	16.7	94.3
Tukey's HSD *P* = 0.05	3.37–3.48	12.00–14.64	4.91–7.14	1.97–3.40	5.58–6.51	19.13–28.71	41.88
MSE	0.36	0.04	0.05	0.05	0.03	0.25	179.00
Treatment (F)	0.02	0.02	0.27	0.61	0.05	0.62	0.70

† MG = Maturity group, PSD = Phomopsis seed decay, PSS = purple seed stain, SMV = soybean mosaic virus, SBD = stink bug (*Pentatomidae*) damage, and SDQ = overall seed quality.

‡ Yield (bu./ac) adjusted to 13% moisture content for comparison.

MSE = Mean square error.

Table 3. Seed pathogen and stink bug damage incidence percentage, seed quality, and yield data from a seed quality trial located at the University of Arkansas System Division of Agriculture's Rohwer Research Station, near Rohwer, Ark., 2020 within MG† 4.5. Post-harvest pathogen incidence and stink bug damage incidence are expressed as percentages where 0 = not found and 100 = found on all seed. Seed quality is expressed as the percentage of seed without visible defects. Data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Tukey's honestly significant difference (HSD) using a log transformation where appropriate at *P* = 0.05. Means shown are untransformed.

Variety	MG†	PSD†	PSS†	SMV†	SBD†	SDQ†	Yield‡
Asgrow AG 45X8	4.5	1.1	5.1	0.4	4.9	30.0	69.5
Credenz CZ 4570X	4.5	0.9	11.8	4.0	3.3	20.0	78.0
Delta Grow DG45E10	4.5	1.3	14.4	4.9	5.1	18.3	71.2
Delta Grow DG45E28XP	4.5	0.7	2.7	2.7	6.0	16.7	84.5
Delta Grow DG49E00/STS	4.5	1.8	3.8	2.4	6.0	16.7	76.4
DM 45X61	4.5	1.8	2.4	1.3	4.2	20.0	90.4
Dyna-Gro S45ES10	4.5	1.6	6.7	3.8	5.1	16.7	73.0
Local LS4565XS	4.5	1.1	3.6	0.7	6.9	20.0	75.8
Progeny 4505RXS	4.5	0.4	5.1	0.9	4.0	26.7	67.3
Tukey's HSD *P* = 0.05		2.09–5.79	11.34–13.62	3.38–4.23	4.89–7.73	22.22–41.99	31.78
MSE		0.05	0.06	0.04	0.03	0.03	117.54
Treatment (F)		0.93	0.04	0.00	0.35	0.55	0.65

† MG = Maturity group, PSD = Phomopsis seed decay, PSS = purple seed stain, SMV = soybean mosaic virus, SBD = stink bug (*Pentatomidae*) damage, and SDQ = overall seed quality.

‡ Yield (bu./ac) adjusted to 13% moisture content for comparison.

MSE = Mean square error.

Table 4. Seed pathogen and stink bug damage incidence percentage, seed quality, and yield data from a seed quality trial located at the University of Arkansas System Division of Agriculture's Rohwer Research Station, near Rohwer, Ark., 2020 within MG† 4.6 non-Xtend© varieties. Post-harvest pathogen incidence and stink bug damage incidence are expressed as percentages where 0 = not found and 100 = found on all seed. Seed quality is expressed as the percentage of seed without visible defects. Data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Tukey's honestly significant difference (HSD) using a log transformation where appropriate at *P* =0.05. Means shown are untransformed.

Variety	MG†	PSD†	PSS†	SMV†	SBD†	SDQ†	Yield‡
Armor 46-E50	4.6	1.8	3.1	1.3	7.6	20.0	73.2
Dyna-Gro S46ES91	4.6	1.6	4.2	1.1	5.6	25.0	75.4
Go Soy 463E20S	4.6	1.3	3.1	1.1	5.1	25.0	78.4
Local ZS4694E3S	4.6	1.6	4.9	0.9	7.6	25.0	70.5
Progeny 4602LR	4.6	0.7	3.3	2.7	10.7	10.0	62.5
Progeny 4682E3	4.6	0.4	4.0	1.8	4.9	30.0	76.5
R15-2422	4.6	0.7	5.6	0.9	5.1	23.3	63.3
R16-253	4.6	1.1	3.1	1.8	6.4	18.3	73.7
R16-259	4.6	0.9	3.6	1.8	5.8	16.7	73.3
R17-2000	4.6	0.4	4.7	1.3	15.6	15.0	88.0
R17C-1056	4.6	2.0	6.2	1.1	8.4	13.3	70.2
R17C-1182	4.6	1.1	5.6	1.6	3.6	23.3	82.5
R17C-1308	4.6	0.7	6.0	0.7	6.9	20.0	67.0
S16-5504R	4.6	1.6	6.4	1.8	7.6	23.3	72.5
Tukey's HSD *P* = 0.05		2.19–6.14	6.29–12.04	1.97–4.00	8.12–19.83	22.22–30.28	45.0
MSE		0.06	0.04	0.03	0.06	0.03	233.71
Treatment (F)		0.96	0.65	0.89	0.94	0.44	0.79

† MG = Maturity group, PSD = Phomopsis seed decay, PSS = purple seed stain, SMV = soybean mosaic virus, SBD stink bug (*Pentatomidae*) damage, and SDQ = overall seed quality.

‡ Yield (bu./ac) adjusted to 13% moisture content for comparison.

MSE = Mean square error.

Table 5. Seed pathogen and stink bug damage incidence percentage, seed quality, and yield data from a seed quality trial located at the University of Arkansas System Division of Agriculture's Rohwer Research Station, near Rohwer, Ark, 2020 within MG† 4.6 Xtend® varieties. Post-harvest pathogen incidence and stink bug damage incidence are expressed as percentages where 0 = not found and 100 = found on all seed. Seed quality is expressed as the percentage of seed without visible defects. Data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Tukey's honestly significant difference (HSD) using a log transformation where appropriate at *P* = 0.05. Means shown are untransformed.

Variety	MG†	PSD†	PSS†	SMV†	SBD†	SDQ†	Yield‡
AgriGold G4620RX	4.6	1.1	6.9	1.3	6.0	26.7	66.1
Armor 46-D09	4.6	0.4	2.9	1.1	7.3	26.7	77.1
Asgrow AG 46X0	4.6	1.6	2.7	1.3	6.4	18.3	80.8
Asgrow AG 46X6	4.6	2.4	5.1	1.6	3.3	13.3	71.0
Credenz CZ 4600X	4.6	1.6	3.6	2.4	4.7	18.3	75.8
Delta Grow DG46X05/STS	4.6	0.4	2.4	1.6	6.2	16.7	80.2
Delta Grow DG46X65/STS	4.6	1.1	6.9	1.6	5.8	11.7	75.1
Dyna-Gro S46XS60	4.6	2.4	6.2	0.7	4.4	20.0	60.2
Eagle Seed ES4640RYX	4.6	0.2	4.7	1.3	6.7	16.7	63.7
Integra 54606NS	4.6	0.9	8.2	1.8	6.0	18.3	71.8
Integra 54660NS	4.6	2.0	6.0	0.4	5.1	15.0	63.6
LGS4632RX	4.6	0.9	2.7	2.2	7.1	18.3	91.0
Local LSX4612XS	4.6	1.6	5.3	1.3	6.4	15.0	67.8
Mission A4618X	4.6	1.6	3.1	0.9	3.3	20.0	75.2
Petrus Seed 4619 GTS	4.6	2.0	3.1	0.9	2.9	20.0	86.8
Pioneer P46A86X	4.6	1.8	4.0	1.1	6.4	20.0	56.9
Progeny 4602LR	4.6	1.0	12.0	1.0	5.3	20.0	61.4
Progeny 4620RXS	4.6	2.2	4.2	1.8	5.6	16.7	79.8
REV 4679X	4.6	0.7	4.9	1.1	8.7	20.0	46.8
USG 7461XT	4.6	1.6	3.6	2.7	6.9	21.7	73.3
Tukey's HSD *P* = 0.05		2.78–4.91	6.78–11.66	2.86–4.52	6.93–9.47	21.76–38.95	48.20
MSE		0.05	0.06	0.04	0.03	0.05	241.16
Treatment (F)		0.57	0.36	0.76	0.29	0.71	0.19

† MG = Maturity group, PSD = Phomopsis seed decay, PSS = purple seed stain, SMV = soybean mosaic virus, SBD = stink bug (*Pentatomidae*) damage, and SDQ = overall seed quality.

‡ Yield (bu./ac) adjusted to 13% moisture content for comparison.

MSE = Mean square error.

Table 6. Seed pathogen and stink bug damage incidence percentage, seed quality, and yield data from a seed quality trial located at the University of Arkansas System Division of Agriculture's Rohwer Research Station, near Rohwer, Ark., 2020 within MG† 4.7. Post-harvest pathogen incidence and stink bug damage incidence are expressed as percentages where 0 = not found and 100 = found on all seed. Seed quality is expressed as the percentage of seed without visible defects. Data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Tukey's honestly significant difference (HSD) using a log transformation where appropriate at *P* = 0.05. Means shown are untransformed.

Variety	MG†	PSD†	PSS†	SMV†	SBD†	SDQ†	Yield‡
Armor 47-E02	4.7	0.7	2.2	1.3	5.8	25.0	73.4
Credenz CZ 4730X	4.7	0.9	4.4	0.4	7.8	13.3	90.0
Credenz CZ 4770X	4.7	1.3	3.8	1.3	6.2	18.3	82.8
Delta Grow DG47E20/STS	4.7	1.3	5.3	1.8	8.0	11.7	75.0
Delta Grow DG47E80/STS	4.7	0.7	3.6	1.6	4.4	16.7	76.3
Delta Grow DG47X95/STS	4.7	1.6	6.0	1.6	8.0	25.0	80.6
DM 47X39	4.7	2.0	5.1	0.9	4.9	18.3	56.0
Dyna-Gro S47XT20	4.7	0.9	4.4	2.2	3.8	25.0	80.1
Eagle Seed ES4772R2Y	4.7	1.8	5.1	1.1	5.3	21.7	72.1
Local LS4795XS	4.7	1.6	6.9	1.6	4.2	30.0	85.8
Local LSX4711GL	4.7	1.8	5.6	1.6	4.0	26.7	61.7
Pioneer P47A76L	4.7	1.3	2.7	0.9	5.3	15.0	76.8
Progeny 4700RXS	4.7	0.7	4.7	1.8	5.3	35.0	74.1
Progeny 4775E3S	4.7	2.0	2.2	2.4	5.3	64.3	79.7
USG 7471ETS	4.7	2.4	4.7	2.0	4.9	16.7	59.6
Tukey's HSD *P* = 0.05		2.6–5.67	5.67–9.15	2.36–5.22	6.19–10.67	24.30–26.32	44.05
MSE		0.05	0.04	0.05	0.03	0.17	211.87
Treatment (F)		0.80	0.47	0.94	0.69	1.31	0.28

† MG = Maturity group, PSD = Phomopsis seed decay, PSS = purple seed stain, SMV = soybean mosaic virus, SBD = stink bug (*Pentatomidae*) damage, and SDQ = overall seed quality.

‡ Yield (bu./ac) adjusted to 13% moisture content for comparison.

MSE = Mean square error.

Table 7. Seed pathogen and stink bug damage incidence percentage, seed quality, and yield data from a seed quality trial located at the University of Arkansas System Division of Agriculture's Rohwer Research Station, near Rohwer, Ark., 2020 within MG† 4.8 non-Xtend® varieties. Post-harvest pathogen incidence and stink bug damage incidence are expressed as percentages where 0 = not found and 100 = found on all seed. Seed quality is expressed as the percentage of seed without visible defects. Data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Tukey's honestly significant difference (HSD) using a log transformation where appropriate at *P* = 0.05. Means shown are untransformed.

Variety	MG†	PSD†	PSS†	SMV†	SBD†	SDQ†	Yield‡
Armor 48-E81	4.8	0.4	9.3	1.3	5.1	28.3	66.3
Delta Grow DG4880	4.8	0.9	3.5	0.9	6.7	41.7	90.6
Delta Grow DG48E10	4.8	2.4	5.5	1.3	8.2	30.0	79.3
Delta Grow DG48E49/STS	4.8	0.7	2.7	0.9	5.6	36.7	82.6
Go Soy 481E19	4.8	1.1	4.0	1.8	8.2	41.7	85.2
GT Ireane	4.8	0.9	2.2	0.9	6.2	25.0	87.1
Progeny 4807E3S	4.8	0.9	4.9	1.6	6.4	25.0	65.9
R13-14635RR	4.8	0.9	5.6	3.6	4.2	35.0	66.4
R16-247	4.8	3.1	3.3	1.8	6.2	20.0	109.6
R17-2069	4.8	0.2	6.0	2.0	5.3	33.3	89.7
R17C-1266	4.8	1.1	4.7	1.1	3.6	30.0	90.4
Tukey's HSD *P* = 0.05		2.66–6.33	6.64–8.02	3.14–7.75	5.29–6.29	26.09–33.95	53.66
MSE		0.07	0.04	0.06	0.02	0.02	331.09
Treatment (F)		0.19	0.19	0.79	0.17	0.21	0.21

† MG = Maturity group, PSD = Phomopsis seed decay, PSS = purple seed stain, SMV = soybean mosaic virus, SBD = stink bug (*Pentatomidae*) damage, and SDQ = overall seed quality.

‡ Yield (bu./ac) adjusted to 13% moisture content for comparison.

MSE = Mean square error.

Table 8. Seed pathogen and stink bug damage incidence percentage, seed quality, and yield data from a seed quality trial located at the University of Arkansas System Division of agriculture's Rohwer Research Station, near Rohwer, Ark., 2020 within MG† 4.8 Xtend® varieties. Post-harvest pathogen incidence and stink bug damage incidence are expressed as percentages where 0 = not found and 100 = found on all seed. Seed quality is expressed as the percentage of seed without visible defects. Data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Tukey's honestly significant difference (HSD) using a log transformation where appropriate at *P* = 0.05. Means shown are untransformed.

Variety	MG†	PSD†	PSS†	SMV†	SBD†	SDQ†‡	Yield§
AgriGold G4820RX	4.8	1.1	3.8	1.3	4.2	38.3 ab	74.1
Armor 48-D25	4.8	2.2	4.9	1.6	4.7	26.7 ab	84.5
Asgrow AG 48X9	4.8	1.1	3.1	0.7	8.4	21.7 abc	88.9
Credenz CZ 4810X	4.8	1.6	6.0	1.3	6.7	26.7 ab	75.3
Credenz CZ 4869X	4.8	0.9	3.1	0.9	7.8	25.0 ab	94.6
Delta Grow DG48X05	4.8	0.4	3.1	1.1	8.2	35.0 ab	81.2
Delta Grow DG48X45	4.8	1.8	6.4	1.1	4.2	33.3 ab	70.8
Dyna-Gro S48XT40	4.8	1.3	4.9	1.8	8.4	40.0 a	69.2
Dyna-Gro S48XT90	4.8	1.1	3.1	1.8	5.6	33.3 ab	73.4
Eagle Seed ES4880RYX	4.8	0.7	2.7	0.4	5.1	31.7 ab	66.0
Integra 54816N	4.8	1.1	4.2	1.1	6.4	20.0 abc	72.4
Integra 54891NS	4.8	1.3	2.2	2.4	8.7	6.7 c	80.2
LGS4899RX	4.8	0.2	2.7	1.6	6.0	33.3 ab	79.1
Local LSX4812XS	4.8	0.2	5.8	1.8	5.6	30.0 ab	77.4
Mission A4828X	4.8	0.7	4.4	1.8	4.2	15.0 abc	79.2
Pioneer P48A60X	4.8	1.1	5.8	2.2	7.1	13.3 abc	68.7
Progeny 4816RXS	4.8	0.7	4.4	3.1	4.7	28.3 ab	84.1
Progeny 4821RX	4.8	1.6	6.4	1.8	4.9	16.7 abc	83.0
Progeny 4851RX	4.8	0.0	3.3	1.1	5.3	23.3 abc	72.6
Taylor T4880XS	4.8	1.1	3.6	1.3	4.9	11.7 bc	74.1
USG 7480XT	4.8	1.6	2.7	2.0	5.1	28.3 ab	74.2
USG 7489XT	4.8	0.9	5.8	1.1	7.3	20.0 abc	82.3
Tukey's HSD *P* = 0.05		2.55–4.58	5.47–9.39	2.73–4.53	6.02–8.81	18.56–29.23	38.54
MSE		0.05	0.04	0.04	0.02	0.03	151.58
Treatment (F)		0.55	0.67	0.67	0.18	0.00	0.52

† MG = Maturity group, PSD = Phomopsis seed decay, PSS = purple seed stain, SMV = soybean mosaic virus, SBD = stink bug (*Pentatomidae*) damage, and SDQ = overall seed quality.

‡ Columns followed by the same letter are not statistically significant at P=0.10 as determined by Tukey's honestly significant difference (HSD) test.

§ Yield (bu./ac) adjusted to 13% moisture content for comparison.

MSE = Mean square error.

Table 9. Seed pathogen and stink bug damage incidence percentage, seed quality, and yield data from a seed quality trial located at the University of Arkansas System Division of Agriculture's Rohwer Research Station, near Rohwer, Ark., 2020 within MG† 4.9. Post-harvest pathogen incidence and stink bug damage incidence are expressed as percentages where 0 = not found and 100 = found on all seed. Seed quality is expressed as the percentage of seed without visible defects. Data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Tukey's honestly significant difference (HSD) using a log transformation where appropriate at *P* = 0.05. Means shown are untransformed.

Variety	MG†	PSD†	PSS†	SMV†	SBD†	SDQ†	Yield‡
AgriGold G4995RX	4.9	1.1	4.0	2.0	6.2	25.0	74.3
Armor 49-D14	4.9	1.6	4.9	1.8	5.8	11.7	66.6
Asgrow AG 49X0	4.9	0.9	5.1	0.7	4.7	23.3	83.8
Credenz CZ 4941X	4.9	0.7	4.4	1.8	6.2	20.0	77.5
Credenz CZ 4979X	4.9	0.4	2.0	0.2	5.3	16.7	95.3
Delta Grow DG49X15	4.9	0.0	2.2	1.3	4.4	21.7	84.8
Delta Grow DG49X25	4.9	0.2	3.3	0.9	2.9	10.0	83.2
DM 49X13	4.9	0.4	4.0	0.4	7.6	15.0	79.7
Dyna-Gro S49EN79	4.9	1.1	4.2	1.3	8.2	31.7	83.5
Dyna-Gro S49XT70	4.9	0.7	2.9	0.9	6.4	25.0	95.5
Go Soy 491E19S	4.9	0.9	8.2	1.1	4.9	11.7	60.2
Integra 54920NS	4.9	1.6	2.9	1.3	3.1	15.0	76.6
Local LS4999X	4.9	0.4	2.2	1.1	7.3	20.0	77.9
Mission A4950X	4.9	0.7	3.3	0.9	5.6	13.3	100.3
Petrus Seed 4916 GT	4.9	1.1	2.7	1.6	7.1	18.3	95.8
Pioneer P49A41L	4.9	1.1	3.8	0.9	6.0	21.7	82.6
Pioneer P49T62E	4.9	1.3	4.4	2.0	6.2	23.3	76.8
Progeny 4902E3	4.9	1.1	4.7	1.8	6.0	25.0	76.8
Progeny 4908E3S	4.9	0.2	2.4	1.3	6.0	25.0	75.2
Progeny 4970RX	4.9	0.4	5.1	1.1	6.4	31.7	94.2
REV 4927X	4.9	0.7	1.6	1.3	4.2	20.0	112.2
REV 4940X	4.9	1.1	2.7	0.2	5.3	18.3	90.0
Taylor T4990XS	4.9	0.4	2.4	2.0	5.6	21.7	77.2
USG 7491ETS	4.9	0.9	2.4	1.6	5.3	16.7	77.8
USG 7496XTS	4.9	1.1	3.3	0.4	3.6	13.3	83.0
Tukey's HSD *P* = 0.05		1.89–3.61	6.66–8.65	2.19–3.21	6.11–9.62	24.24–36.23	56.42
MSE		0.04	0.04	0.03	0.03	0.04	317.46
Treatment (F)		0.68	0.34	0.22	0.65	0.31	0.32

† MG = Maturity group, PSD = Phomopsis seed decay, PSS = purple seed stain, SMV = soybean mosaic virus, SBD = stink bug (*Pentatomidae*) damage, and SDQ = overall seed quality.

‡ Yield (bu./ac) adjusted to 13% moisture content for comparison.

MSE = Mean square error.

Table 10. Seed pathogen and stink bug damage incidence percentage, seed quality, and yield data from a seed quality trial located at the University of Arkansas System Division of Agriculture's Rohwer Research Station, near Rohwer, Ark., 2020 within MGs† 5.0–5.1. Post-harvest pathogen incidence and stink bug damage incidence are expressed as percentages where 0 = not found and 100 = found on all seed. Seed quality is expressed as the percentage of seed without visible defects. Data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Tukey's honestly significant difference (HSD) using a log transformation where appropriate at *P* = 0.05. Means shown are untransformed.

Variety	MG†	PSD†	PSS†	SMV†	SBD†	SDQ†	Yield‡
Credenz CZ 5000X	5.0	0.2	2.5	0.2	6.0	18.3	94.5
Delta Grow DG50E10XP	5.0	0.9	1.6	1.5	5.1	20.0	94.1
Local LS5009XS	5.0	1.8	4.4	0.9	3.8	20.0	82.3
Local LS5087X	5.0	0.5	4.4	0.2	3.6	16.7	89.0
Local ZS5098E3	5.0	1.1	5.1	1.1	3.5	18.3	85.9
Progeny 5016RXS	5.0	0.9	3.8	1.3	4.0	25.0	57.1
S16-3747RY	5.0	0.7	2.5	1.6	4.7	31.7	89.4
Armor 51-E53	5.1	0.5	2.9	0.0	6.0	26.7	92.1
Delta Grow DG51E60	5.1	0.4	2.2	1.4	3.8	25.0	93.3
DM 51X61	5.1	0.4	1.4	0.9	4.2	26.7	84.5
Go Soy 512E21	5.1	0.7	4.2	1.3	3.5	21.7	100.6
Progeny 5170RX	5.1	0.2	2.7	1.3	6.5	28.3	95.2
R15-1587	5.1	0.0	3.6	1.1	4.0	25.0	87.2
Tukey's HSD *P* = 0.05		1.88–2.61	4.35–12.84	1.85–3.36	5.21–9.50	23.35–50.43	48.16
MSE		0.03	0.08	0.04	0.03	0.06	259.53
Treatment (F)		0.32	0.77	0.27	0.80	0.82	0.29

† MG = Maturity group, PSD = Phomopsis seed decay, PSS = purple seed stain, SMV = soybean mosaic virus, SBD = stink bug (*Pentatomidae*) damage, and SDQ = overall seed quality.

‡ Yield (bu./ac) adjusted to 13% moisture content for comparison.

MSE = Mean square error.

Table 11. Seed pathogen and stink bug damage incidence percentage, seed quality, and yield data from a seed quality trial located at the University of Arkansas System Division of Agriculture's Rohwer Research Station, near Rohwer, Ark., 2020 within MGs† 5.2–5.3. Post-harvest pathogen incidence and stink bug damage incidence are expressed as percentages where 0 = not found and 100 = found on all seed. Seed quality is expressed as the percentage of seed without visible defects. Data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Tukey's honestly significant difference (HSD) using a log transformation where appropriate at *P* = 0.05. Means shown are untransformed.

Variety	MG†	PSD†	PSS†	SMV†‡	SBD†	SDQ†	Yield§
Asgrow AG 52X9	5.2	0.2	2.0	0.2 b	8.0	33.3	92.8
Credenz CZ 5251X	5.2	0.2	3.6	0.9 ab	4.7	25.0	90.7
Credenz CZ 5299X	5.2	0.9	2.9	2.2 a	10.2	35.0	96.1
Delta Grow DG52E15/STS	5.2	0.7	2.4	0.4 ab	6.0	41.7	78.3
Delta Grow DG52E22	5.2	1.3	3.1	0.4 ab	8.9	30.0	92.8
Delta Grow DG52X05/STS	5.2	0.2	0.9	0.9 ab	7.6	18.3	93.1
Dyna-Gro S52XS39	5.2	0.4	2.7	0.9 ab	9.3	30.0	78.7
Progeny 5211E3	5.2	0.0	2.2	0.2 b	6.2	33.3	85.3
Progeny 5252RX	5.2	0.2	2.4	1.1 ab	8.4	33.3	87.2
R17-7443RR	5.2	0.9	2.9	0.4 ab	4.4	40.0	96.8
Asgrow AG 53X0	5.3	0.9	2.4	1.3 ab	9.8	26.7	88.6
Asgrow AG 53X9	5.3	0.4	4.9	0.9 ab	7.8	41.7	67.3
Local LS5386X	5.3	0.9	2.4	0.4 ab	7.8	38.3	76.7
Petrus Seed 5319 GT	5.3	0.4	4.4	0.0 b	3.3	41.7	83.2
S16-11651C	5.3	0.9	1.6	1.1 ab	9.6	35.0	55.4
Tukey's HSD *P* = 0.05		1.54–3.66	4.07–6.80	1.80–1.86	7.54–11.82	27.44–29.54	60.59
MSE		0.04	0.05	0.02	0.04	0.02	400.89
Treatment (F)		0.85	0.69	0.01	0.22	0.10	0.50

† MG = Maturity group, PSD = Phomopsis seed decay, PSS = purple seed stain, SMV = soybean mosaic virus, SBD = stink bug (*Pentatomidae*) damage, and SDQ = overall seed quality.

‡ Columns followed by the same letter are not statistically significant at P=0.10 as determined by Tukey's honestly significant difference (HSD) test.

§ Yield (bu./ac) adjusted to 13% moisture content for comparison.

MSE = Mean square error.

Table 12. Seed pathogen and stink bug damage incidence percentage, seed quality, and yield data from a seed quality trial located at the University of Arkansas System Division of Agriculture's Rohwer Research Station, near Rohwer, Ark., 2020 within MGs† 5.2–5.3. Post-harvest pathogen incidence and stink bug damage incidence are expressed as percentages where 0 = not found and 100 = found on all seed. Seed quality is expressed as the percentage of seed without visible defects. Data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Tukey's honestly significant difference (HSD) using a log transformation where appropriate at *P* = 0.05. Means shown are untransformed.

Variety	MG†	PSD†‡	PSS†	SMV†	SBD†	SDQ†	Yield§
Delta Grow DG54X25	5.4	1.1 ab	1.1	1.3	5.1	11.7	104.4
R13-14635RR	5.4	0.9 b	9.6	0.7	7.3	21.7	71.9
R14-1422	5.4	0.9 b	3.1	0.4	8.0	38.3	83.5
R16-1445	5.4	0.9 a	1.6	0.7	6.0	36.7	83.2
Progeny 5554RX	5.5	0.7 ab	1.6	1.1	6.4	38.3	74.1
R13-13997	5.5	0.2 ab	2.9	0.9	5.1	23.3	78.4
Credenz CZ 5700X	5.7	0.2 ab	4.4	0.4	13.8	30.0	96.1
Credenz CZ 6020X	6.0	0.9 ab	5.3	0.7	7.3	36.7	83.2
Tukey's HSD *P* = 0.05		1.98–2.01	6.80–10.02	1.71–2.46	7.08–9.17	30.29–44.77	49.63
MSE		0.02	0.06	0.02	0.03	0.04	296.63
Treatment (F)		0.03	0.33	0.39	0.15	0.24	0.26

† MG = Maturity group, PSD = Phomopsis seed decay, PSS = purple seed stain, SMV = soybean mosaic virus, SBD = stink bug (*Pentatomidae*) damage, and SDQ = overall seed quality.

‡ Columns followed by the same letter are not statistically significant at *P* = 0.10 as determined by Tukey's honestly significant difference (HSD) test.

§ Yield (bu./ac) adjusted to 13% moisture content for comparison.

MSE = Mean square error.

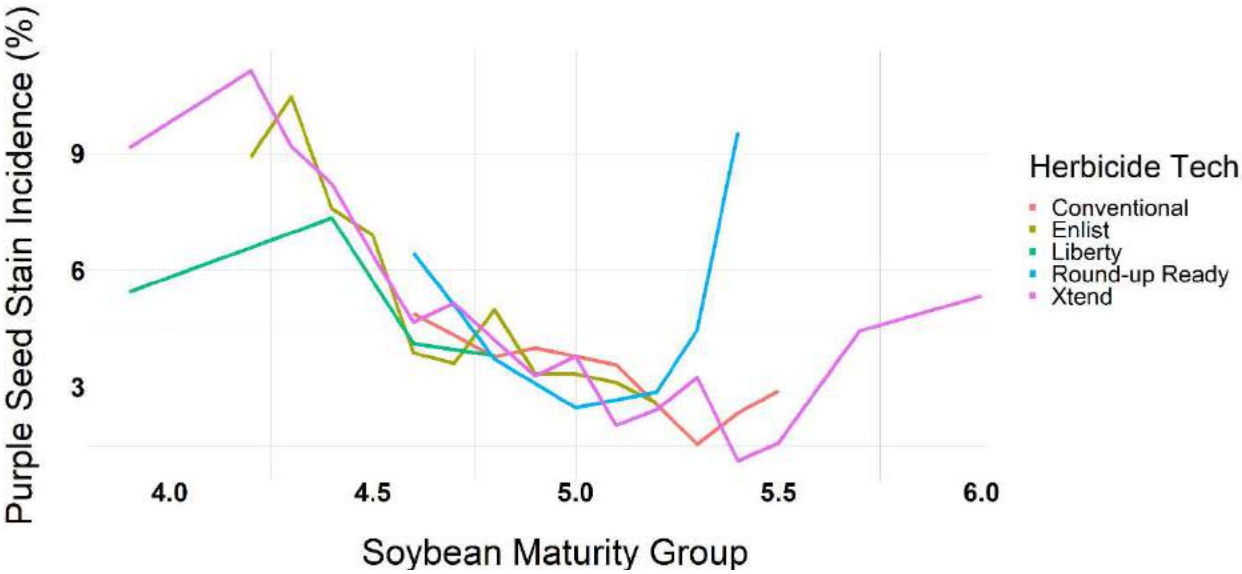

Fig. 1. Percent purple seed stain (*Cercospora spp*.) incidence by maturity group and herbicide technology in a variety trial at the University of Arkansas System Division of Agriculture's Rohwer Research Station, 2020.

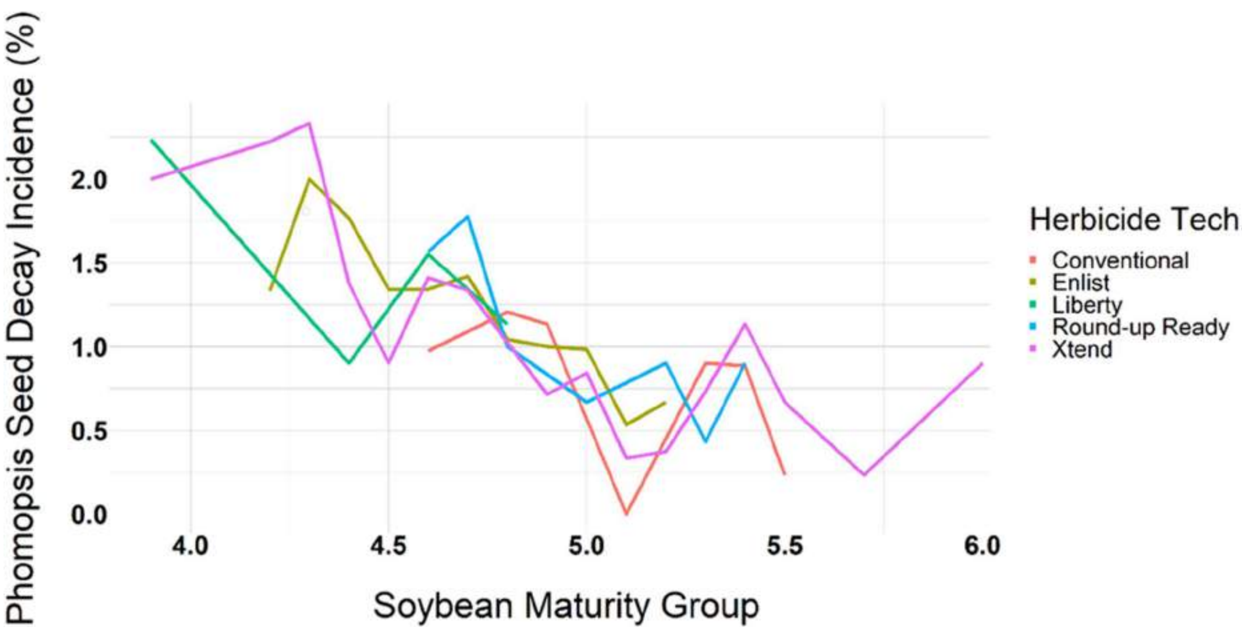

Fig. 2. Percent Phomopsis seed decay (*Phomopsis longicolla*) incidence by maturity group and herbicide technology in a variety trial at the University of Arkansas System Division of Agriculture's Rohwer Research Station, 2020.

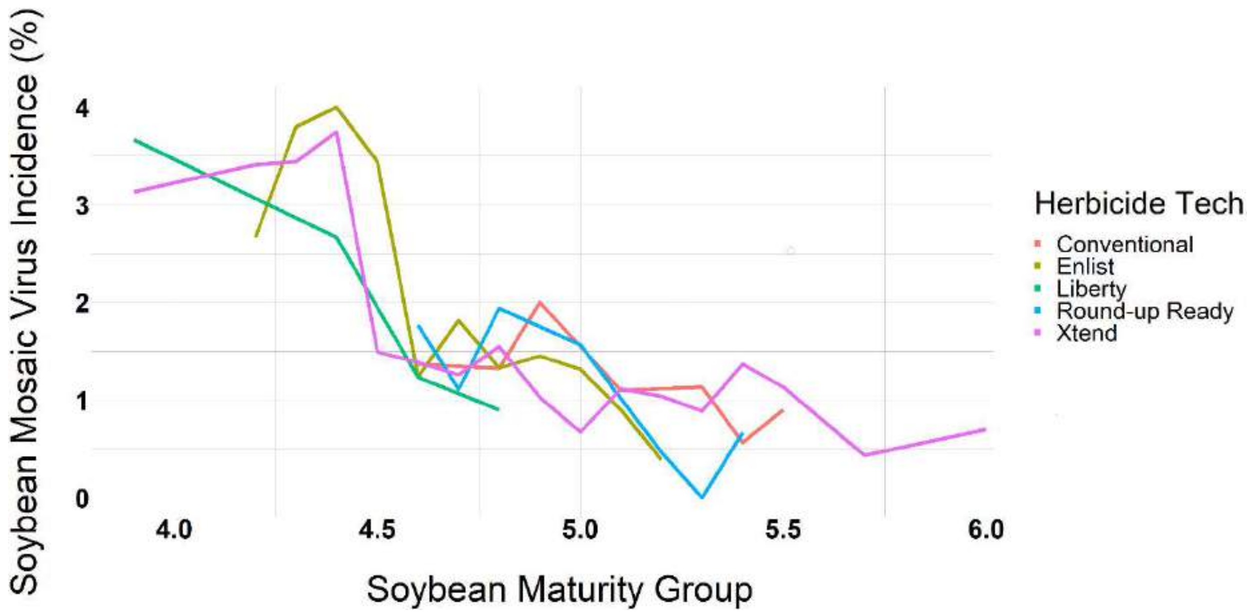

Fig. 3. Percent Soybean mosaic virus (*Potyvirus*) by maturity group and herbicide technology in a variety trial at the University of Arkansas System Division of Agriculture's Rohwer Research Station, 2020.

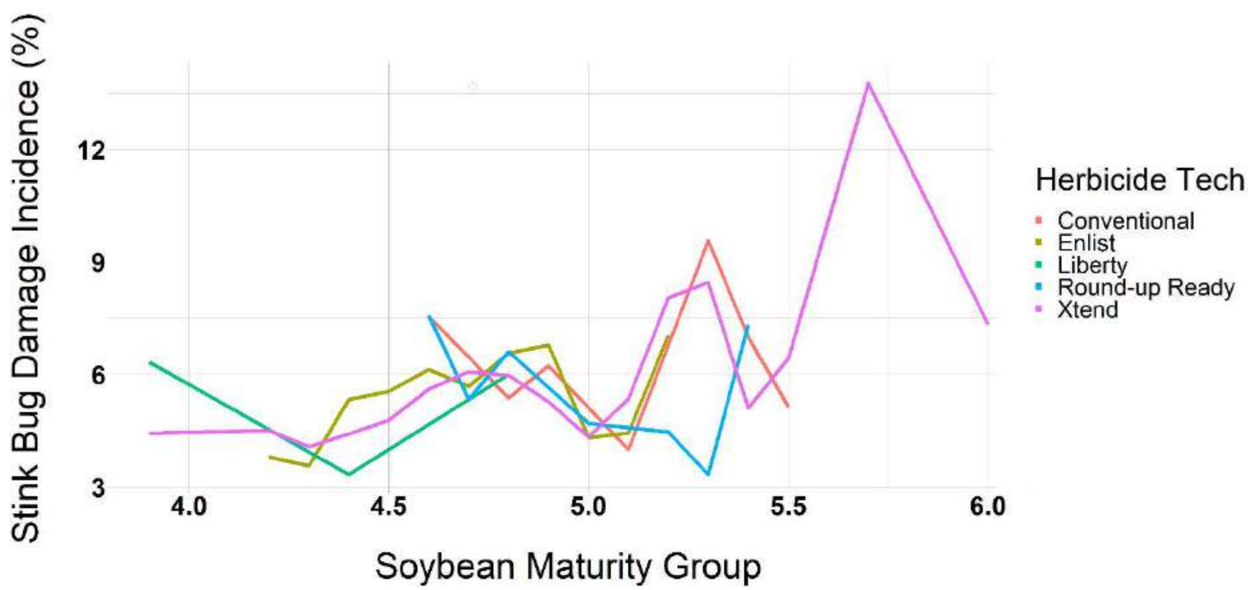

Fig. 4. Percent Stink bug (*Pentatomidae spp*.) damage incidence by maturity group and herbicide technology in a variety trial at the University of Arkansas System Division of Agriculture's Rohwer Research Station, 2020.

Understanding Taproot Decline

T.N. Spurlock,[1] J. A. Rojas,[2] Q. Fan,[2] A.C. Tolbert,[3] and R. Hoyle[3]

Abstract

Taproot decline (TRD) (*Xylaria necrophora)* is a disease of increasing importance in Arkansas soybean [*Glycine max* (L.) Merr.] production. In 2020, the incidence and severity of TRD were examined in 2 commercial fields, on different soybean varieties and with various seed treatments and in-furrow fungicides applied, and on cover crops. To date, TRD has been found in 14 counties of the Arkansas Delta region, with increased severity in southeastern Arkansas. The efficacy of seed treatment, in-furrow fungicide, and variety trials was inconclusive. However, trials to determine cover crop susceptibility demonstrated all species tested were susceptible to TRD.

Introduction

A group of scientists from the University of Arkansas System Division of Agriculture, Mississippi State University, and Louisiana State University has characterized a disease of soybean [*Glycine max* (L.) Merr.] prevalent in their respective states and named it taproot decline (TRD) (Allen et al., 2017). It was determined that the disease is caused by an undescribed fungus in the genus *Xylaria* which has recently been named *Xylaria necrophora* (Garcia-Aroca et al., 2021). The disease presents in early vegetative stages as chlorotic or dead plants located in clusters or streaks within fields. Additionally, in areas of symptomatic plants, gaps in plant stands are evident with mummies of dead plants between the chlorotic plants. When dead plants from TRD are extracted from the soil, the taproot will be malformed and black, if present. In the latter reproductive stages (R5+, beginning seed development), the disease has a "leopard spot" or "sanded" appearance. As the disease progresses, above-ground symptoms include stunting and interveinal chlorosis leading to necrosis. When a plant with TRD is pulled from the soil at this growth stage, the taproot will often break off and have a black coating of stroma. Splitting the root or lower stem longitudinally reveals mild vascular staining, and often white mycelia are seen growing up the pith. Fungal fruiting structures referred to as "dead man's fingers" can sometimes be found in the residue from the previous year's crop.

The regional distributions and yield loss in Arkansas have been unclear to date. However, it has been found as far north as Craighead County, and reports from some farmers and consultants indicate yield losses as high as 10 bu./ac in fields. Currently, we do not have seed treatment fungicide or varietal recommendations for growers to combat TRD. The objectives of the following studies were to determine the distribution of TRD across the soybean production areas in Arkansas, its yield impact, and management strategies, including cover crop use, that could limit damage to soybean and inform growers with TRD on their farms.

Procedures

Determine the Distribution Across the Soybean Production Area in Arkansas. Images representative of field symptoms and signs were made available to county agents, farmers, and consultants via email, text groups, and Twitter® to identify fields with TRD. Samples were collected to confirm the disease. Fields confirmed to have TRD were recorded by GPS location and marked on a larger regional map.

Determine disease severity on commonly planted varieties. Varieties (175) were planted into plots 2-rows wide and 10-ft. long at a seeding rate of approximately 100 seed/row, replicated 3 times. The trial was planted 2 June at the University of Arkansas System Division of Agriculture's Rohwer Research Station near Kelso, Ark. Percent disease incidence and severity based on foliar and root expression were collected 6 Oct. Root incidence was determined by digging and washing 10 plants per plot and recording the number of plants exhibiting stroma. Data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Fisher's protected least significant difference (LSD) at $P = 0.05$.

Determine the Efficacy of Seed Treatment Fungicides Against the Disease. A trial was planted in DG4967LL on 29 May at the Rohwer Research Station. Six seed treatments and 5 in-furrow fungicides were planted into 2-row plots, 10-ft long, and replicated 4 times. Plant stand data and per-

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cent emergence data were collected on 16 June. Harvest data was not collected due to destructive sampling caused by the root sampling procedure. Root incidence was determined at maturity using the method previously described. Data were subjected to ANOVA followed by means separation of fixed effects using Fisher's protected least significant difference (LSD) at $P = 0.05$.

Determine the Within-Field Distribution of Disease. Soil samples from a field located in Chicot County, Ark., were collected on 22 Oct. This field had soybean planted in 2020 and TRD was severe. The north side of the field was divided into 5 transects, and 8 soil samples were taken every 100 ft along the transect. Forty soil samples were collected in total. Soil samples were used to examine the soybean germination and disease incidence. In this study, each soil sample was subsampled for DNA extraction to assess microbial communities. The remaining soil was divided into 2 cups and 6 seeds of soybean cultivar Hutcheson were planted per cup. Cups were placed in the trays in a growth chamber with 25 °C 12-h light–20 °C 12-h dark cycle and plants were watered every other day. Germination at day 7 and day 14 post-planting was recorded. Plant height and root parameters (root weight, root area, and root length) were measured to determine the impact of disease on these parameters. Average values of root parameters were visualized as heat maps to represent the spatial distribution of the sample points in the field.

Determine the Ability of the Pathogen to Colonize Cover Crop Species. Nine types of cover crop species (wheat, barley, winter rye, mustard, black oat, vetch, winter pea, blue lupine, and radish), along with susceptible soybean (cultivar: Hutcheson) were inoculated with *Xylaria necrophora* isolates MSU_SB201401 and TRD_AR in *in vitro* and in growth chamber experiments.

In the *in vitro* experiment, two *Xylaria necrophora* isolates were grown separately on the center of PDA plates for 10 days at room temperature until mycelium colonized on three-fourths of the plates. Six surface-sterilized seeds were plated onto the edge of the colony on each plate. Seeds plated onto clean potato dextrose agar (PDA) plates served as a control. Pathogenicity tests of each isolate on each cover crop species consisted of 4 replicates. Seed plates were incubated under 25 °C 12-h light–20 °C 12-h dark cycle. Fungal colonization on seedlings was rated 14 days post-plating using the following rating scales: 0 = no lesions or mycelium, 1 = minimal lesions or mycelium growth, 2 = significant lesions or mycelium growth, 3 = severe lesions or mycelium growth, 4 = total colonization. A disease severity index was calculated as reported by Rojas et al. (2017) and statistical analyses were conducted using JMP® Pro 16.0.0 using analysis of variance (ANOVA).

Under growth chamber conditions, a seed cup assay was carried out using the same isolates as described in the *in vitro* experiments to test the germination and susceptibility of different cover crop species. Inoculants were prepared in sterilized millet in a flask, 3–4 plugs from the 7-day old culture of each isolate were transferred into a flask containing sterile pearl millet, and flasks were incubated at room temperature for 14 days. The millet inoculum was mixed every other day for full colonization.

The seed cup assay was performed using a 355ml foam cup with 4 drainage holes in the bottom. Each cup contained 200g of well-mixed pre-moistened vermiculite at water holding capacity, 5g of millet either colonized with TRD_AR or MSU_SB201401, or uncolonized sterile millet as the control. The inoculum was covered with vermiculite and 6 surface-sterilized seeds were placed in each cup and covered with another layer of vermiculite. For each cover crop species, there were 3 replicates per treatment. Cups were placed in trays in the growth chamber with 25 °C 12-h light–20 °C 12-h dark cycle and trays were watered every other day. Stand count, plant weight, and root weight data were collected after 14 days to determine the pathogenicity of the two *Xylaria necrophora* isolates on different cover crop species. Statistical analyses were conducted using JMP® Pro 16.0.0 using analysis of variance (ANOVA), followed by mean separation using Tukey's honestly significant difference.

Results and Discussion

Taproot decline was identified in 3 additional counties in 2020 bringing the total counties where it has been found to 14 (Fig. 1). Seed treatment and variety trials planted at the Rohwer Research Station yielded inconsistent results (data not shown). This was due to the disease severity of the trials being low and disease occurrence throughout the trials best described as sporadic. Due to significant rainfall, these trials were planted later than originally planned–which could be a significant learning experience about this disease and future trials. Typically, TRD has been more severe in lighter soils, silt loams, and sands. It is unclear why at this point.

However, this could be due in part to these fields being planted sooner, because of them drying faster from the frequent spring rains in Arkansas. While we do not have sufficient data to prove this, it is a plausible theory. Future TRD trials will be planted as early as possible in the spring, most likely before and no later than mid-April, to simulate the earlier planted soybean fields where this disease may be more severe due to lower soil temperatures at planting.

Soybean planted into soil samples from the Chicot County field showed significant differences between different sample points. Low germination rate was observed in soil samples collected from transect C1 (Fig. 2) at both day 7 and day 14 post-planting. Plant height and root weight parameters showed similar behavior with the germination data indicating that the disease severity was highly variable across the field. This finding is consistent with the clustered appearance of symptoms commonly observed in commercial fields and is also consistent with the typical occurrence of soilborne diseases.

All cover crop species tested in the *in vitro* study were susceptible to both *Xylaria necrophora* isolates. Radish was the most susceptible cover crop among all the cover crop species (Table 1. $P < 0.0001$), followed by the mustard. Blue lupine was the least susceptible to colonization, followed by wheat, vetch, and winter pea. Isolate TRD_AR was the most aggressive of the two isolates tested, exhibiting colonization on all cover crop seedlings when compared to MSU_SB201401 ($P = 0.0008$).

In seed cup assays, the lowest germination rate was observed on mustard (Fig. 3. 16.7% when inoculated with either TRD_AR or MSU_SB201401) and radish seeds (38.9% for TRD, 50% for MSU_SB201401). The remaining cover crops were not different from each other, with a germination percent ranging from 67% to 100%. When comparing the whole plant weight and root weight, wheat, rye, black oat, and barley were the least affected by the *Xylaria* colonization (Fig. 3). Both inoculation treatments were different from the non-inoculated control ($P < 0.0001$), but there were no significant differences between cover crops inoculated with *X. necrophora* isolates TRD_AR and MSU_201401. Both isolates were similarly aggressive in all cover crops (Fig. 3).

Practical Applications

There is still much to learn about how to manage taproot decline. While this disease is becoming more widespread across Arkansas, its impact is only sometimes severe which in some ways makes management more difficult. These studies reinforce TRD behaves like a soilborne disease, meaning that it will likely be perennial, occurring year after year in a similar spot in fields.

Yield losses in these areas in fields will be more severe where susceptible varieties are grown, reinforcing the need to determine which varieties are more susceptible than others.

These studies also indicate that cover crop species could serve as a host in some fields and may increase the inoculum potential for the following soybean crop. As our understanding of this disease has increased, future studies for TRD will incorporate multiple cover crop species, different planting dates, seed treatment, and in-furrow fungicides, and varieties to help formulate an integrated approach for management.

Acknowledgments

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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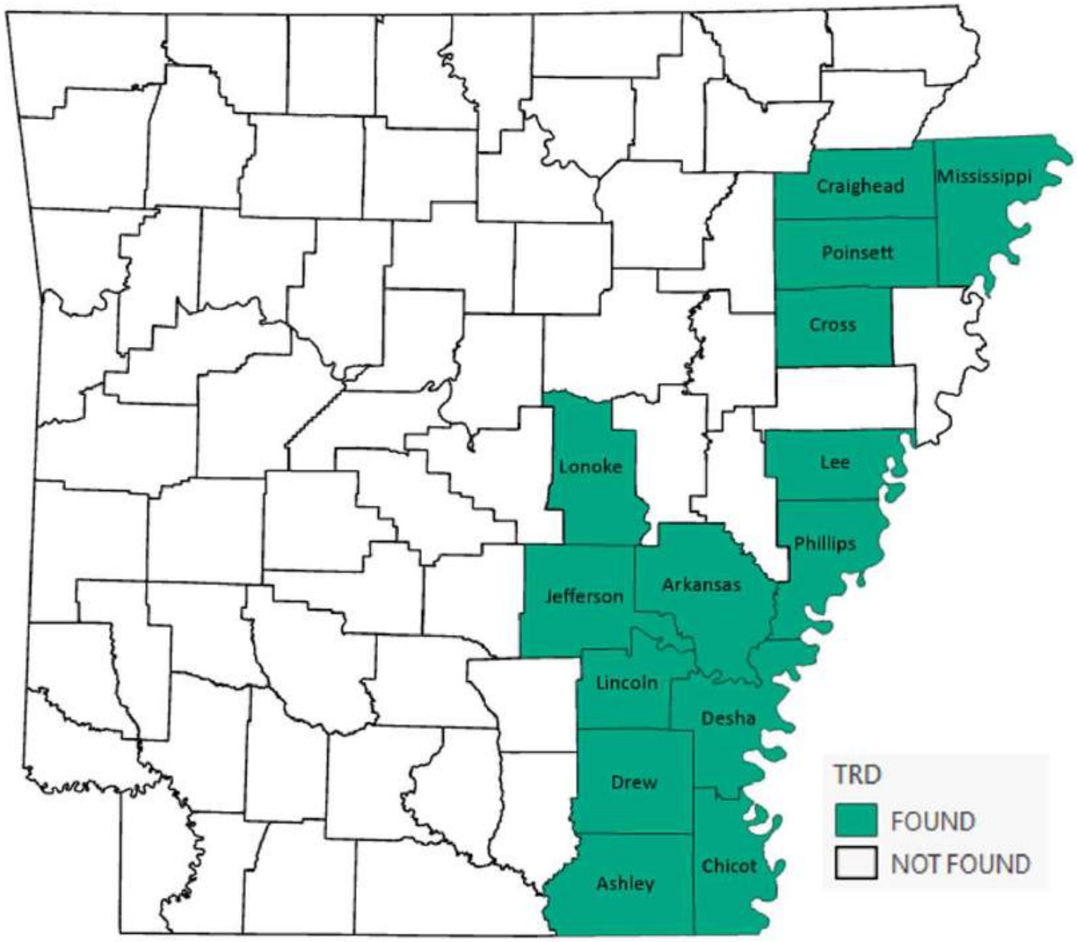

Fig. 1. The current county distribution of taproot decline in the soybean production areas of Arkansas.

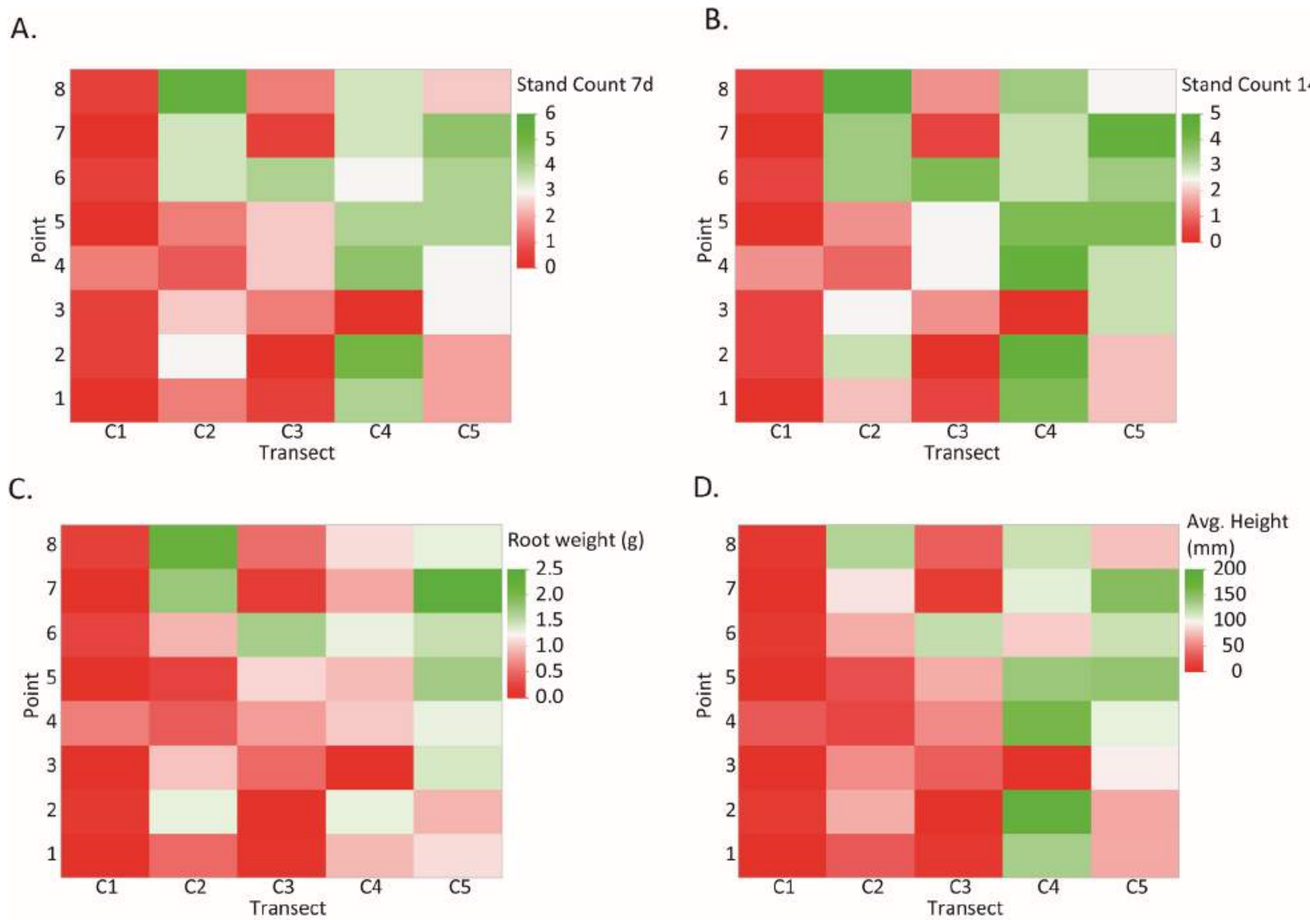

Fig. 2. Heatmap of representing (a) stand counts at 7 days post-planting; (b) stand count 14 days post-planting; (c) Root weight and (d) Shoot height at 14 days of plant growth. Soil collected in a grid sampling strategy was used for seedling assays in growth chambers. Points are ordered based on the order collected.

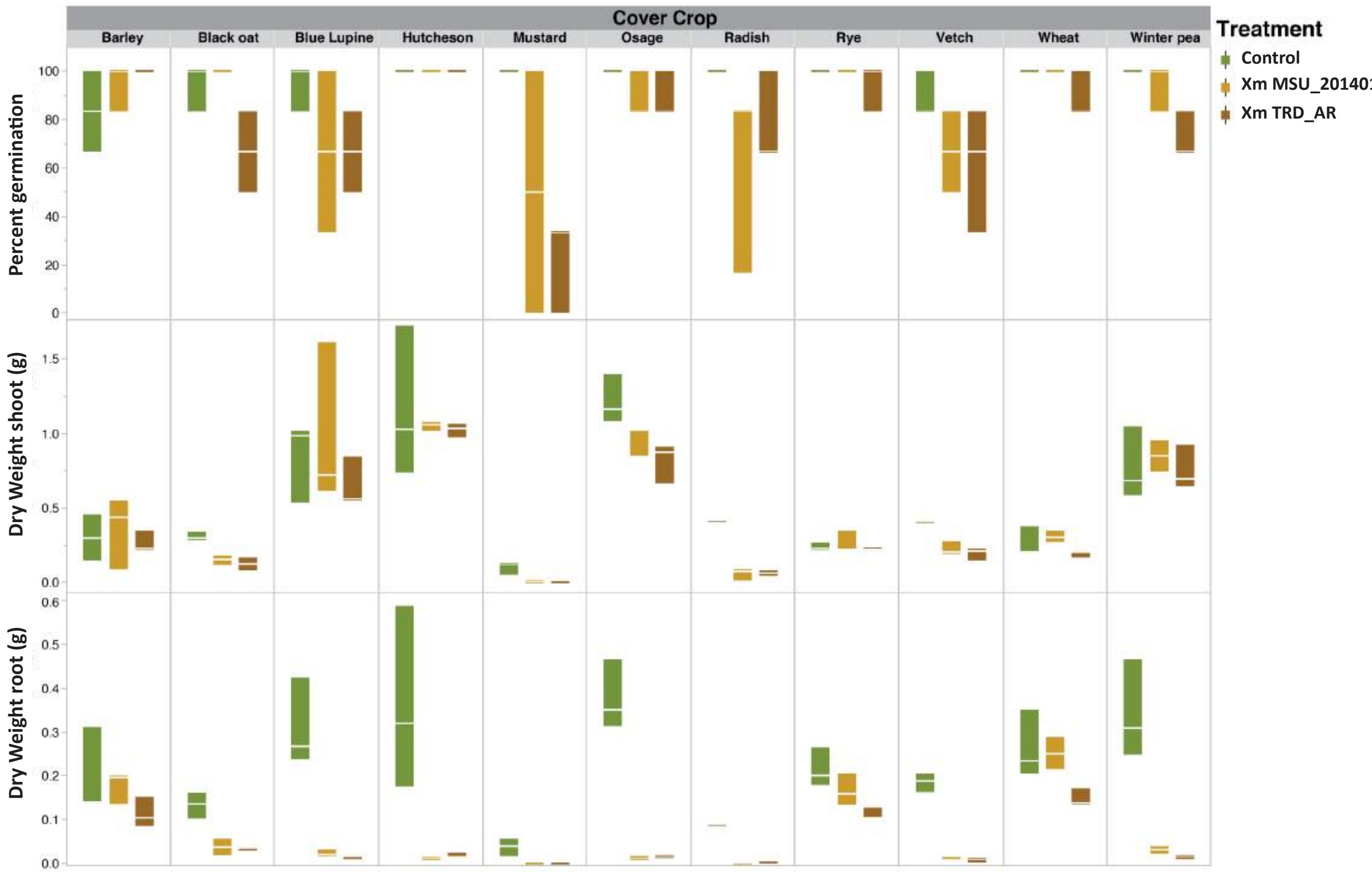

Fig. 3. Box plot of percent germination, dry shoot weight and dry root weight for cover crops challenged with *Xylaria necrophora* isolates MSU_201401 and TRD_AR in a seedling cup assay.

Field Performance of Two New Commercially Available Premix Fungicides Labeled for Control of Foliar Diseases Occurring on Soybean

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

Abstract

Eleven large block foliar fungicide trials were established in soybean fields in 10 Arkansas counties in 2020. The objectives of this work were to determine the efficacy of 2 fungicides new to the market and to evaluate the yield impacts associated with different foliar diseases that might occur. The severity of foliar diseases such as Septoria brown spot (*Septoria glycines*), Cercospora leaf blight (*Cercospora flagellaris*), target spot (*Corynespora cassiicola*), frogeye leaf spot (*Cercospora sojina*), soybean rust (*Phakopsora pachyrhizi*), and aerial blight (*Rhizoctonia solani* AG 1-IA) were determined at each location. Fields maturing later in the season tended to have more severe diseases. Both Miravis® Top and Revytek® provided good control of foliar diseases and protected yield where these diseases were most severe.

Introduction

Soybeans, [*Glycine max*, (L.) Merr.], are grown on approximately 3.3 million acres in Arkansas generating an estimated $1.7 billion annually (Ross, 2017). Foliar diseases are widespread in the state's production area and can cause yield losses, impact grain quality, and reduce farm profit. Management recommendations for foliar diseases involve cultural practices, resistant varieties, and foliar fungicide applications if warranted after scouting (Faske et al., 2014). Unfortunately, due to the high number of new soybean varieties that come to the market each year, multi-year data confirming resistance or susceptibility to the most common foliar diseases occurring in Arkansas is almost impossible to collect every year. Therefore, it is important to continually determine fungicide efficacy and determine the yield loss each disease has the potential to cause across a range of locations, planting dates, and varieties to understand the economic impacts of the most common foliar diseases and management options for each.

Procedures

Eleven large block foliar fungicide trials, ranging in size from 15 to 55 acres, were established in soybean fields in 10 Arkansas counties in 2020. Treatments for each trial were Miravis® Top, which contains the active ingredients pydiflumetofen (a succinate dehydrogenase inhibitor, SDHI) and difenoconazole (a demethylation inhibitor, DMI or triazole) from Syngenta (The Syngenta Group, Basel, Switzerland), applied at 13.7 fl oz/ac; Revytek®, which contains the active ingredients pyraclostrobin (a quinone outside inhibitor, QoI or strobilurin), fluxapyroxad (SDHI), and difenoconazole (DMI) from BASF (BASF SE, Ludwigshafen, Germany) applied at 8 fl oz/ac; and a nontreated control. Trials had 3 replications and treatments were arranged in a randomized complete block design (Fig. 1). Fungicides were applied at R2–R5 (Ross et al., 2021) with a ground-driven sprayer equipped with a 30-ft boom delivering 10 gal/ac at 40 psi using TeeJet XR11002VS tips (Spraying Systems Co, Glendale Heights, Ill.) at 5.0 mph. Five to 10 points, depending on the trial, were marked by GPS approximately equidistant throughout each block, and disease incidence and severity were determined in a 1.5-meter radius around each point at fungicide application and again at R6. Aerial blight incidence was determined by counting the number of diseased patches (foci) within a 5-meter radius of each GPS point. Aerial imagery was acquired using a DJI Inspire 1 small unmanned aerial system (DJI, Shenzhen, China) equipped with a multispectral sensor (Sentera Inc., Minneapolis, Minn.) capturing 5 individual bands (red, green, blue, red edge, and near-infrared) on the day of application and the day disease levels were determined. Grain was harvested with the local farmer's combine and yield monitor and made available for analysis. Yields were adjusted to 13% moisture by volume, buffered by application blocks and the field boundaries, and outliers removed using the interquartile range method before analysis. Data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Tukey's honestly significant difference test (HSD) at $P = 0.05$.

All analyses and a report for each trial location were completed in an automated model in ArcGIS Pro 2.4 (ESRI,

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Redlands, Calif.) using standard tools and custom script tools (developed using Python 3.6.8 or R 4.0.2). Weather and soils data, as well as high-resolution field images, were included in the reports distributed to each cooperating farmer and county agent.

Results and Discussion

In all, 6 different fungal diseases were rated across the trial locations. Septoria brown spot, caused by *Septoria glycines*, was rated at 6 locations, aerial blight, caused by Rhizoctonia solani AG 1-IA, was rated at 1 location, frogeye leaf spot, caused by *Cercospora sojina*, was rated at 1 location, target spot, caused by *Corynespora cassiicola*, was rated at 5 locations, soybean rust, likely caused by *Phakopsora pachyrhizi*, was rated at 1 location, and Cercospora leaf blight, likely caused by *Cercospora flagellaris*, was rated at 1 location. Yields were provided for 9 of the 11 trials. In trials where yields were provided, 2 were not analyzed due to herbicide drift and a suspected herbicide misapplication. Yields for the trials ranged from 33.8 bushels per acre (bu./ac) to 71.1 bu./ac (Table 1). Of the 3 trials where soybeans were R3 in mid-June, 1 had a significant yield response by fungicide treatment where brown spot was severe (Table 2). Of the 4 trials where soybeans were R3 in mid to late July and early August, 3 of the 4 had a significant yield response by fungicide treatment where foliar diseases (frogeye leaf spot, aerial blight (Table 3, Fig. 2), and soybean rust (Table 4) were moderate to severe (Fig. 3). These results point to the value of on-farm trials at various locations in the production area to determine product efficacy and yield impact of several different foliar diseases. Additionally, these results suggest foliar disease pressure is likely to increase on soybean fields progressing through the reproductive stages later in the normal growing season.

Practical Applications

Foliar diseases tended to be more severe in fields where the soybean crop was moving through the reproductive stages later in the season. Fungicides added value to the crop above their application costs in these fields more often than in those moving through reproductive stages earlier in the year. Moving forward, and due to the differences in maturity groups that may be planted in Arkansas, MG 3–MG 5, terminology should shift from defining fields as early or late-planted to early maturing or later maturing when gauging foliar disease pressure (as a group 3 would mature sooner than a group 5 planted at similar times). Due to historical weather patterns, group 5 varieties may have a higher likelihood of increased foliar disease pressure because they will be maturing more slowly. As a rule, one should consider the use of a fungicide more likely to be profitable if a field is in the pod fill stage during the last part of August or into September.

Both products were effective on all diseases rated across locations, which likely speaks to the activity of triazole and SDHI chemistries applied as components of pre-mix products. Due to the genetic resistance of fungal pathogens, strobilurin chemistries are no longer effective on some diseases. This should be considered when using a product that has a strobilurin component and one other, either triazole or SDHI which is likely resulting in a reliance on a single mode of action to control soybean diseases.

Acknowledgments

The authors appreciate the cooperating farmers for granting space for these studies on their farms as well 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. The authors would also like to acknowledge the cooperating county agents Grant Beckwith – Arkansas County, Kurt Beaty – Jefferson County, Steven Stone – Lincoln County, Clay Gibson – Chicot County, John Farabough - Desha County, Amy Carroll – Prairie County, Jan Yingling – White County, Robert Goodson – Phillips County, Kevin Norton – Ashley County, and Keith Perkins – Lonoke County.

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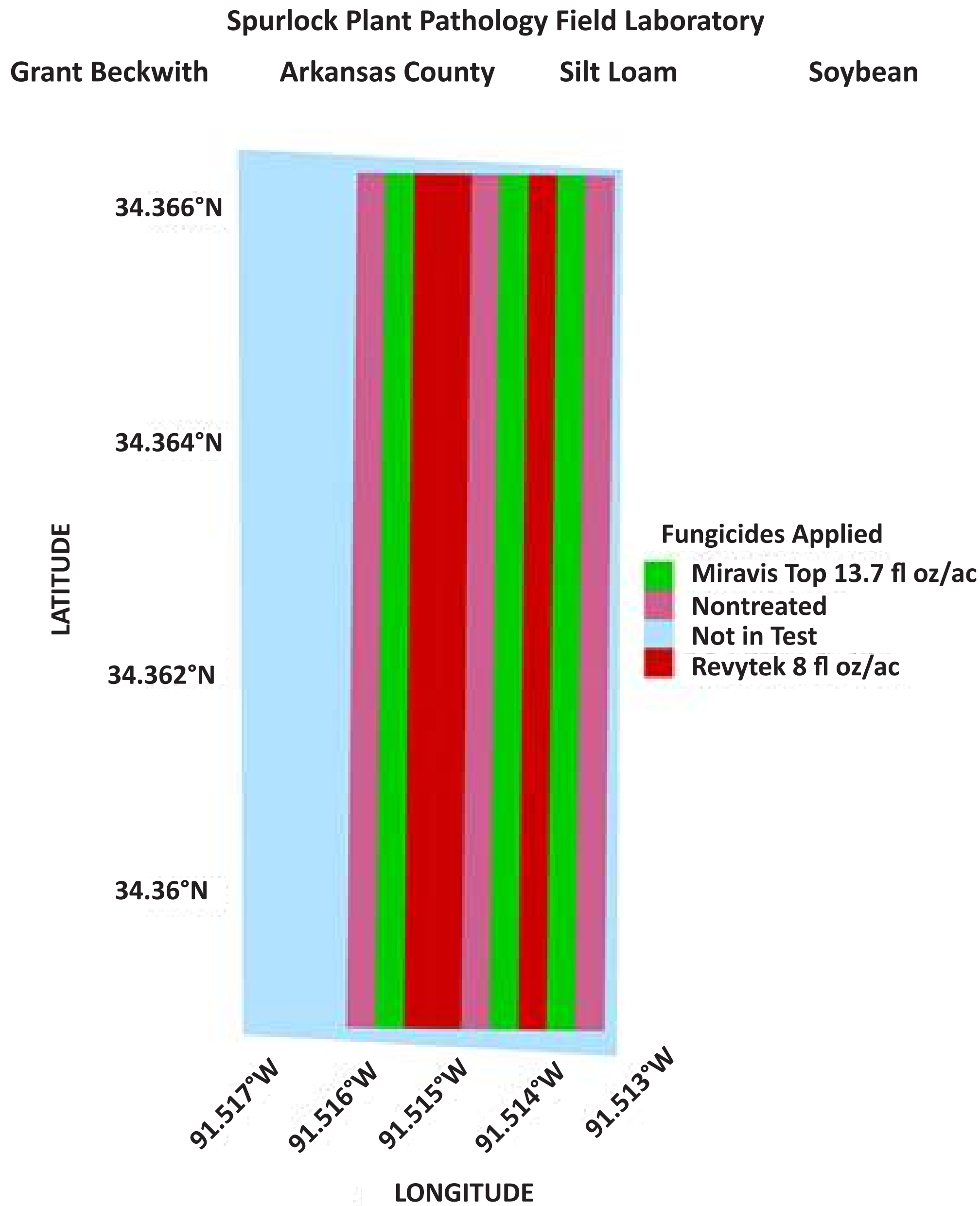

Fig. 1. The plot map of the trial located in Arkansas County. The treatments were arranged in a randomized complete block design extending almost the length of the field. The entire field is represented in the figure. The trial encompassed approximately 55 acres of the 79-acre field.

Table 1. Summary of fungicide trial results, 2020.

Trial	Application date (Growth stage)	Diseases rated	Disease levels	Treatment response	Average yield
Lincoln	June 16 (R2.5)	Target spot	low	*NS* †	yield data not recorded
Lincoln / Jefferson	June 16 (R3)	Septoria brown spot Target spot	low low	* *NS*	60.1 bu./ac ‡
Lonoke	June 17 (R2.5)	Septoria brown spot	high	**	33.8 bu./ac***
Chicot	June 18 (R3)	Septoria brown spot	low	*	71.1 bu./ac
Rohwer	June 18 (R3)	---	---	---	herbicide drift
Phillips	June 30 (R3)	Target spot	low	*NS*	yield data not recorded
Desha	July 14 (R5)	Target spot	low	*	herbicide misapplication
White	July 15 (R4)	Target spot	low	*	49.4 bu./ac
Arkansas	July 23 (R2)	Cercospora leaf blight Aerial blight	low high	*NS* **	55.7 bu./ac ***
Prairie	August 4 (R2.5)	Soybean rust	high	**	70.1 bu./ac *
Ashley	August 10 (R2.5)	Frogeye leaf spot	moderate	*NS*	51.2 bu./ac*

† Data were subjected to analysis of variance. Significance of response levels are symbolized by * = 0.05, ** = 0.01, and *** < 0.0001. *NS* = no significant response.

‡ Yields were adjusted to 13% moisture content for comparison. Harvest data was provided from yield monitors located on the cooperating farmers' combines.

Table 2. Response of Septoria brown spot to fungicide treatments across locations, 2020.

Trial	Product rate/acre	Septoria brown spot incidence †	Septoria brown spot severity ‡	Yield ¶
	fl oz/ac	--------------------------%----------------------		bu./ac
Chicot	Miravis® Top 13.7	23.94 b §	7.06 b	71.1 a
	Nontreated	48.33 c	18.33 c	70.8 a
	Revytek® 8	8.06 a	2.22 a	72.5 a
Lonoke	Miravis Top 13.7	7.29 a	2.54 a	37.4 a
	Nontreated	85.41 c	70.83 c	28.5 b
	Revytek 8	27.08 b	15.04 b	37.3 a
Lincoln / Jefferson	Miravis Top 13.7	17.22 b	2.34 b	60.5 a
	Nontreated	26.00 c	4.34 c	58.8 a
	Revytek 8	9.34 a	1.67 a	59.3 a

† Disease incidence ratings were based on a percentage scale where 0 = no disease and 100 = all plants in the rating area with disease.

‡ Disease severity ratings were based on a percentage scale where 0 = no disease and 100 = dead plants.

§ Columns followed by the same letter are not statistically significant at *P* = 0.05 as determined by Tukey's honestly significant difference test (HSD).

¶ Yields adjusted to 13% moisture content for comparison. Harvest data was provided from yield monitors located on the cooperating farmers' combines.

Table 3. Response of aerial blight to fungicide treatments at the Arkansas County trial, 2020.

Product rate/acre	Aerial blight †	Yield §
fl oz/ac	per 5 meters	bu./ac
Miravis Top 13.7	1.8 b ‡	63.8 a
Nontreated	8.0 c	51.8 b
Revytek 8	0.5 a	63.9 a

† Disease incidence ratings were based on the number of aerial blight patches (foci) in a 5-meter area around each rating point.

‡ Columns followed by the same letter are not statistically significant at P=0.05 as determined by Tukey's honestly significant difference test (HSD).

§ Yields adjusted to 13% moisture content for comparison. Harvest data was provided from yield monitors located on the cooperating farmers' combines.

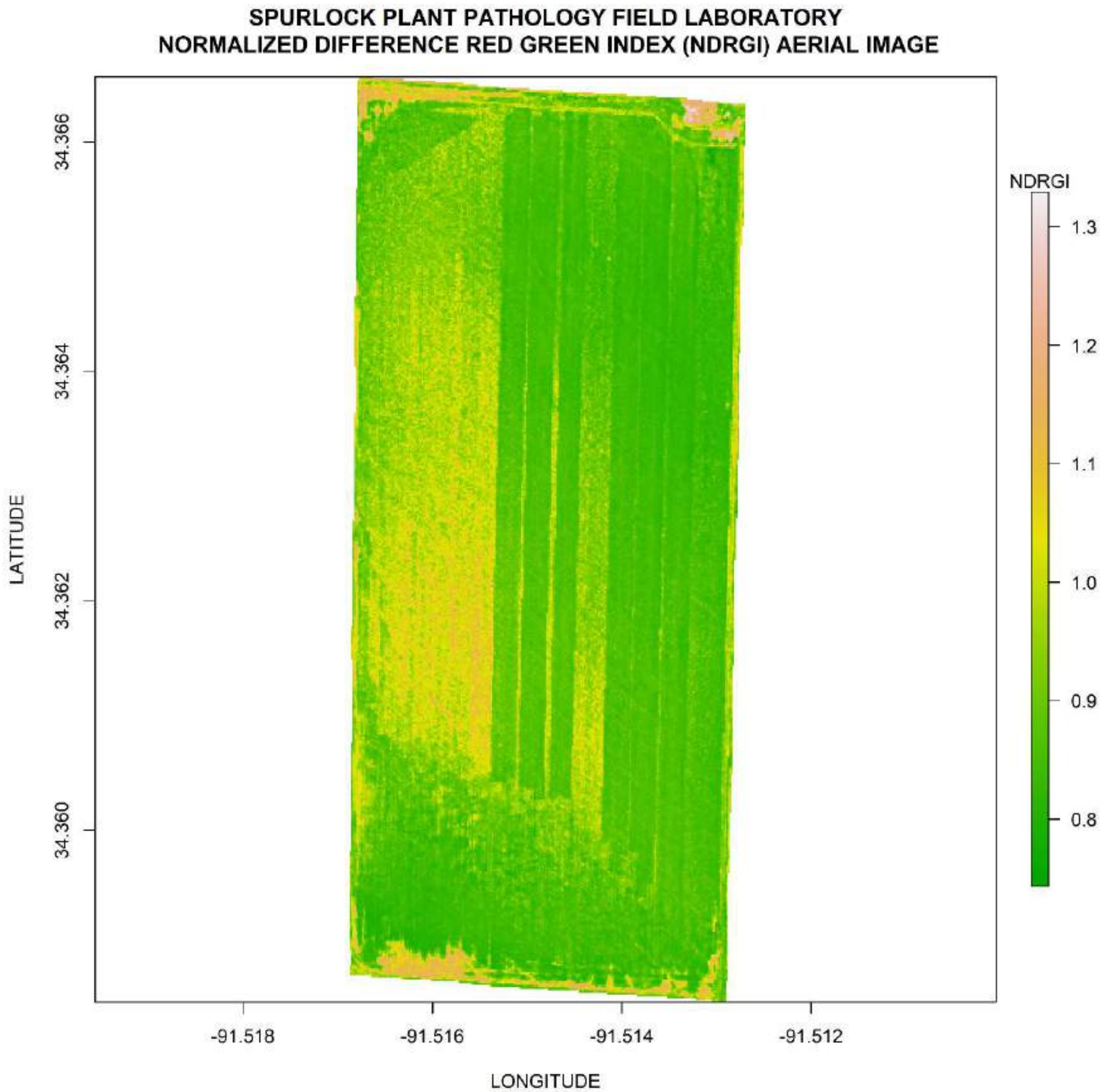

Fig. 2. Imagery collected at the time of disease evaluations (R6). The NDRGI image indicates the fungicide blocks as greener than the untreated controls. More severe aerial blight occurred in the red-orange areas where the fungicide application strips appear greener by contrast.

Table 4. Response of soybean rust to fungicide treatments at the Prairie County trial, 2020.

Product rate/acre	Soybean rust incidence[†]	Soybean rust severity [‡]	Yield [¶]
fl oz/ac	------------------------------------%	----------------------------------	bu./ac
Miravis Top 13.7	3.3 a [§]	2.0 a	71.1 a
Nontreated	2.0 a	2.0 a	70.4 b
Revytek 8	78.0 b	42.0 b	68.9 c

[†] Disease incidence ratings were based on a percentage scale where 0 = no disease and 100 = all plants in the rating area with disease.

[‡] Disease severity ratings were based on a percentage scale where 0 = no disease and 100 = dead plants.

[§] Columns followed by the same letter are not statistically significant at P=0.05 as determined by Tukey's honestly significant difference test (HSD).

[¶] Yields adjusted to 13% moisture content for comparison. Harvest data was provided from yield monitors located on the cooperating farmers' combines.

Fig. 3. Images from locations where disease was most severe. A) Septoria brown spot that had caused disease in the upper third of the soybean canopy at the trial in Lonoke County. B and C) Aerial blight causing severe defoliation and plant death in the trial at Arkansas county. D) Soybean rust causing chlorosis and defoliation in the trial at Prairie County.

PEST MANAGEMENT: DISEASE CONTROL

New Tools to Create Bioherbicides for Palmer Amaranth (Pigweed)

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Abstract

Bioherbicides are organisms that selectively kill specific plant species. Bioherbicides are an attractive alternative to conventional herbicides because of their potential efficacy, specificity, lower cost, and environmental sustainability. However, the commercial development of bioherbicides has been hampered by the innate limitations of many bioherbicide candidates, such as large-scale production obstacles, reduced fitness, or unacceptable host range. Recently, exciting new tools have become available to overcome such limitations. Specifically, the advent of next-generation DNA sequencing, bioinformatics, and genome editing has the potential to revolutionize bioherbicide development. In this project, we developed a workflow integrating the three aforementioned tools to optimize bioherbicide development for the control of Palmer amaranth (e.g., Palmer pigweed; *Amaranthus palmeri*), an invasive weed that is highly problematic for Arkansas soybean producers. While the workflow described herein was developed specifically for bioherbicides targeting Palmer pigweed, it can be applied with minor modification to bioherbicide development for a broad range of agriculturally important weed species.

Introduction

Bioherbicides have tremendous potential for effective, environmentally sustainable management of noxious weed pests in Arkansas and beyond. By definition, bioherbicides are living organisms (often microbes) or their metabolites that have been selected and/or engineered to selectively kill specific unwanted plants, such as weeds or invasive species (Cordeau et al., 2016). The University of Arkansas System Division of Agriculture is known internationally for pioneering research in bioherbicide development, dating to the 1970s when Collego™ was developed into the world's first EPA-registered bioherbicide.

The impetus for Collego™ was the discovery of a natural strain of *Colletotrichum gloeosporioides* f.sp. *aeshynomene* (Cga) that was highly virulent on northern joint vetch (*Aeschynomene virginica* L.), a weed commonly associated with rice production in Arkansas (Templeton et al., 1979). Cga induces lethality in northern joint vetch by attacking and ultimately girdling stems, which rapidly causes plant death without affecting rice or other crop plants in the vicinity (TeBeest et al., 1992).

Historically, biological control of invasive weeds has relied on two distinct strategies (Templeton et al., 1979). In the first, termed the 'classical' tactic, a pathogen is imported from the geographical area where a weed originated and is released to become endemic where the weed has become newly established. This approach assumes that the introduction and establishment of a weed's naturally co-evolved pathogens will reduce and potentially eliminate invasive weed populations. While this approach has the long-term potential to suppress weed populations, the time required for efficacy is often considered too long for pressing agricultural concerns. In the second approach, termed the 'bioherbicide' tactic, microbes that aggressively suppress or kill a given weed are applied like conventional, chemical herbicides. This approach has the advantages of rapid, consistent control, with the potential drawback of requiring consistent, commercial production of microbial propagules for repeated applications over time. Collego™ is an example of the bioherbicide tactic applied successfully to create a commercially viable weed control product.

After the success of Collego™, research programs worldwide adopted the bioherbicide tactic to target a wide variety of weed species in diverse agricultural systems. Unfortunately, these efforts were met with many failures and relatively few successes (Cordeau et al., 2016). To date, 15 bioherbicides based on living microbes have reached market release, and only two of these were still available commercially by 2020 (Morin, 2020).

This low number is not a reflection of market demand; by 2025, the international herbicide market is projected to approach $8 billion in annual value (Yenduri and Sumant, 2018). The gap between the international market demand for herbicides and the remarkably low number of successful bioherbicides underscores the fortuitous nature of the discovery of Cga and other existing biological control agents, the need to apply new tools and approaches to the discovery process underlying bioherbicide development, and the exciting potential for bioherbicide market expansion in future years.

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A recent flood of new genetic technologies is poised to dramatically accelerate bioherbicide discovery and development. In the past 10–15 years, 3 powerful new tools have emerged that will specifically augment bioherbicide research and development. First, the advent of next-generation DNA sequencing has made it possible to obtain DNA sequence information more quickly and inexpensively than previously dreamed imaginable. Second, the exponential expansion of bioinformatics tools has made it possible to apply computational genomics to bioherbicide development. Third, genome editing has emerged most recently as a powerful tool to modify, with great precision, the genomes of biocontrol agents in a non-transgenic manner. Despite the tremendous potential of these tools to redefine the discovery and refinement of biological control organisms, they have not yet been fully applied to the development of new bioherbicides.

In this paper, we report a novel approach to the bioherbicide tactic by applying next-generation sequencing, bioinformatics, and genome editing to bioherbicide development. Our target is Palmer amaranth (*Amaranthus palmeri*), a noxious weed that is problematic for soybean [*Glycine max* (L.) Merr.] producers throughout Arkansas. However, the process we describe could be used to expand (or limit) the host range and increase the lethality of a broad range of biocontrol organisms on diverse weed species. Because our approach to create bioherbicides is non-transgenic, the resulting 'optimized' strain(s) can be considered non-GMO, and thus regulatory and compliance guidelines are less stringent, and full development of a commercially successful product is more likely. This integrated workflow to accelerate bioherbicide development could be highly impactful across the broader landscape of weed control in agriculture.

Procedures

Identify Potential Bioherbicide Organisms. Our primary focus was to identify and isolate naturally occurring pathogens of Palmer pigweed. We focused primarily on fungal pathogens because of their amenability to genetic manipulation and natural inclination towards production on a commercial scale. Diseased Palmer pigweed plants were collected throughout Arkansas from 2017–2019. We selected pathogens from infected stems, petioles, leaves, seeds, seedlings, and roots of Palmer pigweed. Pathogens were isolated following protocols described by Pyenson and Barke (1976). To confirm that fungal isolates were pathogenic on Palmer pigweed (as opposed to non-pathogenic saprophytes), greenhouse and/or growth chamber inoculations were performed following standard protocols. During these evaluations, virulence was assessed by measuring various parameters including the number and size of lesions formed, seedling and/or juvenile plant mortality, and other inductions of reduced plant fitness, such as wilting or reduced fertility.

Identify Potential Commercialization Deficiencies. Since the ultimate goal of this process is to create commercially viable bioherbicides, potential obstacles to large-scale production and field-scale application were evaluated early in the workflow. Candidate bioherbicide organisms were assessed for their ability to produce reproductive propagules (primarily asexual spores, or conidia), viability and stability during short- and long-term storage, growth rate, and pilot-scale suitability for batch fermentation as a mechanism of future large-scale production.

Create Mutants of Candidate Bioherbicide Organisms. The creation and evaluation of mutants of candidate bioherbicide organisms are crucial to dissect various traits associated with commercial optimization. In this project, mutants were created with two approaches. In the first, a reporter construct containing a selectable marker (antibiotic resistance) and a screenable marker (expression of green fluorescent protein, GFP) was randomly inserted into the genome of the candidate organism. In this approach, a genetic transformation protocol was utilized as described by Li et al. (2013). In the second approach, chemical mutagenesis utilizing ethyl methanesulfonate (EMS) was utilized to induce a large number of point mutations throughout the genome. The protocol for EMS mutagenesis of potential bioherbicide organisms was adapted from Li et al. (2019).

Screen for Relevant Phenotypes. Mutations of particular interest can be grouped into two broad categories: 1) enhanced lethality and 2) improved commercial production. For enhanced lethality, mutants were screened on Palmer pigweed as described above and pathogenicity phenotypes were compared to the wild-type strain. For improved commercial production, rapidly screenable phenotypes such as sporulation were evaluated in parallel with lethality phenotypes. Comparatively more labor-intensive and/or time-consuming screens, such as long-term storage viability, were prioritized for the most promising candidate organisms.

Sequence Genomes of Mutants to Identify Genes of Interest. Advances in next-generation DNA sequencing have now made it possible to sequence fungal genomes rapidly and inexpensively. This, in turn, allows the rapid identification of genes underlying phenotypes of interest in mutants. Genome sequencing was performed by BGI Americas (Cambridge, Mass.) on a DNBseq platform. Raw data were processed with Qiagen CLC Genomics Workbench 20.0 for quality control analyses, de novo genome assembly, and comparative genomic analyses and alignments.

Insertion sites of reporter constructs were determined through BLAST (basic local alignment search tool) searches with the sequence of the construct as the query. EMS-induced point mutations were identified through SNP (single nucleotide polymorphisms)-calling by comparison to the wild-type reference strain. SNPs representing EMS-induced transition mutations were mapped to the open reading frames and potential regulatory regions of genes. Genes containing premature stop codons, non-synonymous mutations, promotor mutations, intron/splicing disruptions, and 3' or 5' UTR (untranslated regions) disruptions were prioritized for further analysis.

Modify Genes of Interest in the Original, Wild-Type Strain Through Genome Editing. Genes associated with enhanced lethality or improved commercial production, as identified through the mutant screen and genome sequencing, were modified in the wild-type strain via non-transgenic, transient expression of the CRISPR-Cas 9 system for genome editing. Constructs for genome editing were designed to induce point mutations (to recapitulate EMS-induced mutations) or deletions (to recapitulate insertions of reporter constructs). Protoplast-mediated delivery of CRISPR ribonucleoprotein complexes was utilized for non-transgenic modification.

Results and Discussion

The identification and collection of potential bioherbicide organisms for Palmer pigweed have been described previously (Martin et al., 2020). The most promising isolates to date belong to the genus Colletotrichum, a group of fungi that have many natural properties lending themselves to bioherbicide development (Charudattan, 2001). We have prioritized isolates that are highly virulent on young plants (< 4-in. tall), as lethality at this stage is crucial for effective, field-level Palmer pigweed management. We also have confirmed that candidate bioherbicide organisms have a highly restricted host range, in that they are pathogens against Palmer pigweed but not crop species or other plants within the environment.

When assessing potential commercialization deficiencies, we were fortunate that our most promising isolates generally exhibited favorable traits regarding reproduction, stability, and amenability to batch fermentation. However, some traits are desirable to continually improve, such as conidiation and the storage viability of batch-fermented, ready-to-apply bioherbicide products. Future efforts will focus on these areas and any other traits that emerge as potential commercial limitations.

To create mutants of candidate bioherbicide organisms, we utilized 2 distinct approaches, both with different advantages. First, we adapted an *Agrobacterium*-mediated transformation protocol (Li et al., 2013) for the highly efficient transformation of the above-referenced isolates. With this approach, approximately 250–300 randomly tagged mutants are consistently obtained per transformation event. The expression of GFP in tagged mutants is noted in Fig. 1. This approach has the advantages of consistency, easy adaptation to a wide variety of fungal organisms, and genomic disruptions are 'tagged' with the reporter construct, thus making the underlying gene of interest easy to identify. Disadvantages are that it requires a degree of technical expertise to perform and the generation of mutants is somewhat slower than other approaches. Additionally, this approach generally disrupts 1–3 genetic loci per mutant; while this makes genetic dissection easier for mutants of interest, the presence of fewer mutations per individual mutant means that more mutants need to be screened to discover phenotypes of interest. In the second approach, EMS was utilized as a chemical mutagen to create a large number of point mutations per individual isolate. This approach easily generates 1000+ mutants per mutagenesis event in our hands, with a frequency of inducing mutations in as high as 1 out of every 100 genes in the genome per mutant (not including mutations in intergenic space). Advantages of EMS mutagenesis include low cost, rapid production of large numbers of mutants, minimal technical skill or equipment required to generate mutants, and a large number of mutations per mutant, thus increasing the odds of identifying a phenotype of interest. A key drawback is that a larger number of mutations per mutant strain can complicate the identification of the gene underlying the trait of interest. However, this disadvantage is offset to some degree by the sheer number of mutants that can be screened; independent mutants with the same phenotype can form a subpopulation for association mapping.

Given the large number of mutants required to fully dissect genetic pathways underlying virulence and other traits, a rapid, simple pathogenicity screen is essential for progress. Another key consideration is the high level of genetic diversity in Palmer pigweed. As a dioecious plant, Palmer pigweed has male and female plants and thus must outcross to reproduce, which increases genetic diversity. To account for these issues, we developed and evaluated a seedling assay in which young Palmer pigweed plants (7–10 days after emergence) were wound-inoculated with mutants in a high-throughput manner (Fig. 2). For each mutant, 8 Palmer pigweed plants grown from seed collected at multiple locations (to represent genetic diversity within Arkansas) were inoculated with homogenized mycelium of mutant strains adjusted to a standard concentration. Necrosis induced by each strain was quantified as the average lesion length on stems plus or minus the standard error of the mean. For mutants that induced higher levels of necrosis, the experiment was repeated multiple times to confirm results. This approach allowed for as many as 2000 mutant strains to be evaluated each week. Enhanced virulence was observed in approximately 0.1% of mutant strains.

Whole-genome resequencing of mutants of interest was performed at approximately 50x genomic coverage. The DNBseq approach generates short sequence reads, which are ideal for covering gene space cost-effectively. The wild-type strain of each bioherbicide candidate was initially sequenced at 65x genomic coverage to create a reference genome assembly so that mutations in mutants of interest could be mapped easily. For mutants created via *Agrobacterium* transformation, plasmid sequences were detected as insertions, or, in some cases, reads from flanking sequences had to be manually curated and anchored onto the reference assembly. For mutants created via EMS, most mutations were point mutations as expected, although some mutants (< 10%) also possessed indels and, rarely, chromosomal translocations. Notably, the very recent improvement of alternative, long-read sequencing technologies may lead to a readjusted approach regarding the construction of reference genome sequences from wild-type bioherbicide candidates, as 'finished' genomic references would have potential advantages over short-read assemblies.

The modification of candidate genes via genome editing to enhance virulence and improve commercial production is actively underway. Current research efforts are focused on optimizing the delivery of genome editing components into fungal cells, efficiently regenerating and screening genome-edited strains, and eliminating off-target effects within the genome. We are also exploring a form of 'trait stacking' in which we edit multiple genes simultaneously to save time and expenses during the generation of genome-edited strains.

While this project has exclusively focused on creating bioherbicides for Palmer pigweed, it is important to note that the workflow described above can be applied to virtually any weed pest of agricultural production. In Arkansas, this workflow has considerable promise to be applied to other problematic weeds, including but not limited to, coffeebean (*Hemp sesbania*), bindweed (*Convolvulus arvensis*), and Northern jointvetch (*Aeschynomene virginica*).

Practical Applications

Bioherbicides have tremendous potential to control Palmer pigweed and other noxious weeds in Arkansas. Advantages of bioherbicides include high levels of weed control, specificity, environmental sustainability, and cost-effectiveness. The development of bioherbicides against Palmer pigweed will provide Arkansas soybean producers a valuable tool for weed management at a time when other conventional herbicides are failing. In the long term, the workflow created in this project can be applied directly to accelerate bioherbicide development for many other problematic weeds in Arkansas and beyond.

Acknowledgments

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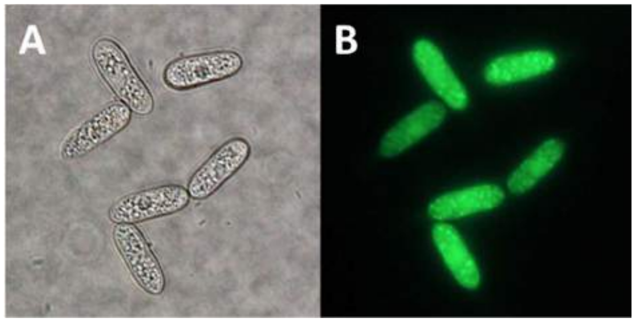

Fig. 1. ***Agrobacterium*****-mediated creation of mutants of *Colletotrichum* spp. (A) Brightfield image of conida. (B) Fluorescence microscopy image of the same conidia. Green coloration indicates expression of green fluorescent protein (GFP).**

Fig. 2. Seedling inoculation assay to rapidly screen mutants of interest. In this assay, ground mycelium of each mutant was wound-inoculated into stems of Palmer pigweed seedlings. Necrosis was scored 5–7 days after inoculation.

Efficacy of Selected Insecticides for Control of Corn Earworm and Soybean Looper in Soybean

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Abstract

Two serious lepidopterous pests of soybean [*Glycine max* (L.) Merr.] in Arkansas are corn earworm [*Helicoverpa zea* (Boddie)] and soybean looper [*Chyrsodeixis includens* (Walker)]. On average, corn earworm is the most damaging insect pest of soybean in Arkansas, while soybean looper is the third most damaging. Selected insecticides were evaluated in grower fields for control of these pests in Lee, Drew, and Phillips Counties, Ark., in 2020. Results indicate that many insecticides provide good control within the first week after application of both corn earworm and soybean looper, but Besiege® and Prevathon® were the only products that provided extended residual control.

Introduction

Corn earworm, *Helicoverpa zea* (Boddie), is the most economically important insect pest of soybean [*Glycine max* (L.) Merrill] in Arkansas (Musser et al., 2016, 2017, 2018, 2019).

Corn earworm in Arkansas usually undergoes 5 generations per year. The first generation typically occurs on wild hosts such as crimson clover, *Trifolium incarnatum* L., with the subsequent generation moving into corn (*Zea mays* L). Host preference of corn earworm is positively correlated to plant maturity, and corn earworm strongly prefers plants in the flowering stage, with corn being the most suitable of all hosts (Johnson et al., 1975).

Once corn begins to senesce, it becomes unattractive to corn earworm adults as an ovipositional host. The third and fourth generations generally occur in other agronomic host crops such as soybean, cotton (*Gossypium hirsutum* L.), and grain sorghum [*Sorghum bicolor* (L.) Moench], with the fifth generation occurring primarily on volunteer crop plants after harvest and other non-crop wild hosts (Hartstack et al., 1973).

Soybean looper (SBL), *Chyrsodeixis includens* Walker, is a major pest of soybean production in Arkansas, costing growers over 29 million dollars in 2017 (Musser et al., 2018). This pest is a defoliator and causes yield loss by feeding on the soybean leaves. SBL migrates northward into Arkansas every year and is typically only a pest of late-planted soybean (Carner et al., 1974). SBL has documented resistance to multiple insecticide modes of action (Leonard et al., 1990, Mascarenhas and Boethel, 1997); therefore it is important for efficacy testing of currently labeled products to be conducted yearly.

The purpose of these trials was to evaluate the control of corn earworm and soybean looper with selected insecticides and determine which insecticides provided the level of residual control over an extended time period.

Procedures

Three trials were conducted evaluating the efficacy of several insecticides on corn earworm and soybean looper. In 2020, a trial was conducted in three different counties (Lee, Phillips, and Drew Counties in Arkansas). Plot size was 12.5-ft. (4 rows) by 40-ft., plot design was a randomized complete block with 4 replications. Applications were made using a Mudmaster high clearance sprayer fitted with 80-02 dual flat fan nozzles at 19.5-in. spacing with a spray volume of 10 gallons per acre (GPA), at 40 psi. Plots were evaluated by making 25 sweeps per plot with a standard 15-in. diameter sweep net. The data was processed using Agriculture Research Manager V.9 (Gylling Data Management, Inc., Brookings, S.D.) and Duncan's New Multiple Range Test (P = 0.10) to separate means.

Results and Discussion

At the Phillips County trial, all treatments reduced corn earworm densities at 3 days after application (DAA) when compared to the untreated check (UTC) (Fig. 1). All insecticides provided better control than Intrepid® 8 oz at 3 DAA. All treatments reduced corn earworm densities at 6 DAA when compared to the UTC. Corn earworm populations crashed at 14 DAA and were not recorded. In the same trial,

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all treatments reduced soybean looper densities at 3 DAA but Prevathon® 14 oz, both rates of Intrepid Edge®, Lambda Cy 1.85 oz + Acephate 0.5 lb, and Steward® 9 oz provided better control than Lambda Cy 1.85 oz (Fig. 2). At 6 DAA, all treatments had lower densities of soybean looper when compared to the UTC with Besiege® 8 oz, both rates of Prevathon and Intrepid Edge, Steward 9 oz, Intrepid 8 oz, and Lannate 16 oz providing the greatest control. At 14 DAA, both rates of Besiege, Prevathon and Intrepid Edge, Lambda Cy 1.85 oz + Acephate 0.5 lb, Steward 9 oz, and Lannate 16 oz provided the greatest control of soybean looper.

At the Drew County trial at 4 DAA, all treatments reduced corn earworm densities when compared to the UTC. For the remainder of the trial, 11, 17, and 24 DAA Besiege 8 oz and Prevathon 14 oz provided the greatest control of corn earworm. In the same trial, all products equally reduced looper densities at 11 and 17 DAA. At 24 DAA, Prevathon and Besiege provided the greatest control of soybean looper.

At the Lee County soybean looper trial at 3 DAA, all products except Hero® reduced looper densities. At 7 DAA, all tested products reduced looper densities when compared to the UTC but Besiege, both rates of Denim®, Intrepid Edge, Prevathon + Brigade, and Prevathon alone provided greater control than Hero®.

Most of the tested products, except for the pyrethroids, provided excellent control of both corn earworm and soybean looper within the first week after application. However, Prevathon and Besiege provided the greatest amount of residual control after this period.

Practical Applications

These data show which insecticides provide the greatest initial and residual control of corn earworm and soybean looper. This allows growers to make a more informed decision when selecting an insecticide to control either of these pests.

Acknowledgments

We would like to thank the Arkansas Soybean Promotion Board and the University of Arkansas System Division of Agriculture for helping to fund this research.

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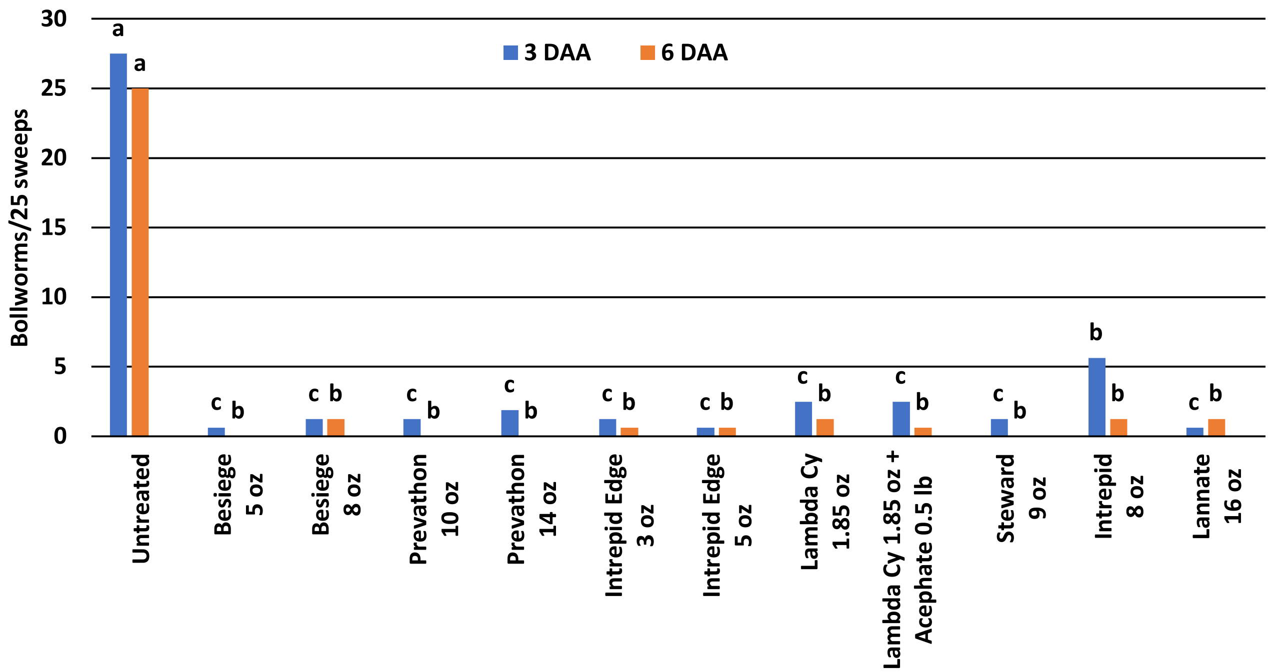

Fig. 1. Efficacy of selected insecticides for control of corn earworm in Phillips County, Ark. Plots were sprayed on 18 Aug. 2020. DAA = days after application. Means followed by the same letter are not significantly different (*P* > 0.10).

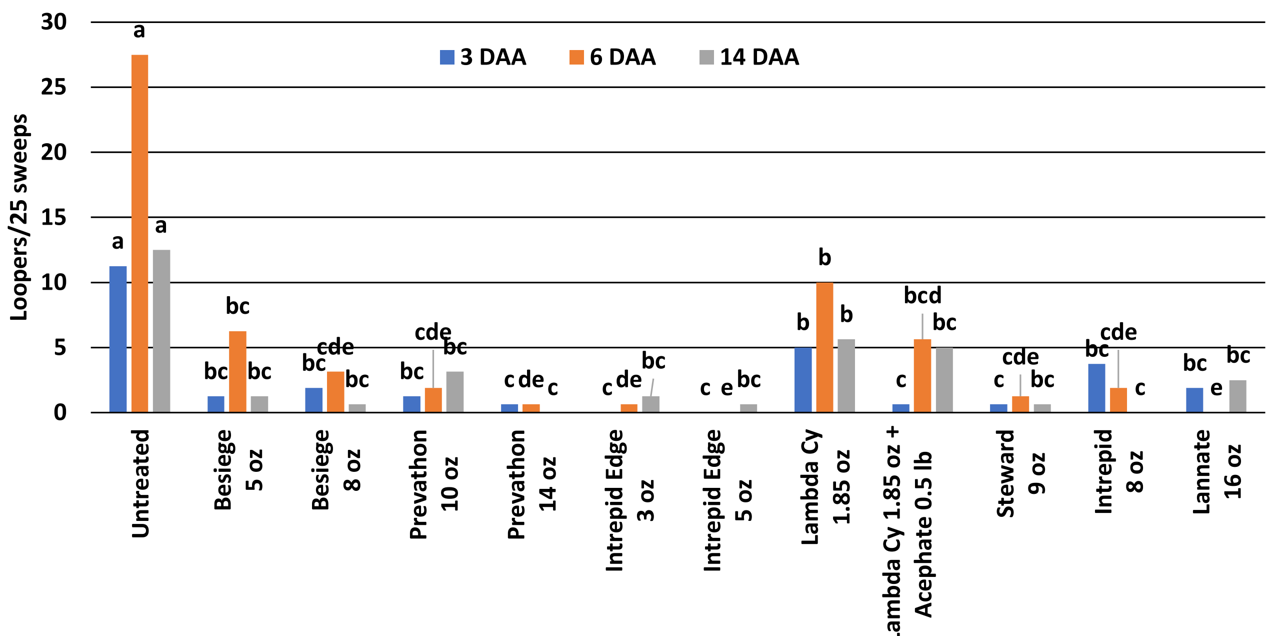

Fig. 2. Efficacy of selected insecticides on soybean looper in Phillip County, Ark. Plots were sprayed on 18 Aug. 2020. DAA = days after application. Means followed by the same letter are not significantly different (*P* > 0.10).

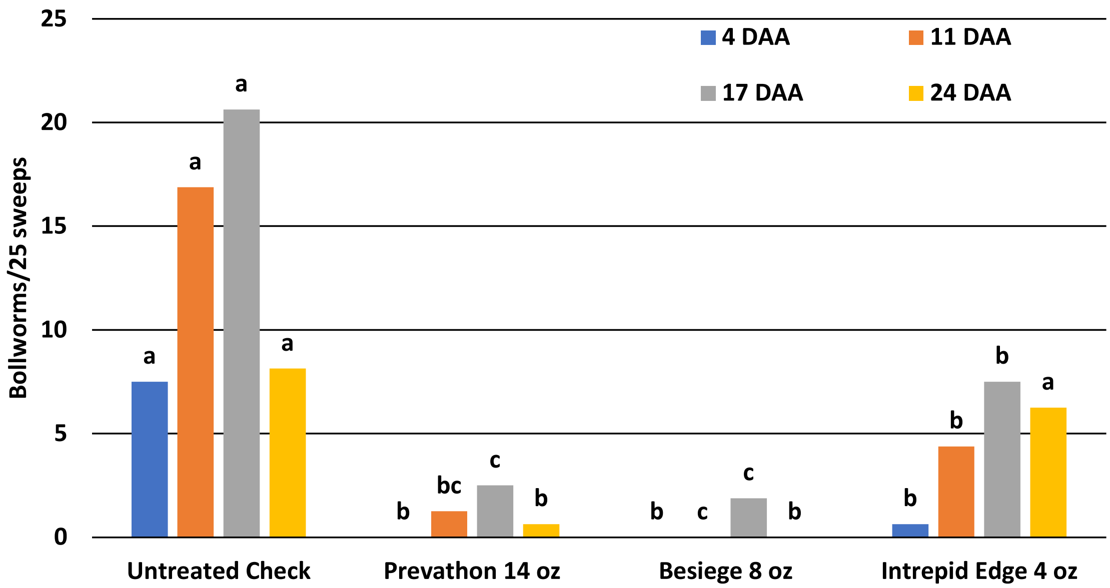

Fig. 3. Efficacy of selected insecticides on corn earworm in Drew County, Ark. Plots were sprayed on 7 Aug. 2020. DAA = days after application. Means followed by the same letter are not significantly different (*P* > 0.10).

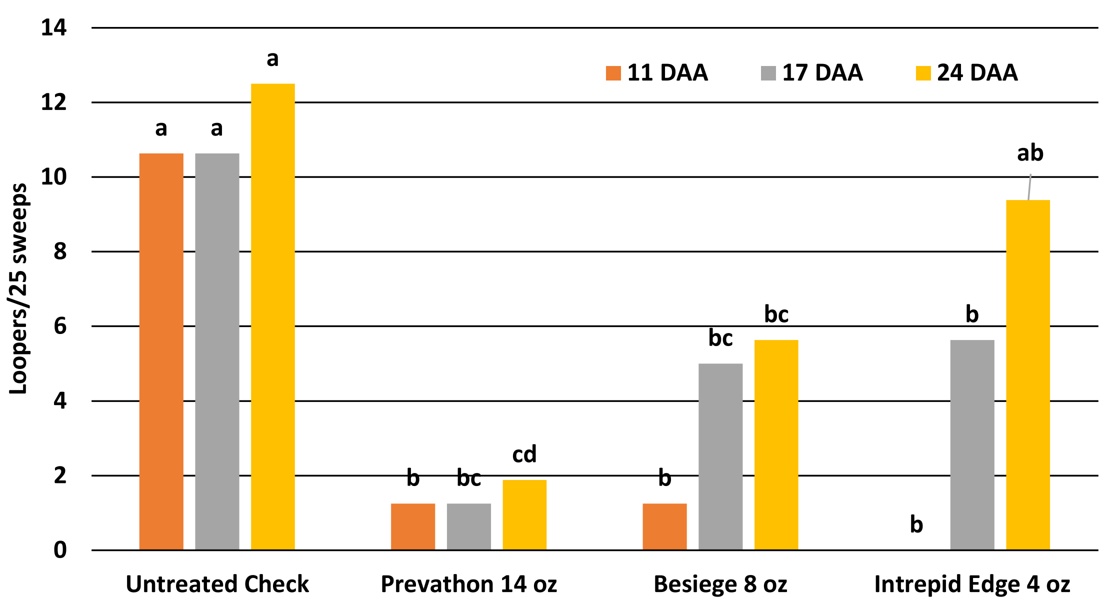

Fig. 4. Efficacy of selected insecticides for control of soybean looper in Drew County, Ark. Plots were sprayed on 7 Aug. 2020. DAA = days after application. Means followed by the same letter are not significantly different (*P* > 0.10).

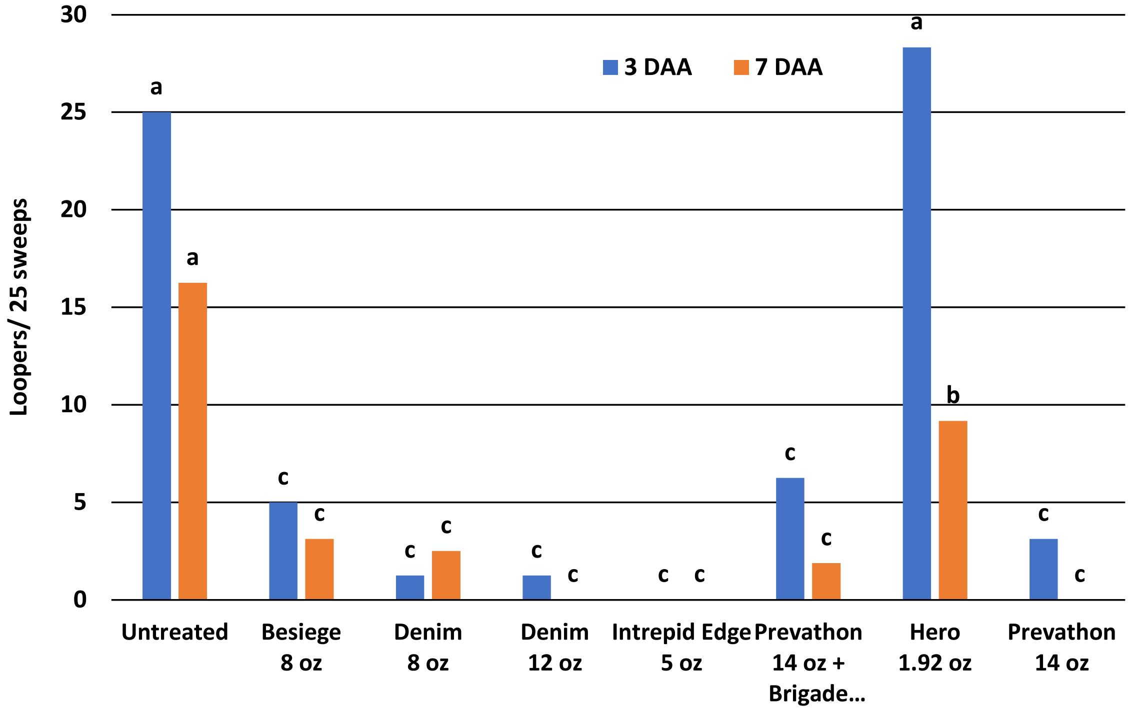

Fig. 5. Efficacy of selected insecticides for control of soybean looper in Lee County, Ark. Plots were sprayed on 1 Sept. 2020. DAA = days after application. Means followed by the same letter are not significantly different (P > 0.10).

2019 and 2020 Soybean Insecticide Seed Treatment Performance in Cover Crops

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Abstract

Many growers are planting cover crops to improve soil quality, suppress weeds, and reduce nutrient loss. However, many insect pests can find refuge in them and can cause substantial injury to the primary crop if not controlled. A cost-effective way to combat many of these pests is the use of an insecticide seed treatment. In 2019 and 2020, three soybean insecticide seed treatments were evaluated against a fungicide-only check in three cover crops and a fallow block. Both years only low densities of insect pests were observed in all cover crop plots. Plots with an insecticide seed treatment yielded an average of 2 bu./ac greater than those containing fungicide-only treated seed.

Introduction

Cover crops have been implemented on a considerable amount of acreage in Arkansas to improve soil quality, suppress weeds, and reduce nutrient loss (Roberts, 2018a; Roberts, 2018b; Roberts, 2020). Although there are documented benefits of using cover crops, there are also drawbacks, one of which is the harboring of insect pests. Problematic insect pests associated with soybean planted behind cover crops include wireworms, pea leaf weevil, stinkbugs, cutworms, and armyworms. From an insect management standpoint, terminating the cover crop 3–4 weeks before planting the commodity crop is the best management practice. However, to get the most out of a cover crop, in terms of biomass for organic matter and ground cover for weed suppression, growers may opt to plant into a green cover crop or terminate just before planting. Foliar insecticides are an option for controlling insect pests but can be ineffective in fields where a cover crop has produced a thick "mat" that impedes insecticide penetration. Currently, it is recommended that growers use an insecticide seed treatment when planting into a cover crop. This study evaluated multiple soybean insecticide seed treatments across several cover crops to assess their value to growers.

Procedures

Studies were conducted in Marianna, Ar at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station in 2019 and 2020 to evaluate the use of insecticide seed treatments in multiple cover crops. A field was split into 4 blocks containing a fallow block and 3 cover crop blocks including cereal rye, Austrian winter pea, and a blend (Balansa fixation clover, winter wheat, crimson clover, oats, purple top turnip, triticale, Daikon radish, and cereal rye; Cattleman's Treasure, Stratton Seed, Stuttgart, Ark.) planted on 25 Oct. in 2019 and 23 Oct. in 2020. Cover crops were terminated by herbicide application and rolling on 17 May, 4 days before planting in 2019, and 9 April, 7 days before planting in 2020. Three insecticide seed treatments were evaluated, including Cruiser Maxx® 3.2 oz/ac, Cruiser Maxx Beans 3.2 oz/ac + Avicta® 3 oz/ac, Cruiser Maxx Beans 3.2 oz/ac + Fortenza® 3 oz/ac, and a fungicide only untreated check (Trilex® 2000). Soybean was planted on 21 May in 2019 and 16 April in 2020, arranged in a randomized complete block design with four replications. Plots were harvested on 8 Oct. Data was analyzed using a student t-test with Tukey's honestly significant difference (JMP Pro 14.1, SAS Institute Inc., Cary, N.C.). Differences were considered significant at $P < 0.10$. Yields between cover crops in 2019 were excluded from analysis due to substantial deer feeding occurred to soybean planted within the cover crop blend.

Results and Discussion

No differences in soybean yield were observed between cover crops or insecticide seed treatments (Fig. 1). However, across all cover crops and the fallow, soybean containing an insecticide seed treatment yielded an average of 2.0 bu./ac greater than the fungicide only ($P < 0.01$) (Fig. 2). These results indicate that regardless of cover crop type or presence, insecticide seed treatments provide a yield advantage over a fungicide-only treated seed, even in the absence of insect pests.

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Practical Applications

This research assesses the value of insecticide seed treatments in a cover crop situation and will allow growers to make a more informed decision when it comes to seed treatment selection.

Acknowledgments

The authors would like to thank the Arkansas Soybean Promotion Board for funding this project.

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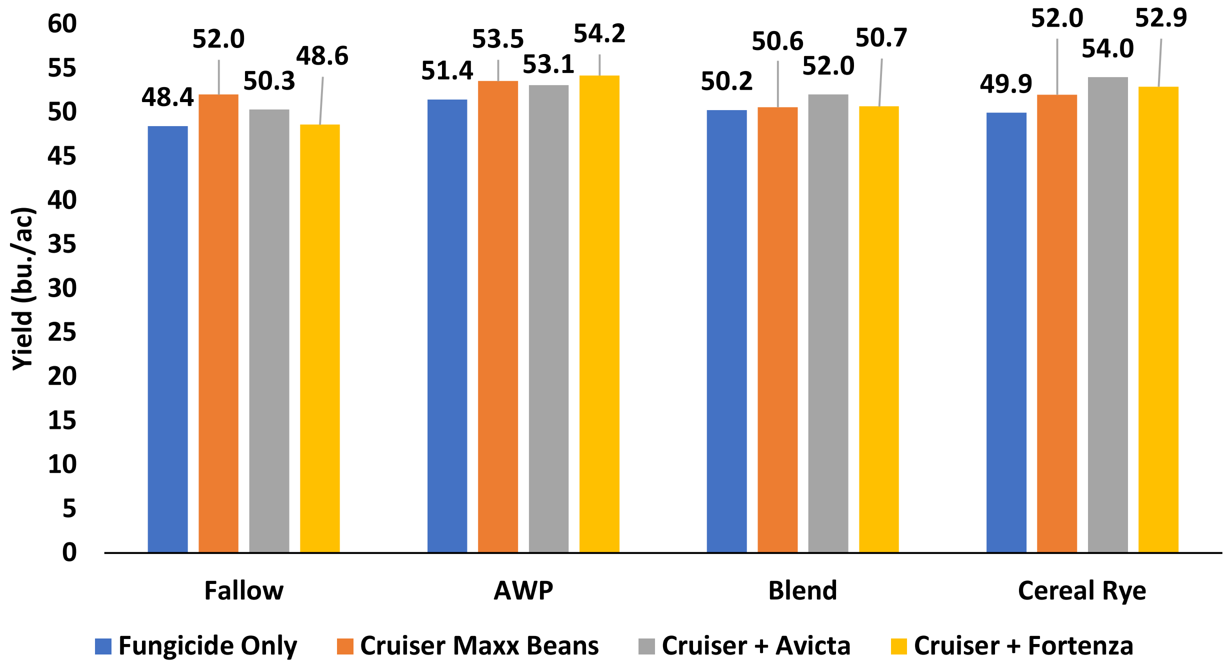

Fig. 1. Yields for fungicide only and insecticide-treated seed and planted into fallow ground or an Austrian winter pea, cereal rye, or blend cover crop in 2020 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station near Marianna, Ark. AWP = Australian Winter Pea.

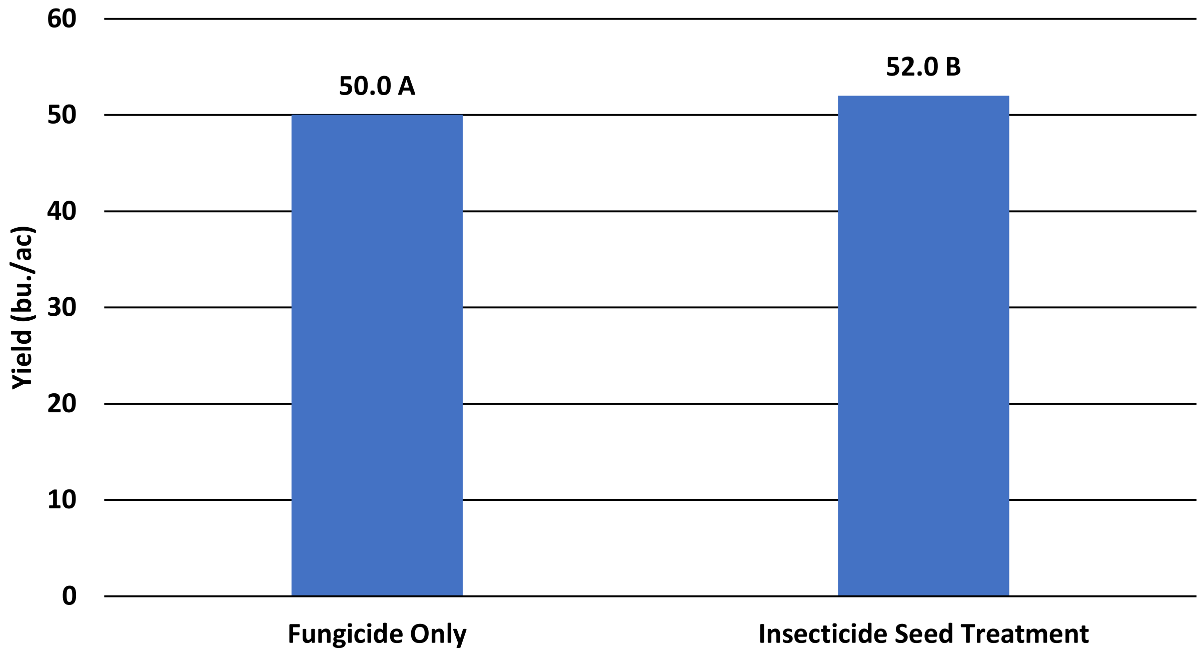

Fig. 2. Yield comparison between fungicide only treated soybean seed and insecticide-treated seed across cover crops (P > 0.01) in 2020 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station near Marianna, Ark. Means followed by the same letter are not significantly different.

Impact of Chrysogen and Purified *ChinNPV* on Soybean Looper Feeding and Mortality

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Abstract

In 2019, 1.72 million acres of soybean were infested with soybean looper, resulting in 1.69 million bushels in losses. Approximately 20% of infested acres were treated with an average insecticide application costing $15.70/ac. Soybean growers are seeking cheaper control options for soybean looper. *ChinNPV* is a target-specific virus designed to control soybean looper at a decreased input cost. Studies were conducted in 2020 to evaluate selected rates of Chrysogen® and purified *Chrysodeixis includens nucleopolyhedrovirus* (*ChinNPV*) for control of soybean looper in soybean. At the V3 growth stage, soybean was treated with Chrysogenâ or purified ChinNPV at rates ranging from 2–4 oz/ac. After application, three 3rd instar larvae were introduced per plant and were observed daily for mortality and defoliation level. All tested Chrysogen rates exceeded the 25% defoliation threshold and remained below 50% mortality at 5 days after application (DAA). All rates of purified ChinNPV kept defoliation levels below the threshold while reaching 90% mortality between 6–7 DAA. No rate response was observed in Chrysogenâ or purified *ChinNPV*.

Introduction

Soybean looper, *Chrysodeixis includens*, is a major pest of soybean in the mid-Southern United States. In Arkansas, growers experienced approximately $13 million in losses due to this pest in 2019 (Musser et al., 2019). The annual migration of soybean looper coincides with late-season soybean production, and after entering a field, this pest can quickly cause severe defoliation resulting in yield reductions if left untreated (Carner et al., 1974). Increased resistance to synthetic insecticides (pyrethroids) has been observed (Felland et al., 1990; Boethel et al., 1992), as well as organophosphates and recently diamides in the southeast, thus an effective and economical option is needed for control of soybean looper. Ingestion of *ChinNPV* by the soybean looper provides control by the production of occlusion bodies within the host, allowing for the spread of more virus upon mortality. Trials were conducted to evaluate Chrysogen® and purified *Chrysodeixis includens nucleopolyhedrovirus* (*ChinNPV)* as a potential alternative from synthetic insecticides in Arkansas soybean production.

Procedures

Two greenhouse studies were conducted at the University of Arkansas System Division of Agriculture's Lonoke Research and Extension Center, Lonoke, Ark. to evaluate the efficacy of Chrysogenâ and purified *ChinNPV* for control of soybean looper in soybean. Each treatment was replicated 10 times and arranged in a randomized complete block design. Soybean cultivar Asgrow 46X6 was planted and allowed to grow until the V3 growth stage. An application of Chrysogenâ was made at the V3 growth stage, using a CO2 backpack sprayer fitted with Teejet TX-VK6 hollow cone spray nozzles on 19.5-in spacing at 10 gallons per acre (GPA) and 40 psi. Before application, soybean plants used as the untreated check (UTC) were placed in a separate greenhouse to avoid contamination. Three 3rd instar larvae, obtained from Mississippi State University's insect rearing lab, were introduced to each soybean plant after application. Looper-infested soybeans were then placed inside an 8-in.by 16-in. insect rearing cage. Each replication was evaluated daily until 14 days after application (DAA) for percent defoliation and mortality. Defoliation was measured for each trifoliate using Leafbyte. Mortality was measured by visual observation.

Soybean Looper Commercial Rate Response Trial. Treatments in this trial were: Commercial Chrysogenâ (Chrysodeixis includens nucleopolyhedrovirus) at 2.5, 3, 3.5, and 4 oz/ac. Commercial Chrysogenâ consists of ChinNPV isolate #460 containing 7.5 × 109 occlusion bodies per milliliter and 65.8% diet substrate.

Soybean Looper Purified Rate Response Trial. Treatments included Purified ChinNPV at 2, 2.5, 3, 3.5, and 4 oz/ac. Purified *ChinNPV* consists of *ChinNPV* isolate #460 with 7.5 × 109 occlusion bodies per milliliter with diet substrate removed.

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Results and Discussion

Soybean Looper Commercial Rate Response Trial. At 1 DAA, Chrysogen® rates 3 oz and greater had less defoliation compared to the UTC (Table 1). At 2 DAA, all rates of Chrysogen had less defoliation than the UTC. At 3–5 DAA, the 4 oz rate was the only rate that had less defoliation than the UTC. At 5 DAA, all rates of Chrysogen® had inadequate control of soybean looper, with all rates exceeding the recommended defoliation threshold of 25%. At 6 DAA, no treatment differed from the UTC. At 7 DAA, the 4 oz rate of Chrysogen® had less defoliation than the UTC. At 8–14 DAA, all treatments had less defoliation than the UTC (Table 2). Mortality for Chrysogen® treatments failed to reach 50% mortality before 14 DAA. Applications of Chrysogen® were not able to inhibit the rate of soybean defoliation and provided low percentages of mortality.

Soybean Looper Purified Rate Response Trial. At 1–4 DAA, no purified *ChinNPV* treatments differed from the UTC (Table 3). At 5–6 DAA, purified *ChinNPV* treatments had less defoliation compared to UTC. At 6 DAA, rates of purified *ChinNPV* less than 3.5 oz/ac reached 50% mortality while rates greater than or equal to 3.5 oz/ac reached 70% mortality (Table 4). At 7–14 DAA, purified *ChinNPV* treatments had less defoliation than the UTC (Table 5) and remained the same, with mortality being observed after 6 DAA. Defoliation thresholds were not exceeded when applications of purified *ChinNPV* were applied for the control of soybean looper. These data suggest that purified *ChinNPV* may result in adequate control of soybean looper, but efficacy may be lost during the commercialization of the product.

The application of Chrysogen® has the potential to be adapted into the insect pest management program in Arkansas soybean production, providing a more sustainable insecticide application at a competitive price. Further research in conjunction with the product manufacturer is needed to further develop product efficacy and application stipulations. Until these needs are met, the application of Chrysogen® as a biological control method is not suggested in Arkansas soybean production.

Practical Applications

With increased insecticide resistance in soybean looper and the increasing cost of soybean production, Arkansas growers need a cost-effective product for soybean looper control. Commercial Chrysogen® applied at all rates failed to protect soybean yield with defoliation from soybean looper exceeding 50%. All rates of purified *ChinNPV* provided control of soybean looper and kept defoliation below the 25% threshold. Purified *ChinNPV* is not available for large-scale use; therefore commercial Chrysogen® applications are not recommended at this time until increased efficacy is observed.

Acknowledgments

The authors wish to thank the Arkansas Soybean Promotion Board, AgBiTech, and the University of Arkansas System Division of Agriculture for their support of this research.

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Table 1. Trial 1 defoliation results comparing selected rates of Chrysogen® for control of soybean looper from 1 to 7 days after application (DAA) in 2020.

Treatment	1 DAA	2 DAA	3 DAA	4 DAA	5 DAA	6 DAA	7 DAA
UTC	4.4 a†	12.6 a	20.4 a	31.9 a	47.7 a	57.9	72.9 a
2.5 oz	2.3 ab	6.8 b	12.7 ab	24.6 ab	38.2 ab	54.1	57.9 ab
3 oz	1.7 b	6.1 b	12.7 ab	20.9 ab	35.8 ab	51.4	58.2 ab
3.5 oz	1.9 b	6.4 b	12.6 ab	20.7ab	34.8 ab	53	59.1 ab
4 oz	1.67b	5.1 b	9.9 b	16.6 b	27.0 b	41.8	47.0 b
P-value	<0.01	<0.01	0.01	0.01	0.01	ns	0.02

† Means followed by the same letter within the column are not significantly different at *P* = 0.10. UTC = Untreated check.

Table 2. Trial 1 defoliation results comparing selected rates of Chrysogen® for control of soybean looper from 8 to 14 days after application (DAA) in 2020.

Treatment	9 DAA	10 DAA	11 DAA	12 DAA	13 DAA	14 DAA
UTC	88.0 a†	89.3 a	91.2 a	93.6 a	94.3 a	94.4 a
2.5 oz	61.4 b	61.5 b	68.5 b	71.2 b	74.0 b	74.9 b
3 oz	65.7 b	65.5 b	71.1 b	71.6 b	72.6 b	75.1 b
3.5 oz	60.2 b	60.4 b	63.6 b	64.9 b	66.5 b	68.0 b
4 oz	52.3 b	52.7 b	57.6 b	59.7 b	61.9 b	63.8 b
P-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

† Means followed by the same letter within the column are not significantly different at *P* = 0.10. UTC = Untreated check.

Table 3. Defoliation results comparing selected rates of purified ChinNPV for control of soybean looper (Trial 2) from 1 day after application (DAA) to 7 DAA in 2020.

Treatment	1 DAA	2 DAA	3 DAA	4 DAA	5 DAA	6 DAA	7 DAA
UTC	0.9	2.4	4.7	10.3	19.7 a†	33.7 a	51.9 a
2 oz	0.5	1.1	1.9	4.9	7.4 b	10.7 b	15.1 b
2.5 oz	0.7	2.6	6	8.5	10 b	11.3 b	12.8 b
3 oz	0.7	1.4	2.8	4.3	5.3 b	5.9 b	7.0 b
3.5 oz	0.6	1.6	3.7	5.2	7.1 b	8.6 b	10.1 b
4 oz	0.7	1.8	3.5	4.5	6.0 b	7.4 b	8.8 b
P-value	ns	ns	ns	ns	<0.01	<0.01	<0.01

† Means followed by the same letter within the column are not significantly different at *P* = 0.10. UTC = Untreated check.

Table 4. Time to mortality of soybean looper with selected rates of Chrysogen® and purified *ChinNPV* up to 14 days after application (DAA) in 2020.

	Chrysogen		*ChinNPV*	
Treatment	Time to 50% Mort.	Time to 70% Mort.	Time to 50% Mort.	Time to 70% Mort.
2.5 oz	+14	+14	6	7
3 oz	+14	+14	6	7
3.5 oz	+14	+14	6	6
4 oz	+14	+14	6	6
P-value	ns	ns	ns	ns

Table 5. Defoliation results comparing selected rates of purified ChinNPV for control of soybean looper (Trial 2) from 8 days after application (DAA) to 14 DAA in 2020.

Treatment	8 DAA	9 DAA	10 DAA	11 DAA	12 DAA	13 DAA	14 DAA
UTC	61.9 a[†]	70.1 a	75.8 a	75.8 a	75.8 a	75.8 a	75.8 a
2 oz	15.1 b	15.1 b	15.1 b	15.1 b	15.1 b	15.1 b	15.1 b
2.5 oz	12.8 b	12.8 b	12.8 b	12.8 b	12.8 b	12.8 b	12.8 b
3 oz	7.0 b	7.0 b	7.0 b	7.0 b	7.0 b	7.0 b	7.0 b
3.5 oz	10.1 b	10.1 b	10.1 b	10.1 b	10.1 b	10.1 b	10.1 b
4 oz	8.8 b	8.8 b	8.8 b	8.8 b	8.8 b	8.8 b	8.8 b
P-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[†] Means followed by the same letter within the column are not significantly different at $P = 0.10$. UTC = Untreated check.

Full Season Weed Control in Enlist® E3 Soybeans

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Abstract

In 2020, a weed control study was conducted at the University of Arkansas System Division of Agriculture's Lonn Man Cotton Research Station near Marianna, Ark., on a Calloway silt loam soil to determine adequate weed control from a full season approach in Enlist® E3 soybeans [*Glycine max* (L.) Merr.]. The objective of this trial was to evaluate herbicide combinations for burndown control of large Canadian horseweed (*Conyza canadensis*) commonly called Marestail as well as other winter annuals. Enlist soybean were planted 15 days after burndown herbicide applications and additional herbicide programs were evaluated to determine efficacy on Marestail, Palmer amaranth, and other problematic weeds. Results indicated that herbicide programs containing Elevore® at 1 oz/ac provided the best control of Marestail, with the combination of Enlist One® 32 oz/ac and Durango® 32 oz/ac providing 90% control of Marestail and other winter annual weeds. Gramoxone® 40 oz/ac plus Verdict® 5 oz/ac provided only 73% control of Marestail but controlled Palmer amaranth 98% at the time of planting. Herbicide combinations at planting (PRE) consisted of either Trivence® 8 oz/ac plus 40 oz/ac Gramoxone or Boundary® 32 oz/ac plus 40 oz/ac Gramoxone. There was no difference in residual control of Palmer amaranth with any PRE 14 days after application (DAA). However, Marestail control was higher (>92%) where combinations of Gramoxone plus Trivence were applied compared to <75% with combinations of Gramoxone plus Boundary. This was likely due to the increased control with Elevore treatments before PRE applications. All other winter or summer annual weeds were controlled effectively following early postemergence (POST) applications, regardless of treatment.

Introduction

In recent years Canadian horseweed (Marestail) (*Conyza canadensis*) and Palmer amaranth (*Amaranthus palmeri*) have become resistant to multiple herbicide modes of action, especially Palmer amaranth, where populations have been identified tolerant to 6 herbicide modes of action (Butts et al., 2020). With this rapidly growing problem, new herbicide traits n soybean [*Glycine max* (L.) Merr.] has been introduced to control these problematic weeds. One of these traits is the Enlist® E3 soybean which is tolerant to over-the-top applications of 2,4-D choline (Enlist One®), glufosinate (Liberty™), and glyphosate (Roundup®). One potential benefit to the Enlist system is the ability to spray Enlist One at planting to remove winter annual weeds. Marestail has become more of an issue with delayed spring plantings, due to the potential for multiple flushes during spring months. Elevore® is a new herbicide that was labeled for Marestail control in 2019, but a 14-day waiting period is required before planting soybean (Barber et al., 2021). The objective of this trial was to determine the best herbicide combination when large Marestail and Palmer amaranth are present in a no-till planting scenario.

Procedures

In 2020, a study was conducted in Marianna, Ark, on a Calloway silt loam soil to evaluate total weed control from a 15-day pre-plant (DPP) burndown program followed by a PRE program in combination with Gramoxone in a no-till Enlist E3 soybean system. This experiment was conducted as a randomized complete block design including four replications, with plot sizes of 12.6-ft wide by 30-ft long. The 15 DPP applications included either Elevore or Gramoxone in combination with other common burndown or pre-plant herbicides. Pre-emerge (PRE) or at-planting combinations of Trivence or Boundary plus Gramoxone were applied to evaluate POST control of any remaining weeds following the pre-plant applications as well as residual control of Palmer amaranth, and other summer annuals. Early Post (EP) applications including Enlist One (2,4-D choline) in combination with glyphosate or glufosinate were compared and glufosinate was utilized as the sole late post (LP) application. The weeds evaluated were Marestail, mayweed (*Anthemis cotula*), annual bluegrass (*Poa annua*), Palmer amaranth, barnyardgrass (*Echinochola crus -galli*), and broadleaf signalgrass (*Urochola platyphlla*).

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All winter annual weeds were >6-in. and Marestail was >12-in. tall at time of burndown (15 DPP) application. All herbicide applications were made using a self-propelled sprayer calibrated to deliver 12 gallons per acre (GPA) at 3 mph with AIXR110015 spray nozzles. Data collected consisted of visible weed efficacy ratings, which are defined as percent control, where 0% was no control and 100% was complete control compared to the untreated check. Weed control ratings were recorded at planting, 14 days after planting (DAP), and 14 days after each application. Data were analyzed and subjected to analysis of variance and means were separated by Fisher's protected least significant difference at a *P*-value of 0.05.

Results and Discussion

Large (>12 in.) Marestail control, in addition to control of common early-season winter annual weeds, was best achieved with Elevore 1 oz/ac plus 32 oz/ac of Durango (glyphosate) and 32 oz/ac of 2,4-D choline (Enlist One) (Table 1). Only numerical differences were observed between Elevore at 1 oz/ac applied with Leadoff 1.5 oz/ac plus 32 oz/ac Durango or 4 oz/ac Canopy® plus 32 oz/ac of Durango. Gramoxone 40 oz/ac applied with 5 oz/ac Verdict achieved only 73% control of Marestail but Palmer amaranth control was the highest at 98% (Table 1). At 14 days after PRE application (14 DAP), all treatments consisting of Elevore had no significant difference in weed control resulting in 92% control or better of horseweed and 93% or better control of Palmer amaranth (Table 2). Gramoxone applied with Boundary herbicide resulted in a 71% control for Marestail and a 95% control average for Palmer amaranth. All EP treatments contained Enlist One 32 oz/ac, resulting in 95% or better control of Palmer amaranth and Marestail across all treatments (data not shown). Treatments that contained the addition of Durango or Liberty with Enlist One EP were effective in controlling common problematic grasses and other broadleaf weeds and were not significantly different (data not shown). Evaluations of the trial were conducted up to crop canopy and it was determined that the LP of glufosinate was not needed for any weed escapes or control (data not shown).

Practical Applications

Based on the data compiled from this research, Elevore provided the best control of large Marestail before planting. Herbicide mixtures that include Gramoxone (paraquat) were the most effective on Palmer amaranth but can also be effective on Marestail if followed by Enlist One with glufosinate early post. When utilizing Gramoxone, two applications will likely be needed for adequate Marestail control dependent on weed size and growth stage at the time of application. Additionally, research shows better weed control with overlapping residual herbicides and applications to appropriate weed height. Both Trivence and Boundary were effective options PRE in Enlist soybean and can be effective in a no-till production system. Additionally, the Enlist system provides effective alternatives for control of many problematic broadleaf and grass weeds with the ability for tank mixture combinations of Enlist One, glufosinate, and /or glyphosate.

Acknowledgments

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Table 1. Evaluation of herbicide treatments 15 days prior to planting on control of Canadian Horseweed (*Conyza canadensis*) and Palmer amaranth *(Amaranthus palmeri)* at the time of planting at the University of Arkansas System Division of Agriculture's Lonn Man Cotton Research Station near Marianna, Ark.

15 Day pre-plant treatment	Canadian horseweed	Palmer amaranth
	--------------------------------% Control------------------------------	
Elevore® 1 oz/ac + Durango® DMA 32 oz/ac + MSO 1% v/v	85	91.3
Elevore 1 oz/ac + Durango DMA 32 oz/ac + Enlist One® 32 oz/ac + MSO 1% v/v	90	94.8
Elevore 1 oz/ac + Leadoff® 1.5 oz/ac + Durango DMA 32 oz/ac + MSO 1% v/v	88.8	93.5
Elevore 1 oz/ac + Canopy® 4 oz/ac + Durango DMA 32 oz/ac + MSO 1% v/v	87.5	90
Gramoxone® 48 oz/ac + Verdict 5 oz/ac	73.8	98
LSD *P* = 0.05	9.49	6.13

Table 2. Evaluation of herbicide treatments for Canadian Horseweed (*Conyza canadensis*) and Palmer amaranth *(Amaranthus palmeri)* control 14 days after planting at the University of Arkansas System Division of Agriculture's Lonn Man Cotton Research Station near Marianna, Ark.

15 Day pre-plant treatment	Preemergence treatments	Canadian horseweed	Palmer amaranth
		-------------% Control-------------	
Elevore® 1 oz/ac + Durango® DMA 32 oz/ac+ MSO 1% v/v	Trivence® 8 oz/ac + Gramoxone®[a] 42 oz/ac + Induce® 0.25% v/v	93.8	98
Elevore 1 oz/ac + Durango DMA 32 oz/ac + Enlist One 32 oz/ac + MSO 1% v/v	Trivence 8 oz/ac + Gramoxone 42 oz/ac + Induce 0.25% v/v	94.5	93.5
Elevore 1 oz/ac+ Leadoff® 1.5 oz/ac + Durango DMA 32 oz/ac + MSO 1% v/v	Trivence 8 oz/ac + Gramoxone 42 oz/ac + Induce 0.25% v/v	92.5	94.8
Elevore 1 oz/ac + Canopy® 4 oz/ac + Durango DMA 32 oz/ac + MSO 1% v/v	Trivence 8 oz/ac + Gramoxone 42 oz/ac + Induce 0.25% v/v	93.8	98
Gramozone 48 oz/ac + Verdict 5 oz	Boundary® 32 oz/ac + Gramoxone 40 oz/ac	68.8	98
LSD *P* = 0.05		9.98	5.27

[a] Grammoxone = 3 lb/ai.

Survey of Spray Water Quality (pH, Hardness, and Cation Concentration) Across Arkansas

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Abstract

Water is the most extensively used carrier for pesticide applications, and spray water quality (pH, hardness, and cation concentrations) has been shown to severely impact herbicide efficacy. The objective of this survey was to assess spray water used for herbicide applications from across Arkansas for pH, hardness, and cation concentration. Samples were solicited through multiple avenues in 2019 and 2020 and tested for pH, calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), and iron (Fe^{3+}) concentrations, and a hardness index (based on Ca^{2+} and Mg^{2+} concentrations). A total of 79 spray water samples were collected and analyzed from across the state. Results indicated approximately 71% of the samples had a pH greater than 7 (alkaline), and 39% of the samples had a hardness index greater than 200 ppm (Very Hard). These levels have the potential to cause a loss in weed control. Cation testing also indicated that Na^{+} and Fe^{3+} were present in large enough concentrations in some samples from multiple counties to antagonize herbicides, causing an additional reduction in weed control. As a result, it is important to have a holistic spray water analysis across multiple cations as the Ca^{2+} and Mg^{2+} hardness index does not account for and correlate with the presence of other problematic cations that could tie up herbicide active ingredients. Future research will investigate the water quality effect on weed control from herbicides, and what adjuvants, if any, help to mitigate these effects.

Introduction

Water is a critical component for spray applications as a carrier for pesticide active ingredients. The chemical characteristics of spray water (pH, hardness, and cation concentration) vary greatly across the United States (USGS, 2021) and have been previously shown to impact pesticide applications, specifically herbicide efficacy and volatility potential.

Reduced spray pH (acidic, <7) has resulted in greater volatility and off-target injury to susceptible plants from herbicides such as dicamba (Mueller and Steckel, 2019). Conversely, greater or alkaline spray water pH (>7) has resulted in reduced efficacy from WSSA (Weed Science Society of America) Group 1 herbicides (McMullan, 1996). Other research showed that acidic spray water (pH <7) increased the efficacy of glufosinate (Liberty®), glyphosate, 2,4-D, and dicamba (Devkota and Johnson, 2016a; Devkota and Johnson, 2019, 2020).

Spray water hardness and cation concentration have also been shown to affect herbicide efficacy. Typically, calcium (Ca^{2+}) and magnesium (Mg^{2+}) are considered the primary hard water cations that cause herbicide antagonism (Thelen et al., 1995). Concentrations greater than 200 ppm of Ca^{2+} and Mg^{2+} alone or in combination have resulted in reduced weed control from mesotrione (Callisto®), glyphosate, glufosinate, and 2,4-D (Devkota et al., 2016; Devkota and Johnson, 2016a, 2016b; Mueller et al., 2006). However, other cations can also impact the effectiveness of herbicides (Johnson et al., 2019). Glyphosate efficacy was antagonized by multiple cations with varying levels of severity in the order of iron (Fe^{3+}) > $Ca^{2+} \geq Mg^{2+}$ > sodium (Na^{+}) (Nalewaja and Matysiak, 1991).

As a result, it is imperative for growers, crop consultants, and applicators to know the quality of their spray water to apply herbicides more effectively. The objective of this survey was to assess spray water used for herbicide applications across Arkansas for pH, hardness, and cation concentration. By knowing the spray water quality distribution across the state, farmers, applicators, and researchers will know their specific water type and be able to modify applications more successfully to maximize herbicide effectiveness.

Procedures

Spray water samples were solicited and collected through multiple avenues in 2019 and 2020. The University of Arkansas System Division of Agriculture's Cooperative Extension Service County Extension Agents were encouraged to collect representative samples from their counties. Social media platforms, blog posts, email, and popular press articles were used to urge farmers, applicators, and crop consultants to submit samples. A minimum of 1 quart (1 L) of water was collected for each sample.

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Water samples were analyzed for pH using a Milwaukee MW102 PRO+ pH and temperature meter (Milwaukee Instruments, Inc., Rocky Mount, N.C.). Cation analysis was conducted with a SPECTRO ARCOS ICP spectrometer (SPECTRO Analytical Instruments GmbH, Germany) at the University of Arkansas System Division of Agriculture's Diagnostic Laboratory (Fayetteville, Ark.). Cations tested for included Ca^{2+}, Mg^{2+}, Na^{+}, and Fe^{3+}. A water hardness index was then calculated based on the concentration of Ca^{2+} and Mg^{2+} detected using Eq. 1 (Boyd, 2000).

$$\text{Hardness (ppm)} = [2.5*\text{Ca (ppm)}] + [4.1*\text{Mg (ppm)}] \qquad \textit{Eq. 1}$$

Water hardness was classified on the following scale: 0 to 60 ppm, Soft; 61 to 120 ppm, Moderately Hard; 121 to 180 ppm, Hard; and >180 ppm, Very Hard (USGS, 2021). Data were explored and graphically analyzed using a spreadsheet software package (Microsoft 365 Excel Version 2102, Microsoft, Redmond, Wash.) and distribution maps were created.

Results and Discussion

A total of 79 spray water samples were collected for quality analysis in 2019 and 2020 across 17 counties in Arkansas (Fig. 1). The pH and water hardness index (based on Ca^{2+} and Mg^{2+} concentrations) values are presented in Fig. 2. Previous research noted that losses in weed control were observed with several herbicides when spray water had a pH greater than 7 and/or hardness levels greater than 200 ppm. Of the 79 spray water samples tested across Arkansas, approximately 72% of the samples had a pH greater than 7, 29% had a hardness index greater than 200 ppm, which were considered Very Hard, and 22% had both a pH greater than 7 and hardness index greater than 200 ppm (Fig. 2.). This indicates a potential for losses in weed control to occur because of the inherent spray water quality used across the state for herbicide applications. Little to no correlation was observed between pH and water hardness values.

The spray water with the greatest (alkaline) pH (8.82) was submitted from Poinsett County (Table 1). Conversely, the lowest (acidic) pH (5.91) came from White County (data not shown). The hardest spray water (414 ppm) came from Arkansas County (Table 1). One sample tested from Poinsett County had the 2nd highest pH (8.80) and the 7th hardest water (332 ppm), indicating very poor spray water quality for herbicide applications.

The cation concentrations of spray water samples revealed interesting results regarding spray water quality. Calcium was more prevalent in spray water samples from across the state than Mg^{2+}, and no single water sample was in the top 5 of both cation categories (Table 1). As a result of the equation (Eq. 1) that used Ca^{2+} and Mg^{2+} to calculate the hardness index values, all spray samples that were in the top 5 of each category were classified as Very Hard.

The limit for Fe^{3+} in drinking water is 0.3 ppm, and one sample from Conway County tested nearly 10-fold greater (Table 1). Additionally, the limit for Na^{+} in drinking water is 20–100 ppm, and samples from multiple counties were tested with greater concentrations. High levels of Fe^{3+} and Na^{+} were identified in multiple spray water samples but were considered "Soft" water based on the standard definition derived from Ca^{2+} and Mg^{2+} concentrations. The concentrations of Fe^{3+} and Na^{+} in multiple Arkansas spray water samples were great enough to require equivalent amounts of ammonium sulfate (AMS) to neutralize hard water antagonism as observed Ca^{2+} and Mg^{2+} concentrations (Johnson et al., 2019). This indicates the importance of having a holistic spray water analysis across multiple cations as the Ca^{2+} and Mg^{2+} hardness index does not account for and correlate with the presence of other problematic cations that could tie up herbicide active ingredients. Table 1 also highlights the unpredictable nature of spray water quality across pH, hardness, and cation concentration. Very few samples were in the top 5 of more than one category, indicating that having elevated levels of pH, hardness, or one cation category does not necessarily mean the same spray water will be elevated in another category.

Practical Applications

This research provided insight into the spray water quality used for herbicide applications across Arkansas. A large percentage of submitted spray water samples tested high in pH (alkaline) and at least one problematic cation concentration that could result in a loss of herbicide efficacy. It highlights the importance of growers, crop consultants, and applicators conducting a holistic test across more cations than just Ca^{2+} and Mg^{2+} of the spray water to assess quality. Future research projects will be enacted to investigate the water quality effect on weed control from herbicides, and what adjuvants, if any, help to mitigate these effects.

Acknowledgments

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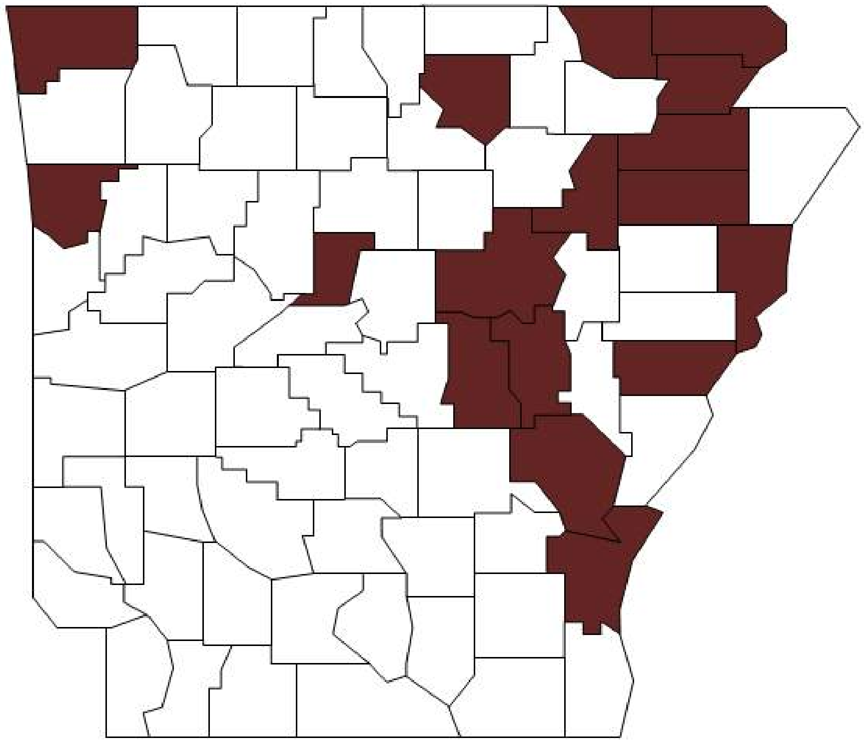

Fig. 1. Arkansas map illustrating counties where spray water samples were collected for water quality testing in 2019 and 2020 (shaded dark red).

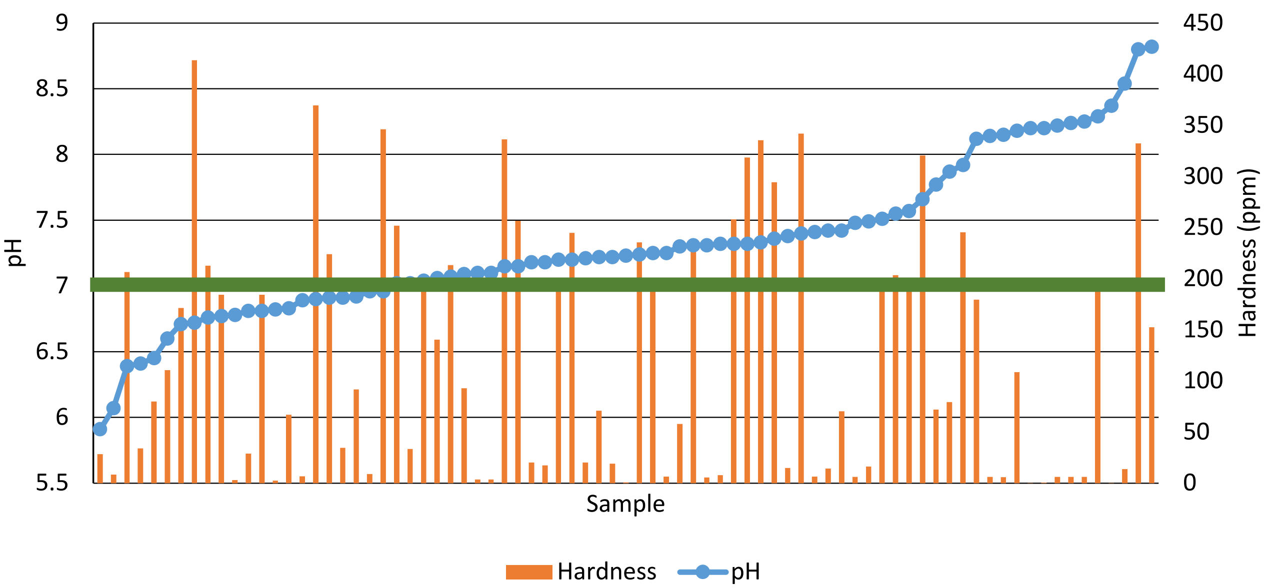

Fig. 2. The pH and hardness index of 79 spray water samples collected from across Arkansas. The green bar indicates a neutral pH (7) and water hardness of 200 ppm, both limits indicated from previous literature in which herbicide efficacy may be decreased if pH and water hardness values are greater than 7 and 200 ppm, respectively.

Table 1. Subsamples of tested spray water collected from across Arkansas in 2019 and 2020. The top five samples (see green shaded areas) in each water quality category (pH, hardness index, and individual cation concentration) are presented.

Sample	County	pH	Hardness[a]	Hardness index[a]	Iron (Fe^{3+})	Calcium (Ca^{2+})	Magnesium (Mg^{2+})	Sodium (Na^{+})
			(ppm)		ppm			
30	Poinsett	8.82	152	Hard	0.06	21.89	23.82	139.82
29	Poinsett	8.80	332	Very Hard	0.03	81.98	31.04	88.83
21	Clay	8.54	14	Soft	0.03	4.28	0.73	175.42
79	Desha	8.37	0	Soft	0.07	0.01	0.00	66.30
78	Prairie	8.29	187	Very Hard	0.06	55.79	11.67	4.12
45	Arkansas	6.72	414	Very Hard	0.06	112.87	32.03	51.91
53	Izard	6.90	369	Very Hard	0.06	76.29	43.58	7.37
11	Lee	6.96	346	Very Hard	0.03	85.23	32.42	6.49
69	Crawford	7.40	342	Very Hard	0.07	111.90	15.15	14.37
60	Izard	7.15	336	Very Hard	0.06	68.84	40.03	4.23
26	Conway	6.91	35	Soft	2.87	7.95	3.56	3.87
50	Crittenden	6.82	2	Soft	0.28	0.84	0.04	44.46
58	Crittenden	7.10	3	Soft	0.27	1.35	0.00	38.68
64	Crittenden	7.23	1	Soft	0.14	0.22	0.00	48.57
67	Benton	7.30	58	Soft	0.12	18.63	2.75	94.43
45	Arkansas	6.72	414	Very Hard	0.06	112.87	32.03	51.91
69	Crawford	7.40	342	Very Hard	0.07	111.90	15.15	14.37
27	Conway	7.33	335	Very Hard	0.03	96.24	23.08	16.41
15	Prairie	7.66	321	Very Hard	0.07	88.02	24.49	16.41
11	Lee	6.96	346	Very Hard	0.03	85.23	32.42	6.49
53	Izard	6.90	369	Very Hard	0.06	76.29	43.58	7.37
75	Izard	7.92	245	Very Hard	0.06	31.95	40.35	5.58
60	Izard	7.15	336	Very Hard	0.06	68.84	40.03	4.23
10	Lee	7.32	318	Very Hard	0.03	68.89	35.66	14.57
68	Izard	7.36	294	Very Hard	0.06	59.25	35.63	2.12
12	Lee	8.18	109	Moderately Hard	0.03	30.75	7.74	313.43
39	Greene	8.24	6	Soft	0.04	2.10	0.19	207.46
40	Greene	8.15	6	Soft	0.03	2.05	0.19	204.70
37	Greene	8.22	6	Soft	0.04	2.01	0.26	199.54
35	Greene	8.14	6	Soft	0.03	1.98	0.25	198.00

[a] Calculated based on the concentration of Ca^{2+} and Mg^{2+} cations (See Eq. 1).

Does the Addition of Potassium Tetraborate Tetrahydrate as a Volatility Reducing Agent Impact Weed Control?

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Abstract

The N,N-bis(3-aminopropyl)methylamine (BAPMA) salt of dicamba (Engenia®) and diglycolamine (DGA) salt of dicamba with VaporGrip™ (XtendiMax™) are labeled for preemergence and postemergence control of broadleaf weeds in Xtend™ cotton (*Gossypium hirsutum* L.) and soybean [*Glycine max* (L.) Merr] systems. Dicamba applications to cotton and soybean have resulted in a record number of complaints regarding the off-target movement of the herbicide since the initial introduction in 2017. To counteract dicamba volatility, the University of Arkansas System Division of Agriculture has pursued potassium tetraborate tetrahydrate (potassium borate) as a volatility-reducing tank additive following the success of preliminary volatility experiments conducted in 2019. To investigate the impact of this additive on weed control in an Xtend-based system, an experiment was conducted in 2020 to evaluate the efficacy of dicamba when mixed with the additive on Palmer amaranth (*Amaranthus palmeri* S. Watson) and johnsongrass (*Sorghum halepense* L. Pers). Two low-volatile dicamba formulations (XtendiMax and Engenia) plus the potassium salt of glyphosate (Roundup PowerMax®) were combined with potassium borate at 0, 0.015, 0.3, and 0.1 M concentrations. No concentration of potassium borate compromised broadleaf or grass weed control when added to either formulation of dicamba, although some numerical decreases were observed. Overall, the addition of potassium borate to dicamba has great potential in reducing the off-target movement of dicamba without sacrificing efficacy on key weed species.

Introduction

The introduction of the Xtend™ technology allows cotton (*Gossypium hirsutum* L.) and soybean [*Glycine max* (L.) Merr] producers to utilize the XtendiMax™ [diglycolamine salt of dicamba (DGA)] plus VaporGrip™ and Engenia™ [N,N-bis(3-aminopropyl)methylamine (BAPMA)] formulations of dicamba for postemergence control of problematic broadleaf weeds. However, usage of these relatively new low-volatile formulations of dicamba has caused a record number of complaints regarding damage caused by off-target movement of the herbicide via volatility, specifically in the Mid-South (Oseland et al., 2020). To combat dicamba volatility, the University of Arkansas System Division of Agriculture has pursued potassium tetraborate tetrahydrate (potassium borate) as a volatility reducing agent due to its capacity as an ion scavenger, pH buffer, and nutritional additive. The additive functions by scavenging hydrogen protons that are present under low solution pH conditions, preventing the formation of volatile dicamba acid.

Preliminary data from 2019 suggest that potassium borate is very promising in reducing dicamba volatility, minimizing risks for producers that utilize the technology (unpublished data, 2019). However, low-volatile formulations of synthetic auxin herbicides such as 2,4-D or dicamba can often sacrifice efficacy on weeds (Peterson et al., 2016). Ensuring that potassium borate has a minimal impact on broadleaf and grass weed control is essential due to the already limiting postemergence herbicide options in cotton and soybean. Overall, the objective of this study was to assess the impact of potassium borate on broadleaf and grass weed control when combined with a dicamba plus glyphosate mixture.

Procedures

A non-crop field experiment was conducted at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Education Center in Fayetteville, Arkansas, in the summer of 2020. An area was selected with a uniform population of Palmer amaranth (*Amaranthus palmeri* S. Watson) and johnsongrass (*Sorghum halepense*). The experimental structure was a 2-factor randomized complete block design with 4 replications. The first factor being dicamba formulation (DGA with VaporGrip and BAPMA) combined with glyphosate at 1.13 lbs ae/ac and the second being the concentration of potassium borate (0, 0.015, 0.03, 0.1 M). A nontreated control was included for all comparisons. All treatments were applied to 10 – 12-in. Palmer ama-

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ranth and johnsongrass to better detect differences amongst dicamba formulation and potassium borate concentration. All plots were over-sprayed 7 days after treatment (DAT) with S-metolachlor (Dual Magnum®) at 1 lb ai/ac to avoid the emergence of new weeds throughout evaluations, including the nontreated control. Weed control ratings were taken for each weed species at 21 days after treatment on a scale of 0% to 100%, with 0% being no control and 100% representing no live plants present. All data were analyzed in JMP Pro 15, and means were separated using Fisher's protected least significant difference ($\alpha = 0.05$).

Results and Discussion

The addition of potassium borate at concentrations ranging from 0- to 0.1-M to a dicamba plus glyphosate spray solution, did not compromise Palmer amaranth or johnsongrass efficacy regardless of the labeled low-volatile formulations of dicamba (DGA with VaporGrip and BAPMA) used. Regarding Palmer amaranth, all treatments achieved 94% control or greater despite the addition of potassium borate, and Palmer amaranth control did not decline as potassium borate concentration increased (Fig 1). The only numerical exception observed for Palmer amaranth control was the BAPMA formulation containing 0.1 M potassium borate (88% control). In addition to acceptable levels of control for Palmer amaranth, all treatments provided 100% control of johnsongrass. Further experiments are needed to evaluate and refine the selected field use rates of the volatility reducing agent, potassium borate.

Based on two replications of a potassium borate titration low tunnel experiment, potassium borate concentrations ≥0.25 M are sufficient to substantially reduce dicamba volatility as well as satisfy foliar boron requirements in cotton or soybean (unpublished data, 2020).

Practical Applications

Due to the record number of complaints regarding the off-target movement of dicamba in Arkansas following the introduction of the Xtend technology in 2017, addressing dicamba volatility is important to preserve the technology for producers combating resistant weeds.

Potassium borate coupled as a volatility reducing agent and nutritional additive may allow producers to mitigate the off-target movement of dicamba and potentially amend boron deficiencies, which are common in Arkansas. The next step in evaluation is to ensure that the concentration of potassium borate needed to reduce dicamba volatility to an acceptable amount does not sacrifice weed control and is an economical solution for producers that rely on Xtend technology to control problematic weeds.

Acknowledgments

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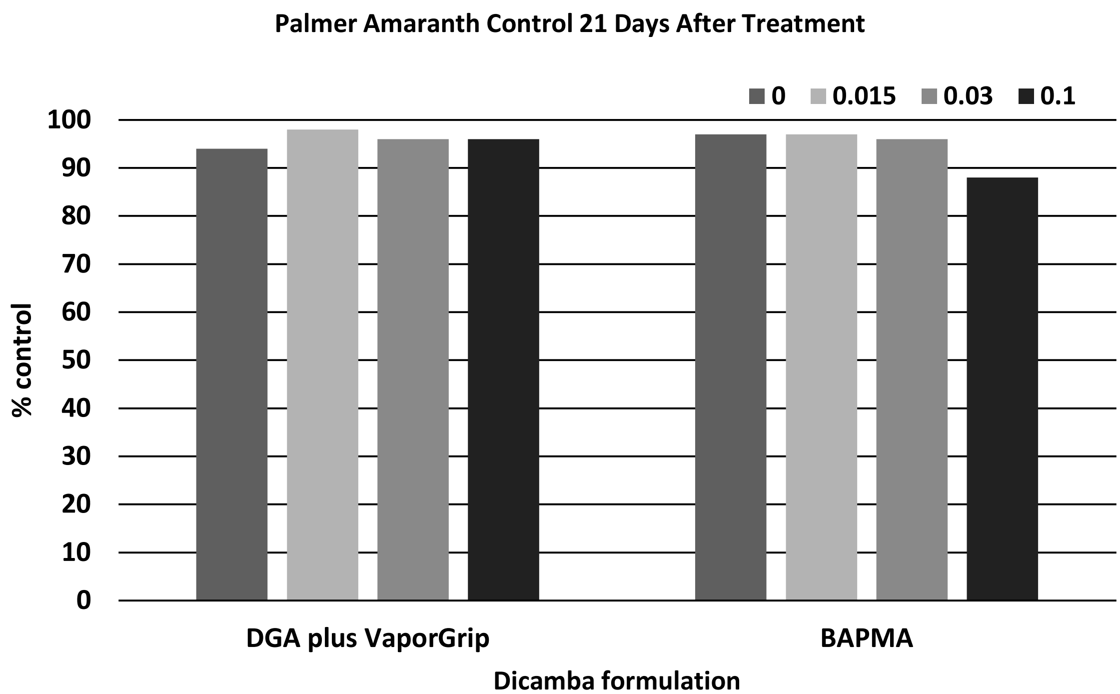

Fig. 1. Palmer amaranth (*Amaranthus palmeri* S. Watts)control 21 days after treatment for the diglycolamine (DGA) plus VaporGrip and N,N-bis(3-aminopropyl)methylamine (BAPMA) formulations of dicamba plus 1.13 lb ae glyphosate/ac combined with potassium borate at 0, 0.015, 0.03, and 0.1 M concentrations. Results were not significantly different at α = 0.05.

Exploring Target Site Mutation in a Glufosinate-Resistant Palmer Amaranth Accession from Arkansas

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Abstract

Palmer amaranth (*Amaranthus palmeri* S. Watson) is a very difficult to control weed in different cropping systems including cotton (*Gossypium hirsutum* L.) and soybean [*Glycine max* (L.) Merr.]. Different chemistries have been used to control it, gradually leading to a loss of susceptibility. A Palmer amaranth accession was collected in eastern Arkansas after the failure of glufosinate to effectively control this weed in cotton. Under greenhouse conditions, the application of glufosinate at the recommended field rate (1×, 32 fl oz/ac) has not been effective. The objective of this research was to elucidate if single nucleotide polymorphisms are involved in the recently documented resistance within this accession. For that purpose, the glutamine synthetase (*GS*) gene was sequenced following standard procedures. Comparison of the nucleotides and their deduced protein between resistant and susceptible accessions have revealed no amino acid substitution at position 171, the site where resistance has occurred in other weeds. The outcome of this research suggests that the resistant accession most likely has a resistance mechanism other than a target-site mutation that leads to the ineffectiveness of glufosinate on this population.

Introduction

Palmer amaranth, (*Amaranthus palmeri* S. Watson) a dioecious North American weed species, is widely distributed across the United States (U.S.) soybean [*Glycine max* (L.) Merr.] production region. It is considered the most troublesome weed of U.S. agriculture because of its resistance to herbicides, prolific seed production, rapid growth, and economic impact on crops resulting from yield loss caused by interference (Bagavathiannan and Norsworthy, 2016; Steckel, 2007; Ward et al., 2013). Palmer amaranth is easily dispersed by water, wildlife including migratory birds, and human activities (Smith et al., 2011; Sosnoskie et al., 2012; Ward et al., 2013). For many years, the management of Palmer amaranth has relied on the use of herbicides. Repeated use of herbicides has selected Palmer amaranth accessions for resistance to a wide array of herbicide sites of action.

Glufosinate is one of the few herbicides that has remained effective for controlling Palmer amaranth. Glufosinate inhibits glutamine synthetase (GS). In higher plants, 2 different isoforms have been reported: 1 that corresponds to the cytosolic (GS1) and the other that comprise the plastidic (GS2). However, their proportion varies depending on the plant species and tissue (Miflin and Habash, 2002; Unno et al., 2006). Glutamine synthetase catalyzes the buildup of L-glutamine from L-glutamate and ammonia. Inhibition of this enzyme results in ammonia accumulation, which has been used as an indication of GS inhibition (Salas-Perez et al., 2018; Takano et al., 2019). At first instance, it was thought that the inhibition of photorespiration causes the plant's death; however, new studies have demonstrated that the production of reactive oxygen species is associated with the toxicity of glufosinate (Edwards et al., 1990; Takano et al., 2019; Takano and Dayan, 2020; Wild and Wendler, 1993).

The objective of this study was to assess the presence of target-site mutations previously reported in other glufosinate-resistant species in a glufosinate-resistant Palmer amaranth accession collected from eastern Arkansas.

Procedures

Young leaf tissue approximately 0.0017 oz (50 mg) of Palmer amaranth plants was collected, placed on 2-mL tubes, and immediately snap-frozen with liquid nitrogen. Total RNA was extracted using a Monarch Total RNA Miniprep Kit (New England Biolabs, Ipswich, Mass.) and quantified spectrophotometrically using a nanodrop (Nanodrop 2000c, Thermo Scientific, Waltham, Mass.). Complementary DNA (cDNA) was obtained by using 1 µg of total RNA as a template using the iScript Reverse Transcription Supermix (Bio-Rad Laboratories Inc., Hercules, Calif.) in 20-µL reaction.

A set of primers was designed based on the glutamine synthetase (*GS*) gene sequence of *A. palmeri* available at http://weedscience.org/Sequence/sequence.aspx and using

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the freely available Primer3Plus software (Untergasser et al., 2007). Thus, the forward (5' TGGCACAAATACTTG-CACCTTAC 3') and reverse (5' CTCAGCCTCAAGTGTTG-GCTC 3') primers were designed to amplify 1259 bp of the *GS* gene. Primers were synthesized by Integrated DNA Technologies (IDT, Coralville, Iowa).

Polymerase chain reactions (PCRs) (25 µL) were performed with 1× Colorless GoTaq Flexi Buffer (Promega Corp., Madison, Wisc.), 1.5 mM $MgCl_2$, 0.2 mM dNTP's, 0.2 µM each forward and reverse primer, 1 µL cDNA, and 0.625 units of GoTaq® Hot Start Polymerase (Promega Corp., Madison, Wisc.) in a T100 thermocycler (Bio-Rad Laboratories Inc., Hercules, Calif.). PCRs cycling conditions were as follows: 94 °C for 2 min., 35 cycles of 94 °C for 30 s, 67 °C for 30 s and 72 °C for 1:20 min, followed by 72 °C for 5 min.

After the PCR cycle, 5 µL of PCR product was visualized in 1.2% agarose gel for 30 min. at 80 v using 1× TBE (tris-borate-EDTA) buffer to assess correct amplification. After PCR products were cleaned up using the Wizard SV Gel and PCR Clean Up System (Promega Corp., Madison, Wisc.) kit and Sanger sequenced (Eurofins Genomics, Louisville, Ken.) in both forward and reverse senses. Raw sequences were reviewed and aligned using the BioEdit (Hall, 1999) and Multalin (Corpet, 1988) software.

Results and Discussion

Sequences obtained and their predictive proteins were searched against the Basic Local Alignment Search Tool (BLAST) for nucleotides (BLASTn) and proteins (BLASTp), respectively. Predictive proteins were obtained using the Open Reading Frame Finder (available at https://www.ncbi.nlm.nih.gov/orffinder/).

A total of 1192 bp of the *GS* gene of the resistant and susceptible plants were sequenced. Alignment of the obtained GS nucleotide sequences using BLASTn demonstrated a high percentage identity (87%) with the GS sequences of quinoa (*Chenopodium quinoa* Willd., GenBank accession number: XM_021872051.1), spinach (*Spinacia oleracea* L., GenBank accession number: XM_021993446.1), and common beet (*Beta vulgaris* L., GenBank accession number: AY026353.1) with an e-value (Expect value) of 0.0.

In addition, alignment of deduced amino acids demonstrated 90% identity with those GS proteins of olive (*Olea europaea* L., GenBank accession number: CAA2957941.1), spinach (GenBank accession number: XP_021849138.1), and quinoa (GenBank accession number: XP_021727743.1) with e-values of 0.0 in all cases.

Comparison of nucleotides between the resistant and susceptible accessions did not show any amino acid change at position 171 (numbered with respect to that of wheat- *Triticum aestivum* L., GenBank accession number: DQ124213.1) as has been described in glufosinate-resistant Italian ryegrass [*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot] (Avila-Garcia et al., 2012; Murphy and Tranel, 2019) (Fig. 1). Further assays have deciphered metabolism as the main resistance mechanism in one accession studied, whereas no amino acid change was detected in another glufosinate-resistant accession (Brunharo et al., 2019). However, the role of such mutation in conferring resistance is unclear, since it does not affect the enzyme sensitivity to glufosinate (Brunharo et al., 2019; Takano and Dayan, 2020).

In other plant systems, such as soybean cell cultures subjected to glufosinate selection, it has been demonstrated that mutation His-249-Tyr is involved in the loss of sensitivity to glufosinate, suggesting the feasibility of plants to evolve target-site resistance (Pornprom et al., 2009).

Practical Applications

Our results suggest that a mechanism other than target-site resistance from a mutation in glutamine synthetase of Palmer amaranth is responsible for the failure of glufosinate to control this population. The use of multiple management tactics is needed to maintain a high level of Palmer amaranth control in soybean, with these strategies relying on more than just herbicide alone. The occurrence of resistance in this population does not mean that glufosinate is no longer effective on most populations of Palmer amaranth in Arkansas, and the use of this herbicide in mixture with other effective herbicides where possible should be considered.

Acknowledgments

The authors acknowledge the support of the Arkansas Soybean Promotion Board and the University of Arkansas System Division of Agriculture.

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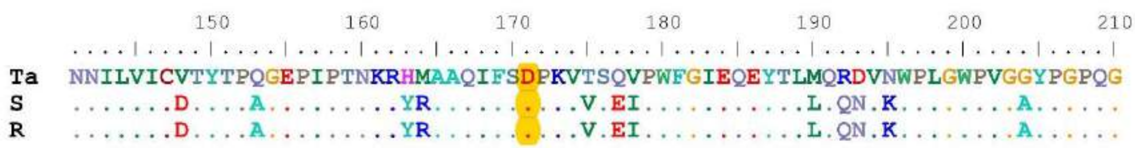

Fig. 1. Partial alignment of the glutamine synthetase gene of *T. aestivum* (Ta), glufosinate-susceptible (S), and glufosinate-resistant (R) accessions of Palmer amaranth. Yellow highlighting indicates amino acid position 171 based on the *T. aestivum* GS sequence (GenBank accession number: DQ124213.1).

Chloroacetamide Residual Activity on Two Palmer amaranth Populations

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Abstract

In 2019 and 2020, 2 experiments were conducted to determine if Group 15 (chloroacetamide) herbicides could continue to control Palmer amaranth and if control differed by application rate. Chloroacetamide herbicides including Dual Magnum®, Outlook®, Warrant®, and Zidua® SC were applied preemergence (PRE) at various rates to determine the length of residual control of a Palmer amaranth (*Amaranthus palmeri* S. Wats) population with known resistance to metolachlor and a population with no known metolachlor resistance. In the 2019 experiment, only Outlook provided control greater than 90% of metolachlor-resistant Palmer amaranth at 2 weeks after application (WAA) at rates of 12.8 oz/ac and 16 oz/ac. All chloroacetamide treatments provided less than 75% control of this population 4 WAA. In the trial conducted in 2020, all chloroacetamide applications provided greater than 90% control of Palmer amaranth with no known metolachlor resistance, excluding either application rate of Warrant 2 WAA. Dual Magnum at 32 oz/ac, Outlook 16 oz/ac, and Zidua at any rate, provided greater than 70% 4 WAA. The highest rate of Zidua (5 oz/ac) provided the most control (85%) in the study by 4 WAA. Chloroacetamide herbicides are not as effective in controlling Palmer amaranth populations with known resistance to metolachlor. Results indicated that Outlook provided the best control to a resistant population at 2 WAA, but control was significantly reduced at the later evaluations. Control of the non-metolachlor-resistant biotype was consistent with all chloroacetamide herbicides, depending on rate, except Warrant.

Introduction

In the past few years, Palmer amaranth's (*Amaranthus palmeri* S. Wats.) resistance to different herbicide modes of action, such as Group 15 chloroacetamide herbicides, has become a growing problem for Arkansas soybean [*Glycine max* (L.) Merr.] producers (Heap 2021). The use of chloroacetamide herbicide chemistry for control of multiple site-of-action resistant Palmer amaranth is not as effective as it had been in recent years (Hill et al., 2020). The objective of this experiment was to determine if chloroacetamide herbicides can continue to aid in residual control of metolachlor-resistant Palmer amaranth and continue to monitor the efficacy of Palmer amaranth populations that have not been identified as metolachlor-resistant. Additionally, application rates were evaluated to determine if higher baselines should be set on populations not identified as resistant.

Procedures

In 2019, an experiment was conducted in Marion, Ark., on a Palmer amaranth population known to be resistant to metolachlor (Group 15) herbicides. The same experiment was repeated in 2020 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station in Marianna, Ark., on a Palmer amaranth population susceptible to metolachlor herbicides. These experiments were conducted on a Dubbs silt loam soil in Marion, Ark., and a Calloway silt loam soil in Marianna, Ark. Both experiments were conducted as a randomized complete block design with plot sizes of 12.6-ft by 30-ft and planted to Credenz variety CZ4410GTLL. Applications were made using a pressurized tractor-mounted sprayer with a spray volume of 12 gals/ac (GPA) with AIXR110015 nozzles. Visual estimations of weed control were taken at 2 and 4 weeks after application (WAA). Dual Magnum® (*S*-metolachlor) was applied at 16, 20.8, and 32 fl oz/ac, Outlook® (dimethenamid) at 12.8 and 16 fl oz/ac, Warrant® (acetochlor) at 32 and 48 fl oz/ac, and Zidua® SC (pyroxasulfone) at 2, 3.25, 4, and 5 fl oz/ac. All herbicides were applied before weed emergence, and an activating rainfall of 0.25 inches was received at both locations within 48 hours of application. Visual estimations of weed control were defined as percent control, where 0% was no control and 100% was complete control when compared to the nontreated plots. Data were analyzed and subjected to analysis of variance and means were separated by Fisher's protected least significant difference test at $\alpha = 0.05$.

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Results and Discussion

In the 2019 experiment, only Outlook provided control greater than 90% of metolachlor-resistant Palmer amaranth at 2 WAA at both rates of 12.8 fl oz/ac and 16 fl oz/ac (Table 1). Warrant at 32 fl oz/ac and 48 fl oz/ac provided the least amount of control 2 WAA at 43% and 60%, respectively. Dual Magnum only provided 64% control with the 16 fl oz/ac rate. When Dual Magnum rate was increased to 32 fl oz/ac control increased to 79%. Zidua SC applied at 3.25 fl oz/ac resulted in 86% control, which was not different than the highest rate (5 fl oz/ac) at 2 WAA (Table 1). All chloroacetamide herbicides provided less than 79% control 4 WAA regardless of the rate applied. A rate response was still evident with Dual Magnum, which ranged in control from 33% with 16 fl oz/ac to 63% following the 32 fl oz/ac rate. Zidua rates of 3.25, 4, and 5.0 fl oz/ac did not differ in control with ratings ranging from 70%–79%, respectively (Table 1).

In 2020, 2 WAA, all chloroacetamide applications provided greater than 90% control of the Palmer amaranth population that was not suspected to be metolachlor-resistant, except for Warrant at either rate (Table 2). Efficacy of Warrant was less than or equal to 59% at both 32 and 48 fl oz/ac rates 2 WAA. By 4 WAA, Outlook at 16 fl oz/ac provided 78% control and only 53% control at 12.8 fl oz/ac. All rates of Dual Magnum had diminished to less than or equal to 74% control by 4 WAA (Table 2). Zidua SC provided greater than 70% control at all rates 4 WAA while providing 85% control at its highest rate of 5 fl oz/ac. The rate response from Dual Magnum was not significant on this population of Palmer amaranth at 4 WAA (Table 2).

Practical Applications

It is important to know if herbicide-resistant Palmer amaranth is present in a field. Although metolachlor resistance is not widespread at this time, populations of Palmer amaranth that are resistant to metolachlor will respond differently to chloroacetamide (Group 15) herbicides and rates applied. Outlook and Zidua SC provided the best control of metolachlor-resistant Palmer amaranth. In situations where metolachlor-resistant Palmer amaranth populations are not widespread, most chloroacetamides will provide over 90% control 2 WAA. However, by 4 WAA, control was significantly reduced, suggesting that postemergence (POST)herbicides will be required to maintain Palmer amaranth control between three and four weeks following initial application of any chloroacetamide herbicide. While some chloroacetamide herbicides do provide control at planting to Palmer amaranth, they should be applied in combination with other mode-of-action herbicides such as metribuzin. These preemergence applications should be followed by timely and effective POST applications to assist in the control of Palmer amaranth.

Acknowledgments

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Table 1. Metolachlor-resistant Palmer amaranth *(Amaranthus palmeri)* control at 2 and 4 weeks after application (WAA) in Marion, Ark. 2019.[a]

Treatment	Rate (s)	Application Timing	2 WAA	4 WAA
	fl oz/ac		--------------------% Control---------------	
Dual Magnum®	16	PRE	64	33
Dual Magnum	20.8	PRE	66	50
Dual Magnum	32	PRE	79	63
Warrant®	32	PRE	43	0
Warrant	48	PRE	60	13
Outlook®	12.8	PRE	95	40
Outlook	16	PRE	98	45
Zidua® SC	2.0	PRE	69	57
Zidua SC	3.25	PRE	86	70
Zidua SC	4.0	PRE	83	72
Zidua SC	5.0	PRE	89	79
LSD (*P* = 0.05)			13.0	13.11

[a] Abbreviations: LSD = least significant difference; fl oz/ac =fluid ounces/acre; PRE = preemergence; WAA = weeks after application.

Table 2. Metolachlor-susceptible Palmer amaranth *(Amaranthus palmeri)* control at 2 and 4 weeks after application (WAA) at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station near Marianna, Ark. 2020.[a]

Treatment	Rate (s)	Application Timing	2 WAA	4 WAA
	fl oz/ac		-----------------% Control----------------	
Dual Magnum®	16	PRE	94	63
Dual Magnum	20.8	PRE	93	68
Dual Magnum	32	PRE	96	74
Warrant®	32	PRE	59	0
Warrant	48	PRE	55	0
Outlook®	12.8	PRE	95	53
Outlook	16	PRE	97	78
Zidua® SC	2.0	PRE	95	73
Zidua SC	3.25	PRE	96	74
Zidua SC	4.0	PRE	97	74
Zidua SC	5.0	PRE	99	85
LSD (*P* = 0.05)			13.0	13.08

[a] Abbreviations: LSD = least significant difference; fl oz/ac = fluid ounces/ac; PRE = preemergence; WAA = weeks after application.

Minimizing Off-target Movement of Florpyrauxifen-benzyl to Soybean

B.L. Cotter,[1] J.K. Norsworthy,[1] J.W. Beesinger,[1] T.R. Butts,[2] and L.T. Barber[2]

Abstract

Following the commercial launch of Loyant® (florpyrauxifen-benzyl) in 2018, frequent off-target movement of the herbicide to adjacent soybean [*Glycine max* (L.) Merr.] fields was observed. Hence, field experiments were conducted in 2020, at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark, to evaluate soybean injury following low rates (0.003 oz ai/ac to 0.094 oz ai/ac) of florpyrauxifen-benzyl applied either as a foliar spray or coated on urea at the V3 stage. In 2 separate field experiments, the response of soybean was evaluated when florpyrauxifen-benzyl was applied in wide-row (36-in.wide rows) and narrow-row (7-in.wide rows) systems at 7, 14, 21, and 28 days after application. In both experiments, 100% soybean injury (death) occurred following foliar spray applications in both wide- and narrow-row soybean. However, when coated on urea, the maximum soybean injury from florpyrauxifen-benzyl occurred at 0.094 oz ai/ac was 20% and 24% in wide- and narrow-row soybean, respectively. At all timings, an equivalent rate of florpyrauxifen-benzyl on urea caused less injury than that of the foliar applications. Overall, florpyrauxifen-benzyl coated on urea reduced soybean injury 50% to 91% and 61% to 92% in wide- and narrow-row soybean, respectively, across all rating dates when compared to foliar applications. Impregnating florpyrauxifen-benzyl onto urea appears to substantially reduce the risk for off-target movement of the herbicide onto soybean and may allow for a means of safely applying the herbicide by air. Additional research is underway to establish the effectiveness of this application technique on weed control.

Introduction

Florpyrauxifen-benzyl is a Weed Science Society of America group 4 synthetic auxin rice (*Oryza sativa*) herbicide that was commercially launched in 2018 as Loyant®. As a rice herbicide, florpyrauxifen-benzyl offers greater than 75% control of many weeds of rice when applied at 0.5 oz ai/ac (Miller and Norsworthy 2018a).

As of 2019, soybean (*Glycine max*) and rice are the top 2 agronomic crops harvested in Arkansas based on harvested acres and the total value of production (NASS 2019). Although florpyrauxifen-benzyl is an effective rice herbicide, there is a potential for off-target movement of the herbicide to adjacent soybean fields. When evaluating multiple crops [soybean, cotton (*Gossypium hirsutum*), corn (*Zea mays*), grain sorghum (*Sorghum bicolor*), sunflower (*Helianthus annuus*)] to florpyrauxifen-benzyl, it was concluded that soybean exhibited the greatest sensitivity to the herbicide (Miller and Norsworthy 2018b). In Arkansas, 51% of herbicide applications were reported by aerial application, and herbicide drift was identified as the main concern (Butts et al., 2021). To reduce the potential of off-target movement via physical drift, coating herbicides onto fertilizers may be one possible solution to the problem. In conservation tillage systems, herbicide-coated fertilizers can help create a uniform coverage because fertilizer granules can infiltrate a crop canopy and residue more effectively (Kells and Meggett, 1985). However, under application can lead to decreased weed control, and over applications can lead to increased crop injury (Wells and Green, 1991). Because of the potential injury to soybean from aerial spray applications of florpyrauxifen-benzyl, experiments were conducted to determine if coating the herbicide onto urea would reduce the risk for soybean injury.

Procedures

Two field experiments evaluating the risk of off-target movement to wide- and narrow-row soybean of florpyrauxifen-benzyl impregnated on urea were conducted in 2020 at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark. Both experiments were conducted as 2-factor randomized complete block designs where seven florpyrauxifen-benzyl rates and 2 application methods were the factors with 4 replications. Credenz soybean variety 4410GTLL (BASF, Florham Park N.J.) was planted on 36-in. wide raised beds at a seeding rate of 145,000 seeds/ac for the

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wide-row experiment, and flat-planted in a 7-in. wide row, using a seed drill, at a seeding rate of 152,700 seeds/ac for the narrow-row experiment on 11 June 2020. Applications were made on 10 July 2020 when soybeans reached the V3 growth stage. The center 2 rows (6 ft) of each plot were treated to prevent contamination from adjacent plots. Foliar-applied florpyrauxifen-benzyl rates of 0, 0.003, 0.006, 0.012, 0.024, 0.047, and 0.094 oz ai/ac were applied to simulate sub-lethal doses of the spray. Florpyrauxifen-benzyl-treated urea was applied at the same rates as the foliar-applied treatments to the center 120 ft^2 of each plot. The florpyrauxifen-benzyl rate of 0.5 oz ai/ac was coated onto 283 urea lb/ac, and rates equivalent to foliar applications were measured and applied to compare injury directly from foliar and coated applications. Visual injury ratings were recorded at 7, 14, 21, and 28 days after the application and evaluated using a 0–100 scale, where 0 represents no injury and 100 complete crop death. Grain yield was harvested from the two center rows in the wide-row experiment and 9 out of 10 rows harvested in the narrow-row experiment. Grain moisture was adjusted to 13%. All injury data were subjected to regression analysis using a Weibull Growth Model for injury level prediction. All yield data were subjected to regression analysis using an Exponential 2P Model to predict yield.

Results and Discussion

In both wide- and narrow-row soybean experiments, coating florpyrauxifen-benzyl onto urea decreased levels of soybean injury (Figs. 1 and 2). At 21 days after treatment and 0.094 oz ai/ac, soybean injury from florpyrauxifen-benzyl coated urea reached 20% and 22% in wide- and narrow-row soybeans, respectively. On the contrary, all soybean plants were killed by the florpyrauxifen spray at 0.094 oz ai/ac in both experiments. Across all rating timings, coating florpyrauxifen-benzyl onto urea decreased soybean injury 50% to 91% and 61% to 92% in wide- and narrow-row soybean, respectively. Coating florpyrauxifen-benzyl onto urea caused no effect on yield in both soybean experiments, whereas foliar drift rates had a significant reduction in yield (Figs. 3 and 4). Both experiments resulted in complete soybean yield loss when 0.094 oz ai /ac of florpyrauxifen-benzyl was foliar applied. Coating florpyrauxifen-benzyl onto urea appears to be an effective application method to reduce the risk of off-target movement via physical drift.

Practical Applications

Florpyrauxifen-benzyl is currently being applied aerially in limited amounts in Arkansas because of the risk for physical drift of the herbicide to soybean. Coating florpyrauxifen-benzyl onto urea would provide a safer means of herbicide application, as well as, potentially decreasing the required number of aerial applications at the pre-flood timing in rice by combining a herbicide and fertilizer application. Urea granules are larger in size and weight than other nitrogen fertilizers available and would be less likely to move off-target from a physical drift occurrence. Florpyrauxifen-benzyl is needed as an additional herbicide option in rice production with an increasing amount of herbicide-resistant weeds.

Acknowledgments

This research was conducted in cooperation with Corteva Agriscience Inc. We would like to thank Corteva for partially funding this research and providing the florpyrauxifen-benzyl. Partial support for this research was also provided by the Arkansas Soybean Checkoff Program administered by the Arkansas Soybean Promotion Board and United Soybean Board. Lastly, the facilities were made possible by the University of Arkansas System Division of Agriculture.

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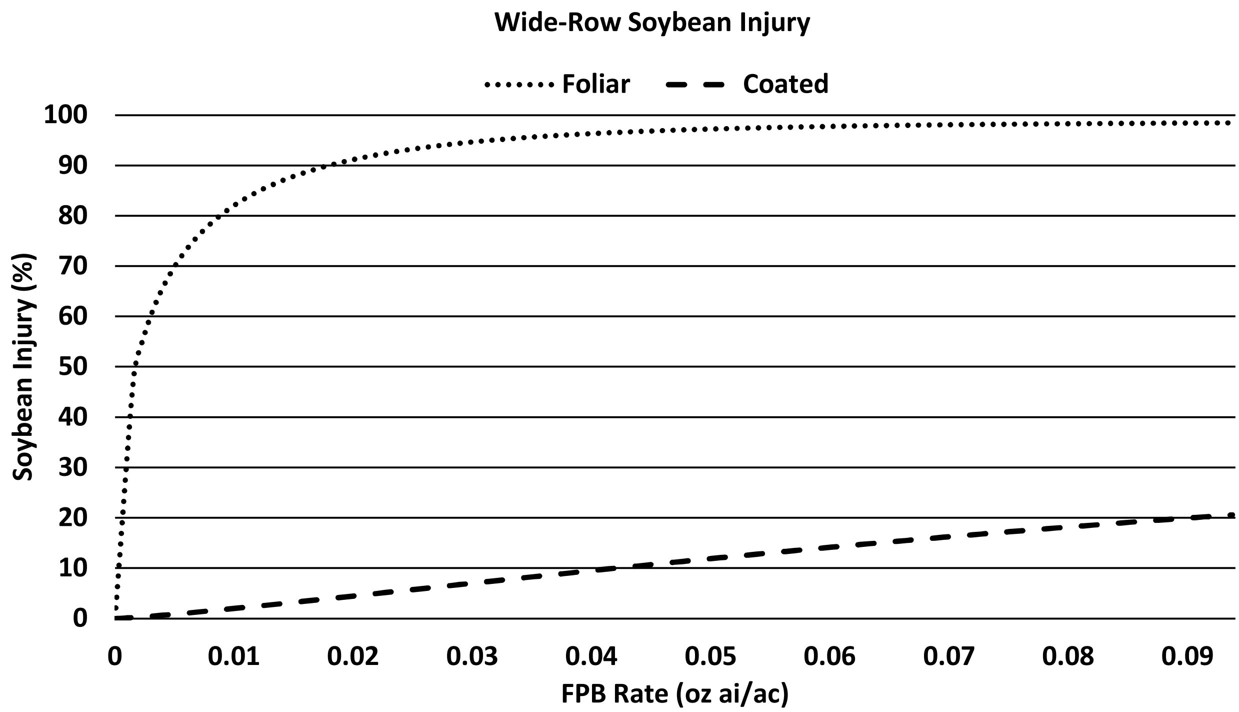

Fig. 1. Weibull growth model, Y = a(1-EXP(-(rate/b)c)), of wide-row soybean visual injury 21 days after treatment of florpyrauxifen-benzyl (FPB) applications. Foliar treatments produced an R^2 = 0.985 and coated treatments produced an R^2 = 0.872.

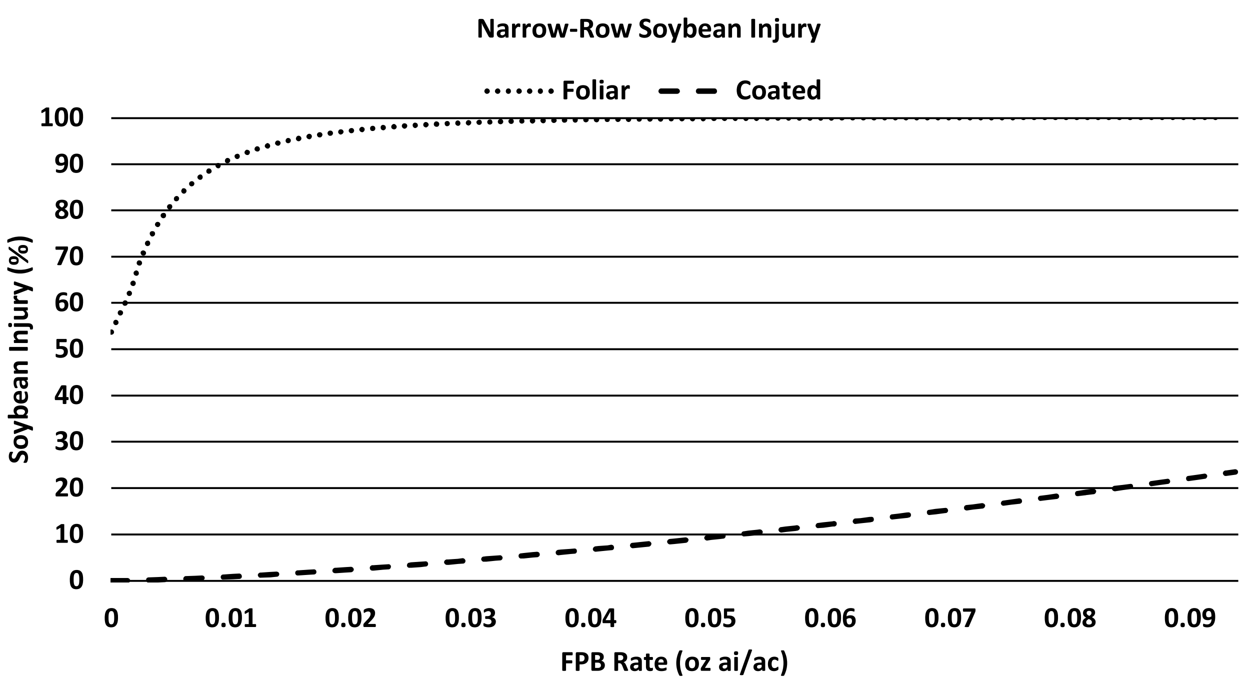

Fig. 2. Weibull growth model, Y = a(1-EXP(-(rate/b)c)), of narrow-row soybean visual injury 21 days after treatment of florpyrauxifen-benzyl (FPB) applications. Foliar treatments produced an R^2 = 0.993 and coated treatments produced an R^2 = 0.942.

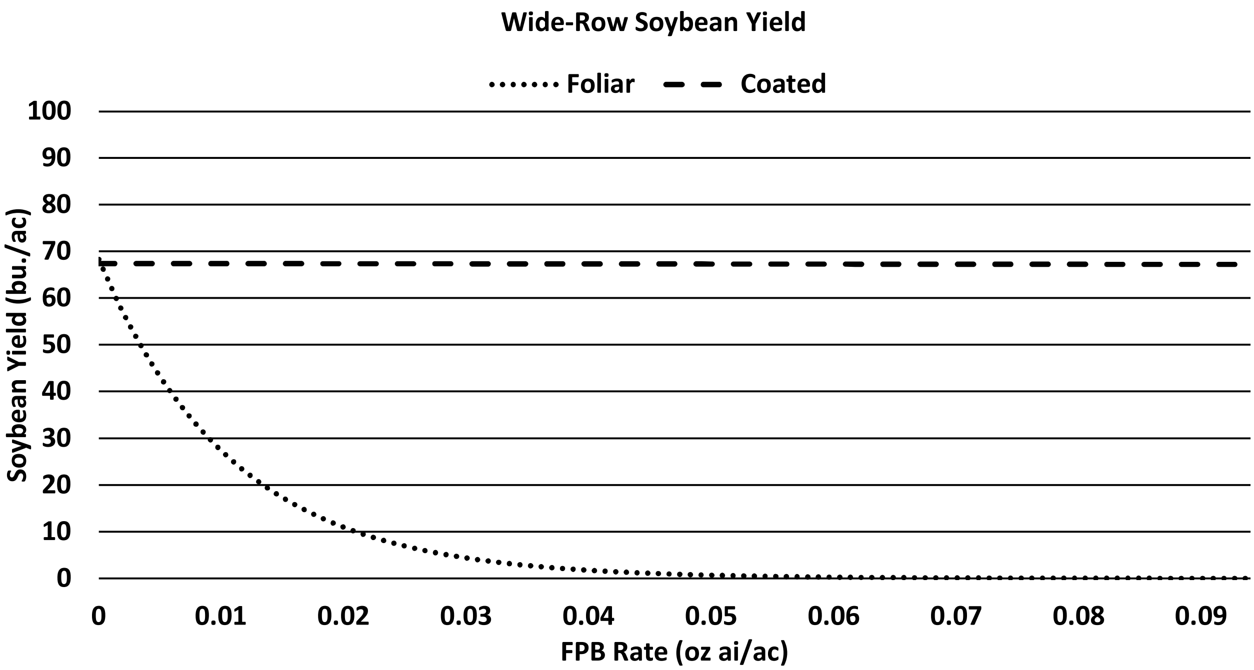

Fig. 3. Exponential 2P model, Y = a(EXP(b*rate)), of wide-row soybean yield. Florpyrauxifen-benzyl (FPB) foliar treatments produced an R^2 = 0.939 and coated treatment means were averaged due to no differences.

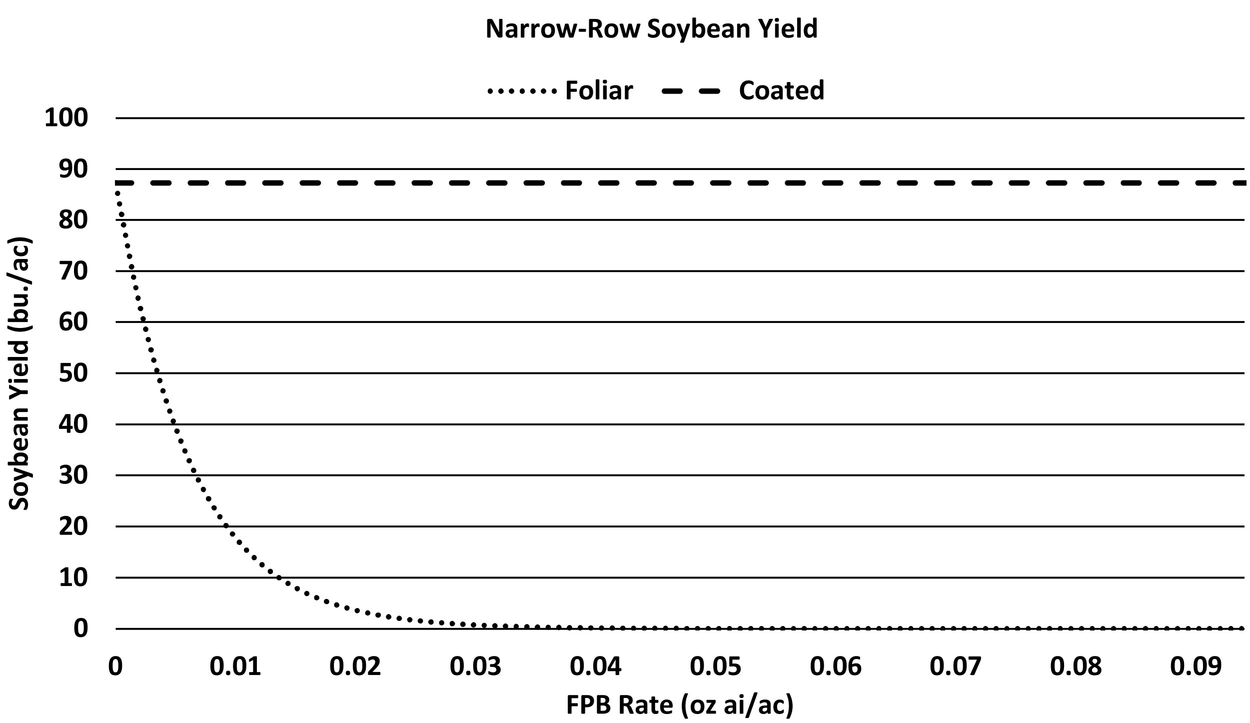

Fig. 4. Exponential 2P model, Y = a(EXP(b*rate)), of narrow-row soybean yield. Florpyrauxifen-benzyl (FPB) Foliar treatments produced an R^2 = 0.905 and coated treatment means were averaged due to no differences.

Optimization of Roller Wiper Applications of Dicamba in Soybean

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Abstract

The commercialization of dicamba-resistant soybean [*Glycine max* (L.) Merr.] has brought forth concerns of off-target movement of dicamba onto non-target vegetation. In order to mitigate off-target movement, producers and applicators are considering applications that do not broadcast herbicide via spray droplets, such as rope wicks and other wiper-type applicators. While wiper-type applications have been made in-crop before, the use of auxin-type herbicides such as dicamba has not been investigated. Two studies were conducted at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center near Keiser and the Milo J. Shult Agricultural Research and Extension Center in Fayetteville in the summer of 2020 to determine the optimum application parameters for roller wiper application of dicamba in soybean. This study was designed as a 3-factor factorial with the first factor being target weed height, the second being herbicide concentration, and the third being the number of application directions. Results from these studies found that Palmer amaranth [*Amaranthus palmeri* (S.) Wats.] mortality increased from 31% for a single application direction to 43% with the addition of a second application direction. Mortality also increased from 30% to 44% as a result of increased herbicide concentration. An increase in soybean injury was observed with the higher herbicide concentration, but there was no impact on grain yield. The findings from this study could aid producers in optimizing wiper applications of dicamba if these practices become common.

Introduction

Dicamba is an effective herbicide option for postemergence control of glyphosate and protoporphyrinogen oxidase (PPO)-resistant Palmer amaranth [*Amaranthus palmeri* (S.) Wats.] in dicamba-resistant soybean [*Glycine max* (L.) Merr.] in Arkansas (Coffman et al., 2021). However, concerns regarding the off-target movement of dicamba onto non-target vegetation have lead producers and applicators to search for innovative strategies to reduce any unintentional damage caused by dicamba. Off-target movement of dicamba is typically categorized into 3 categories: volatilization, physical spray drift, and tank contamination (Steckel et al., 2010). One particular application strategy that is being considered to reduce particle drift is wiper-type applicators such as rope wicks and roller wipers. Wiper-type applicators were previously used to apply non-selective herbicides like glyphosate to weeds, such as johnsongrass [*Sorghum halepense* (L.) Pers.], that grew above crop canopy before the commercialization of glyphosate-resistant soybean (Keeley et al., 1984; Schneider et al., 1982). By only applying herbicide on what the wiper or wick touches, the risk of particle drift is greatly reduced, but the reduction of volatility is not likely. As a result, two studies were conducted in the summer of 2020 to determine how to most effectively utilize roller wiper applications of dicamba for Palmer amaranth control in soybean.

Procedures

Research studies were conducted in the summer of 2020 at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark. and the Northeast Research and Extension Center (NEREC) near Keiser, Ark. to investigate the potential of utilizing roller wiper applicators for Palmer amaranth control in soybean. At both locations, dicamba-resistant Asgrow 46X6 (Bayer CropScience, St. Louis, Ill.) soybean was planted on 36-in. row spacings at Fayetteville and on 38-in. row spacings at Keiser. This study was designed as a randomized complete block with a three-factor factorial (3 × 2 × 2) with the first factor being the target Palmer amaranth height at application (8–12 in., 16–20 in., and 24–28 in.), the second being herbicide concentration [1 part Xtendimax®:1 part Roundup PowerMax®:6 parts water (v:v:v) or 1 part Xtendimax:1 part Roundup PowerMax:2 parts water (v:v:v)], and the third factor being application direction (one or two

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passes down the row). A nontreated check was included for comparison.

All plots besides the nontreated control were treated with *S*-metolachlor at 0.5 lb ai/ac (Dual Magnum®) at planting using a CO_2-pressurized backpack sprayer at 15 gal/ac using TeeJet AIXR 110015 nozzles. Roller wiper applications were made using a 6-foot Grassworks weed wiper (Fig. 1) placed 4 in. into the crop canopy. The ground speed of the tractor was 5.3 mph. Initial applications were made when Palmer amaranth measured 8–12 in. in height.

At the time of initial postemergence application, 10 Palmer amaranth plants were marked with orange marking paint at the base to assess mortality (proportion of dead to alive plants) at 28 days after final application (DAFA). Visible estimates of soybean injury caused by wiping a high concentration of herbicide on the crop were taken at 7, 14, 21, and 28 DAFA on a scale of 0–100, where 0 represents no plant symptomology and 100 represents plant death. Xtend® soybean are typically not injured by spray applications of glyphosate and dicamba, but the high concentration of both herbicide products in the wiper was expected to cause some injury due to the amount of solvents in the formulated products. Soybean grain from the 2 treated rows of each plot was harvested at maturity. Data were analyzed using R version 4.0.3 and subjected to analysis of variance (ANOVA) using least significant difference (LSD) with Tukey's adjustment at $\alpha = 0.05$.

Results and Discussion

Palmer amaranth mortality at 28 DAFA was influenced by the number of application directions made by the roller wiper. The additional application direction resulted in an increase in Palmer amaranth mortality from 31% to 43% when compared to the single application direction (Table 1). The increase in control and mortality may be attributed to an increase in coverage by the roller wiper when applying from two different directions. As the tractor and roller wiper moved through the plots, large Palmer amaranth were pushed forward, potentially covering one side of the plant, but with the second application direction, the other side of the weed would be able to contact the roller wiper. Palmer amaranth mortality at 28 DAFA was also dependent on the concentration of herbicide applied. Treatments receiving the high concentration of herbicide (1 part Xtendimax:1 part Roundup Powermax:2 parts water) resulted in 44% Palmer amaranth mortality as opposed to the low concentration, which resulted in 30% mortality (Table 1). This difference can be attributed to the increased amount of the active ingredient that would be available in the solution when the wiper contacts the plant.

Additionally, Palmer amaranth mortality at 28 DAFA was dependent on an interaction between target weed height and location. At Keiser, there were no differences in mortality between all three target weed heights, which ranged from 17% mortality for the 8–12 in. height target to 38% mortality for the 24–28 in. target height. At Fayetteville, there were significant differences, where the 8–12 in. and the 16–20 in. target weed heights resulted in the greatest mortality at 53% and 60%, respectively, while the tallest target height (24–28 in.) resulted in the lowest Palmer amaranth mortality with 31% mortality (Table 1). The cause for the difference between the 2 locations may be due to differences in Palmer amaranth density, where the density of Palmer amaranth at Keiser was 270 plants/ft^2 and the densitiy at Fayetteville was 80 plants/ft^2. The increased densities may have allowed Palmer amaranth to cover other Palmer amaranth as the wiper moved through the plots. In contrast, plots with lower densities would not have had the same protection. In Keiser, the reduced control at the taller target height may be attributed to the reduced control typically observed when attempting to control large weeds with salvage applications.

Visible soybean injury at 14 days after the application was impacted by the herbicide concentration applied. The high concentration resulted in significantly greater soybean injury with 9% injury observed compared to only 6% after soybean was subjected to the lower concentration (Table 1). Similar to the effect seen with Palmer amaranth mortality, the increased soybean injury may be attributed to the increased amount of formulated product in solution in the high concentration relative to the low concentration. Though the soybean used in this study is resistant to both glyphosate and dicamba, the associated adjuvants in the formulated product, especially at these high concentrations, may be enough to cause the chlorosis that was observed in the upper leaves of the plant (Fig. 2). The observed injury in this trial did not hurt soybean yield, however, as there were no differences in crop yield (Table 1).

Practical Applications

Findings show that to optimize the effectiveness of the roller wiper for managing Palmer amaranth, applications must be made using a high concentration of product and wiped from two directions. Applications should be made when a majority of weeds are at or slightly above the crop canopy to ensure adequate coverage, but before weeds become larger than 24 in. as weed control continues to decrease as weed size increases. While roller wiper applications may be optimized at these parameters, the overall mortality of Palmer amaranth was still low, especially relative to what may be provided by broadcast applications as seen in other research studies where dicamba was used (Farr et al., 2020; Priess et al., 2020; Coffman et al 2021). Additionally, allowing Palmer amaranth to interfere with soybean early in the season before becoming large enough to treat could harm soybean yield.

Acknowledgments

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(A) (B)

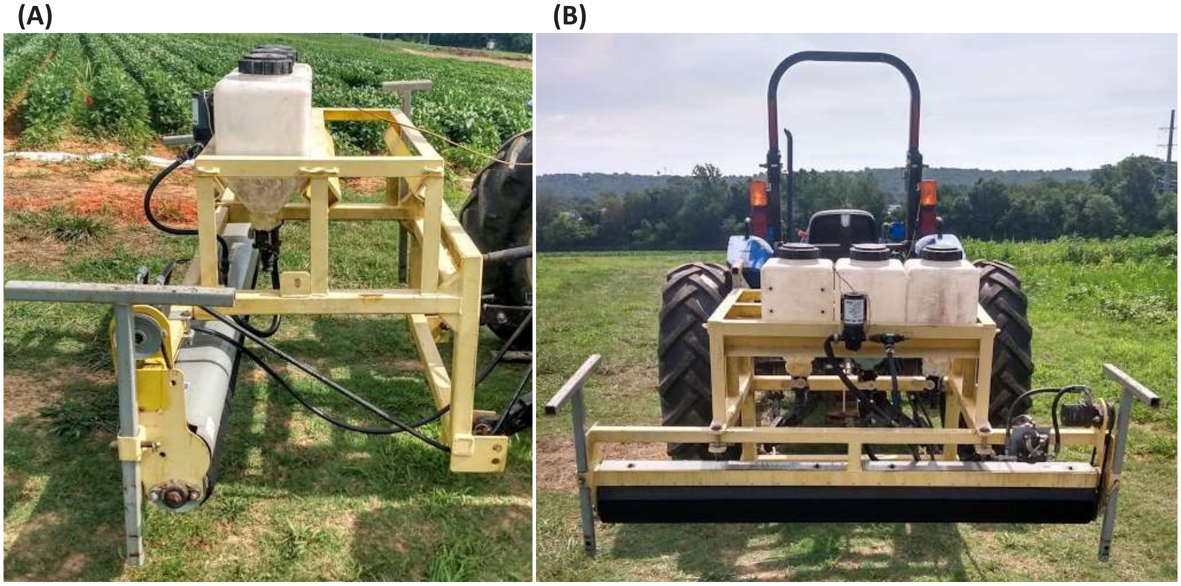

Fig. 1. Side (A) and rear (B) view of the two-row Grassworks® roller wiper used for both studies.

Fig. 2. Image of chlorotic soybean injury as a result of roller wiper application 14 days after final treatment.

Table 1. Palmer amaranth [*Amaranthus palmeri* (S.) Watts.] mortality at 28 days after final application (DAFA), soybean injury 14 DAFA, and soybean yield from the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center near Keiser and the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark. in 2020.

Treatment		Palmer amaranth mortality 28 DAFA[†]		Soybean injury 14 DAFA		Yield
		------------------------%------------------------				bu./ac
Rate[‡]						
High		44	a	9	a	42
Low		30	b	6	b	46
Direction[§]						
One		31	b	7		45
Two		43	a	8		45
Location	Target height					
Fayetteville	8–12 in.	53	ab	-		-
	16–20 in.	60	a	-		-
	24–28 in.	31	c	-		-
Keiser	8–12 in.	17	c	-		-
	16–20 in.	24	c	-		-
	24–28 in.	38	bc	-		-

[†] Means followed by the same letter are not significantly different at $P = 0.05$.

[‡] High rate = 1 part Xtendimax:1 part Roundup Powermax:2 parts water; low rate = 1 part Xtendimax:1 part Roundup PowerMax:6 parts water.

[§] Direction = one or two passes down the row.

Soybean Varietal Tolerance to Preemergence Metribuzin

M.M. Houston,[1] J.K. Norsworthy,[1] J.R. Ross,[2] T.R. Butts,[2] L.T. Barber,[2] and L.B. Piveta[1]

Abstract

Metribuzin is a photosystem II (PSII) inhibitor, primarily used as a preemergence (PRE) herbicide for residual weed control in soybean [Glycine max (L.) Merr.]. This herbicide, widely used in the mid-South for control of Palmer amaranth [Amaranthus palmeri (S.) Wats] in soybean, can cause severe injury and yield loss if a highly sensitive variety is planted and sprayed. Because of the importance of metribuzin in soybean for control of Palmer amaranth in Arkansas, a greenhouse screening was conducted in 2020 evaluating current soybean varieties and their tolerance to a labeled rate of soil-applied metribuzin. Injury, which was evaluated at 14 and 21 days after treatment (DAT), showed that nearly 59% of the tested varieties showed little to no response. Thirty-six percent of the tested varieties showed symptoms and were labeled as moderately tolerant to the herbicide. The remaining 5% of varieties screened exhibited severe injury when treated with metribuzin and should be avoided if metribuzin is included in a weed control program. Regardless of the herbicide technology chosen by a grower, there are sufficient varieties that allow metribuzin to be integrated into weed control programs that focus on controlling Palmer amaranth.

Introduction

Metribuzin is primarily used as a preemergence (PRE) herbicide in soybean [*Glycine max* (L.) Merr.], targeting both dicotyledonous and monocotyledonous weed species. Research has shown that when applied at or above 0.45 pounds of active ingredient per acre (lb ai/ac) or 500 grams active ingredient per hectare (g ai/ha), PRE metribuzin significantly reduced the emergence of junglerice [*Echinochloa colona* (L.) Link], large crabgrass [*Digitaria sanguinalis* (L.) Scop.], and Palmer amaranth among other weeds (Meyers et al., 2017; Tuti and Das 2011). In Arkansas, with Palmer amaranth already confirmed resistant to 7 Weed Science Society of America (WSSA) sites of action, metribuzin-containing PRE-herbicide programs are necessary for soybean producers to control multi-resistant Palmer amaranth (Houston et al., 2019).

Metribuzin is a WSSA group 5 herbicide belonging to the *s*-triazine chemical family. Metribuzin, like other *s*-triazine herbicides when soil-applied, shows a decrease in soil adsorption and plant phytotoxicity with an increase in pH and vice versa (Ladlie et al., 1976). Naturally, the inclusion of this herbicide into potential weed control programs must be evaluated with caution of several key factors such as soil pH, organic matter, and texture. Another important factor in the potential use of metribuzin is crop varietal tolerance. Differences in soybean varietal response to metribuzin have long been documented. Therefore, due to the importance of this herbicide to Arkansas soybean producers, screening of varieties entered into the University of Arkansas System Division of Agriculture's Official Variety Testing Program was performed for metribuzin tolerance (https://www.mssoy.org/uploads/files/metribuzin-screening-all-yr-ua.pdf).

Procedures

In the fall of 2020, 170 soybean varieties were tested for metribuzin tolerance at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark. The screening was conducted in the greenhouse, with soil being a Captina silt-loam (fine-silty, siliceous, active, mesic Typic Fagiudult) with a pH of 6.4, and organic matter content of 1.82%. All 170 varieties were planted in Sterilite® 6-quart (5.7 liter) plastic containers (13.2-in. long × 8.3-in. wide × 4.9-in. tall, 35.56 cm long × 21 cm wide × 12.4 cm tall) filled with the soil previously mentioned. Each variety was replicated 4 times, with 3 being treated and 1 used as a nontreated comparison. Each variety consisted of 10 seeds per replication, with a maximum of 4 separate varieties per container. Directly after planting, metribuzin was applied to the soil surface at a rate of 0.5 lb ai/ac (560 g ai/ha). The applications were conducted in a spray chamber with a set speed of 1 mph (1.6 km/h) producing a volume of 20 gal/ac (GPA; 187 L/ha). The 2-nozzle

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boom, which was set at a height of 18 in. (46 cm), contained TP 1100067 Teejet® extended range nozzles spaced 20-in. (51 cm) apart. After application, all containers were transported into the greenhouse where overhead irrigation was used to activate the metribuzin.

Data were collected in the form of percent injury relative to the nontreated control at 14 and 21 DAT and subsequently converted into 3 categorical groupings based on the level of injury observed. The categories are as follows: Slight–some symptoms observed in the greenhouse, but unlikely to show field-level injury if applied at the correct labeled rate, depending on the target soil type; Moderate–symptoms present in the greenhouse, likely to show field-level injury even if applied at lower rates for the target soil type; Severe–extreme symptoms observed; any formulation or labeled rate is expected to show detrimental injury and subsequent yield loss.

Results and Discussion

Out of the total 170 varieties tested, there were 100 varieties categorized as having a Slight response (58.8%) (Table 1), 61 as a Moderate response (35.9%) (Table 2), and 9 as a Severe response (5.3%) (Table 3). The varieties severely injured included: Credenz CZ 4941X, Credenz CZ 4979X, Credenz CZ 5700X, Delta Grow DG46X65, Delta Grow DG52E15, DONMARIO 44X31, Dyna-Gro S52XS39, Local LS5386X, and Progeny 5170RX (Table 3). There was no discernable trend of tolerance based on criteria of seed company, herbicide technology trait, or maturity group for these varieties. Numerous soybean varieties and respective herbicide technology traits are available in the Slight category, providing producers with several options of each if metribuzin is included in their weed control program. Metribuzin mixed with another residual herbicide is recommended if soil characteristics are such that allow its use for control of multi-resistant Palmer amaranth.

Practical Applications

Producers have a wide selection of soybean varieties, regardless of the maturity group, herbicide technology trait, or seed distributor for use in soybean. Care should be taken to avoid planting varieties categorized as having a severe response if metribuzin is to be used as part of a soybean weed control program.

Acknowledgments

The authors would like to thank the Arkansas Soybean Promotion Board for funding the screening of soybean varieties for metribuzin tolerance, and the University of Arkansas System Division of Agriculture for their support.

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Table 1. Slight categorical injury rating of 2020 soybean varieties to preemergence (PRE) metribuzin application (0.5 lb ai/ac). Rating taken at 28 days after treatment (DAT).

Variety[a,b]	Herbicide Technology Trait[c]	Maturity Group
AgriGold G4620RX	Xtend	4.6
AgriGold G4820RX	Xtend	4.8
AgriGold G4995RX	Xtend	4.9
Armor 44-D49	Xtend	4.4
Armor 44-D92	Xtend	4.4
Armor 44-E44	Enlist	4.4
Armor 46-E50	Enlist	4.6
Armor 48-E81	Enlist	4.8
Armor 49-D14	Xtend	4.9
Armor 51-E53	Enlist	5.1
Asgrow AG 45X8	Xtend/SR	4.5
Asgrow AG 48X9	Xtend/SR	4.8
Asgrow AG 49X0	Xtend/SR	4.9
Asgrow AG 53X9	Xtend	5.3
Credenz CZ 3930GTLL	LL/GT27	3.9
Credenz CZ 4410GTLL	LL/GT27	4.4
Credenz CZ 4730X	Xtend	4.7
Credenz CZ 5000X	Xtend	5.0
Credenz CZ 5251X	Xtend	5.3
Credenz CZ 5299X	Xtend	5.2
Credenz CZ 6020X	Xtend	6.0
Delta Grow DG4880	RR2	4.8
Delta Grow DG48E10	E3	4.8
Delta Grow DG48X05	Xtend	4.8
Delta Grow DG49X25	Xtend	4.9
Delta Grow DG50E10XP	E3	5.0
Delta Grow DG52E22	E3	5.2
Delta Grow DG54X25	Xtend	5.4
DM 51X61	Xtend	5.1
Dyna-Gro S43EN61	E3	4.3
Dyna-Gro S43XS70	Xtend/STS	4.3
Dyna-Gro S47XT20	Xtend	4.7
Dyna-Gro S48XT90	Xtend	4.8
Dyna-Gro S49EN79	E3	4.9
Eagle Seed ES4640RYX	Xtend	4.6
Eagle Seed ES4772R2Y	RR2	4.7
Eagle Seed ES4880RYX	Xtend	4.8
Go Soy 481E19	Enlist	4.8
Go Soy 491E19S	Enlist/STS	4.9
Go Soy 512E21	Enlist	5.1
GT Ireane	RR1	4.9
Integra 54606NS	Xtend/STS	4.6
Integra 54660NS	Xtend/STS	4.6

Continued

Table 1. Continued.

Variety[a,b]	Herbicide Technology Trait[c]	Maturity Group
Integra 54816N	Xtend	4.8
Integra 54920NS	Xtend/STS	4.9
LGS4464RX	Xtend	4.4
LGS4899RX	Xtend	4.8
Local LS3976X	Xtend	3.9
Local LS4299XS	Xtend/STS	4.2
Local LS4795XS	Xtend/STS	4.7
Local LS5009XS	Xtend/STS	5.0
Local LS5087X	Xtend	5.0
Local LSX3911GL	LL/GT27	3.9
Local LSX4711GL	LL/GT27	4.7
Local LSX4812XS	Xtend/STS	4.8
Local ZS4694E3S	E3/STS	4.6
Local ZS5098E3	E3	5.0
Mission A4448X	Xtend	4.4
Mission A4828X R	Xtend	4.8
Mission A4950X	Xtend	4.9
Petrus Seed 4619 GTS	RR1	4.6
Petrus Seed 4916 GT	RR1	4.9
Petrus Seed 5319 GT	RR1	5.3
Pioneer P46A86X	Xtend	4.6
Pioneer P47A76L	LL	4.7
Pioneer P48A60X	Xtend	4.8
Pioneer P49A41L	LL	4.9
Pioneer P49T62E	E3	4.9
Progeny 4265RXS	Xtend/STS	4.2
Progeny 4444RXS	Xtend/STS	4.6
Progeny 4505RXS	Xtend/STS	4.5
Progeny 4700RXS	Xtend/STS	4.7
Progeny 4807E3S	E3/STS	4.8
Progeny 4902E3	E3	4.9
Progeny 4908E3S	E3/STS	4.9
Progeny 4970RX	Xtend	4.9
Progeny 5016RXS	Xtend/STS	5.0
Progeny 5554RX	Xtend	5.5
R13-13997[b]	Conv.	5.5
R13-14635RR:0010[b]	RR1	4.8
R13-14635RR:0013[b]	RR1	4.8
R14-1422[b]	Conv.	5.4
R15-1587[b]	Conv.	5.1
R16-247[b]	Conv.	4.9
R16-259[b]	Conv.	4.6
R17-2000[b]	Conv.	4.7
R17-2069[b]	Conv.	4.8

Continued

Table 1. Continued.

Variety[a,b]	Herbicide Technology Trait[c]	Maturity Group
R17C- 1182[b]	Conv.	4.7
R17C-1266[b]	Conv.	4.9
S16-11651C[b]	Conv.	5.3
S16-3747RY[b]	RR2	5.0
S16-5504R[b]	RR1	4.6
Taylor T4880XS	Xtend	4.8
Taylor T4990XS	Xtend	4.9
USG 7461XT	Xtend	4.6
USG 7471ETS	E3/STS	4.7
USG 7480XT	Xtend	4.8
USG 7491ETS	E3/STS	4.9
USG 7496XTS	Xtend/STS	4.9

[a] Abbreviations: DM = DONMARIO; USG = UniSouth Genetics.

[b] Varieties are breeding lines labeled with current designation.

[c] Abbreviations: Conv. = Conventional; Enlist = Enlist™; E3 = Enlist 3™; LL = LibertyLink®; LL/GT27 = LibertyLink®GT27™; RR1 = RoundupReady®; RR2 = RoundupReady2®; SR = sulfonylurea ready; STS = sulfonylurea tolerant soybean; Xtend = Xtend®.

Table 2. Moderate categorical injury rating of 2020 soybean variety to preemergence (PRE) metribuzin application (0.5 lb ai/ac). Ratings taken at 28 days after treatment (DAT).

Variety[a,b]	Herbicide Technology Trait[c]	Maturity Group
Armor 46-D09	Xtend	4.6
Armor 47-E02	Enlist	4.7
Armor 48-D25	Xtend	4.8
Asgrow AG 43X0	Xtend/SR	4.3
Asgrow AG 46X0	Xtend/SR	4.6
Asgrow AG 46X6	Xtend	4.6
Asgrow AG 52X9	Xtend/SR	5.2
Asgrow AG 53X0	Xtend	5.3
Credenz CZ 4280X	Xtend	4.2
Credenz CZ 4341X	Xtend	4.3
Credenz CZ 4570X	Xtend	4.5
Credenz CZ 4600X	Xtend	4.6
Credenz CZ 4770X	Xtend	4.7
Credenz CZ 4810X	Xtend	4.8
Credenz CZ 4869X	Xtend	4.8
Delta Grow DG45E10	E3	4.5
Delta Grow DG45E28XP	E3	4.5
Delta Grow DG46X05	Xtend/STS	4.6
Delta Grow DG47E20	E3/STS	4.7
Delta Grow DG47E80	E3/STS	4.7
Delta Grow DG47X95	Xtend/STS	4.7
Delta Grow DG48E49	E3/STS	4.8
Delta Grow DG48X45	Xtend	4.8
Delta Grow DG49E00	E3/STS	4.7
Delta Grow DG49X15	Xtend	4.9
Delta Grow DG51E60	E3	5.1
Delta Grow DG52X05	Xtend/STS	5.2
DM 45X61	Xtend	4.5
DM 47X39	Xtend	4.7
DM 49X13	Xtend	4.9
Dyna-Gro S45ES10	E3/STS	4.5
Dyna-Gro S46ES91	E3/STS	4.6
Dyna-Gro S46XS60	Xtend/STS	4.6
Dyna-Gro S48XT40	Xtend	4.8
Dyna-Gro S49XT70	Xtend	4.9
Go Soy 463E20S	Enlist/STS	4.6
LGS4632RX	Xtend	4.6
Local LS4407X	Xtend	4.4
Local LS4565XS	Xtend/STS	4.5
Local LS4999X	Xtend	4.9
Local LSX4612XS	Xtend/STS	4.6
Mission A4618X	Xtend	4.6
Progeny 4241E3	E3	4.2
Progeny 4602LR	LL/GT27	4.6

Continued

Table 2. Continued.

Variety[a,b]	Herbicide Technology Trait[c]	Maturity Group
Progeny 4682E3	E3	4.6
Progeny 4775E3S	E3/STS	4.7
Progeny 4816RXS	Xtend/STS	4.8
Progeny 4821RX	Xtend	4.8
Progeny 4851RX	Xtend	4.8
Progeny 5211E3	E3	5.2
Progeny 5252RX	Xtend	5.2
R13-14635RR:0009[b]	RR1	4.8
R15-2422[b]	Conv.	4.7
R16-1445[b]	Conv.	5.4
R16-253[b]	Conv.	4.6
R17-7443RR[b]	RR1	5.2
R17C-1056[b]	Conv.	4.7
R17C-1308[b]	Conv.	4.7
USG 7447XTS	Xtend/STS	4.4
USG 7489XT	Xtend	4.8

[a] Abbreviations: DM = DONMARIO; USG = UniSouth Genetics.
[b] Varieties are breeding lines labeled with current designation.
[c] Abbreviations: Conv. = Conventional; Enlist = Enlist™; E3 = Enlist 3™; LL/GT27 = LibertyLink®GT27™; RR1 = RoundupReady®; SR = sulfonylurea ready; STS = sulfonylurea tolerant soybean; Xtend = Xtend®.

Table 3. Severe categorical injury rating of 2020 soybean varieties to preemergence (PRE) metribuzin application (0.5 lb ai/ac). Ratings taken at 28 days after treatment (DAT).

Variety[a,b]	Herbicide Technology Trait[c]	Maturity Group
Credenz CZ 4941X	Xtend	4.9
Credenz CZ 4979X	Xtend	4.9
Credenz CZ 5700X	Xtend	5.7
Delta Grow DG46X65	Xtend/STS	4.6
Delta Grow DG52E15	E3/STS	5.2
DM 44X31	Xtend	4.2
Dyna-Gro S52XS39	Xtend/STS	5.2
Local LS5386X	Xtend	5.3
Progeny 5170RX	Xtend	5.1

[a] DM = DONMARIO.
[b] Varieties are breeding lines labeled with current designation.
[c] Abbreviations: E3 = Enlist 3™; STS = sulfonylurea tolerant soybean; Xtend = Xtend®.

Evaluation of Multiple Growth Regulating Herbicides Effect on Soybean Injury at Vegetative and Reproductive Growth Stages

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Abstract

Off-target movement of spray particles, vapor drift, and tank contamination has occurred with the use of synthetic auxin herbicides near crops that are not resistant. Field trials were conducted in 2020 to evaluate the effects of multiple rates of auxin herbicides [2,4-D (Enlist One®), dicamba (Xtendimax®), florpyrauxifen-benzyl (Loyant®), and quinclorac (Facet®)] on susceptible soybean [*Glycine max* (L.) Merr] during different growth stages. Visual estimations of injury, unmanned aerial system (UAS) UAS imagery reflectance data, and yield data were collected to determine damage. Injury observed from each synthetic auxin herbicide varied slightly in symptomology. Applications made at both vegetative and reproductive stages resulted in visual crop response. Reflectance data from UAS imagery closely matched visual estimations of injury and yield data supporting ground-based assessments. Xtendimax and Loyant were the most damaging synthetic auxin herbicides to soybean at reduced rates and could cause yield loss. Further research is needed to evaluate the implications of reduced rates of each of these synthetic auxin herbicides on soybean and the role UAS imagery may play in their identification and severity.

Introduction

The use of synthetic auxin herbicides has increased in recent years with the development of auxin-resistant soybean [*Glycine max* (L.) Merr] technology. Although these herbicides provide control of problematic broadleaf weeds, significant phytotoxicity and yield loss can result if off-target movement occurs onto susceptible crops (McCown et al., 2018; Robinson et al., 2013; Scholtes et al., 2019). Soybean is more susceptible to dicamba when exposed at flowering (R1 to R2 stage) compared with vegetative stages (V1 to V7) (Kniss, 2018). Previous research has demonstrated significant yield losses with dicamba at rates as low as 0.23 g ae/ac (0.02 fl oz/ac, Xtendimax) when applied at sensitive (R1) stages of growth (Barber et al., 2014). The objective of this research was to compare visual soybean injury symptoms from multiple synthetic auxin herbicides at reduced rates and determine yield loss associated with this injury at different soybean growth stages. A secondary objective was to utilize unmanned aerial system (UAS) imagery to collect reflectance data which subsequently could be used in efforts to determine the specific auxin herbicide causing injury and predict yield loss.

Procedures

Two field trials were conducted in the summer of 2020 at the University of Arkansas System Division of Agriculture's Jackson County Extension Center near Newport, Ark. The first trial evaluated the effect of multiple rates of 4 growth regulating herbicides on soybean at the V5–V6 growth stage. The second trial repeated all treatments but was applied to the R2 growth stage soybean. In both trials, LibertyLink GT27® (BASF, Florham Park, N.J.) soybean was planted in 30-in. row widths, and plot size consisted of 4 rows 30-ft in length. Applications were made using a Bowman MudMaster equipped with a multi-boom system calibrated to deliver 15 gallons per acre (GPA) at 3 miles per hour with TTI 110015 nozzles.

The experimental design for both trials was a randomized complete block with a 4 (herbicide) x 3 (rate) factorial arrangement of treatments, and a weed-free control was included for comparisons. Dicamba (Xtendimax®), 2,4-D-choline (Enlist One®), florpyrauxifen-benzyl (Loyant®), and quinclorac (Facet® L) were applied at 0.1x, 0.01x, and 0.001x of their respective label rates (Table 1). Visual estimations of injury were collected at 1, 2, 3, and 4 weeks after treatment (WAT), UAS imagery reflectance data were collected at 1, 2, 3, and 4 WAT, and yield data were collected at harvest when the crop reached full maturity and adjusted to 12.5% moisture. The overall effects of the herbicide were visually assessed relative to the nontreated control, using a scale of 0 (no visible injury) to 100 (complete desiccation). The UASV imagery was collected via a DJI Matrice 210V2 (iFlight Tech Company Ltd. Shenzhen, China) flying at 197 ft. altitude with a MicaSense

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RedEdge MX (AgEagle Inc. Wichita, Kan.) multispectral sensor that collects five discrete spectral bands (Blue, Green, Red, RedEdge, and Near Infrared) producing a spectral resolution of 4.1 cm/pix. Pre-processing including the ortho-rectification and radiometric calibrations of raw images was completed in Pix4D's (Pix4D Inc. Lausanne, Switzerland) Ag multispectral automated workflow, which processes the raw band layers and calculated normalized difference vegetative index (NDVI) shown in Figs. 1 and 2. Data were subjected to analysis of variance (ANOVA) using SAS v9.4. Visual estimations of injury and UAS NDVI data were analyzed assuming a beta distribution and yield was analyzed assuming a gaussian distribution. Means were separated within soybean growth stage application timing using Tukey's honestly significant difference test at $\alpha = 0.05$.

Results and Discussion

Injury observed from each synthetic auxin herbicide varied slightly in symptomology. General symptoms, although influenced by rate, were as follows: Loyant caused trifoliates to flip upside-down, Xtendimax caused leaf cupping, Enlist One caused leaf strapping, and Facet L caused leaf cupping, strapping, and bubbling.

All treatments resulted in visual injury at both application timings (Fig. 3); however, only Loyant at the 0.1x rate applied at the V5–V6 growth stage, as well as Xtendimax and Loyant at the 0.1x rate applied at the R2 growth stage caused reductions in yield (Fig. 4). The greatest visual injury and yield loss occurred from the 0.1x rate of Loyant at the V5–V6 growth stage, which resulted in 100% plant death. Reflectance data from UAS imagery closely matched trends in both visual estimations of injury and yield data (Fig. 5). Results from raw NDVI plot observations suggest that the camera and vegetation indices used were able to pick up subtle differences in rates applied to the plots indicating that the remote sensing of light drift rates is possible. Statistical results suggested that index values correlated highest with visual observations from V5–V6 treated plots producing R^2 values between 0.70 and 0.81 (Fig. 6). The highest correlations were found between the visual ratings at 2 WAT ($R^2 = 0.80$) and 4 WAT ($R^2 = 0.81$) to the UASV imagery at 3 WAT. Soybean plots treated at the R2 growth stage revealed similar trends; however, the strength of the correlation begins to erode (Fig. 7). Results from R2 treated plots showed a slightly weaker correlation range (R^2 = 0.65–0.70). The strongest relationships were found between the visual ratings at 1 WAT ($R^2 = 0.68$) and 2 WAT ($R^2 = 0.70$) to the UASV imagery collected 2 WAT for the R2 treated soybean. It is important to note that due to the inherent nature of visual estimations of injury and the reduced sensitivity of this data collection method compared to a more continuous, quantitative data collection method like NDVI, it may be difficult to improve correlations beyond what was observed in this research. Further analysis is required to fully assess correlations between reflectance data and herbicide active ingredient or yield loss. Results from this research indicate that multiple reduced rates of synthetic auxin herbicides can cause severe phytotoxicity to soybean, but the visual injury does not always result in yield loss.

Practical Applications

Xtendimax and Loyant were the most damaging synthetic auxin herbicides to soybean at reduced rates and could cause plant death and yield loss. Further research needs to be done to evaluate the implications of reduced rates of each of these synthetic auxin herbicides on soybean and the role UAS imagery may play in their identification. Although UAS imagery alone does not provide enough evidence for drift investigation as of now, it may prove valuable to producers making input decisions regarding a damaged crop or play a role in crop insurance claims when combined with visual assessment.

Acknowledgments

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

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Table 1. The list of treatments to evaluate multiple growth-regulating herbicides' effect on soybean injury at vegetative and reproductive growth stages in 2020 at the University of Arkansas System Division of Agriculture's Jackson County Extension Center near Newport, Ark.

Treatment Number	Herbicide	Trade Name	Relative Rate	Actual Rate
			x[th] label rate	fl oz/ac
1	Nontreated Control			
2	2,4-D-choline	Enlist One©	0.1x	3.2
3	2,4-D-choline	Enlist One	0.01x	0.32
4	2,4-D-choline	Enlist One	0.001x	0.032
5	dicamba	Xtendimax©	0.1x	2.2
6	dicamba	Xtendimax	0.01x	0.22
7	dicamba	Xtendimax	0.001x	0.022
8	quinclorac	Facet© L	0.1x	3.2
9	quinclorac	Facet L	0.01x	0.32
10	quinclorac	Facet L	0.001x	0.032
11	florpyrauxifen-benzyl	Loyant©	0.1x	1.6
12	florpyrauxifen-benzyl	Loyant	0.01x	0.16
13	florpyrauxifen-benzyl	Loyant	0.001x	0.016

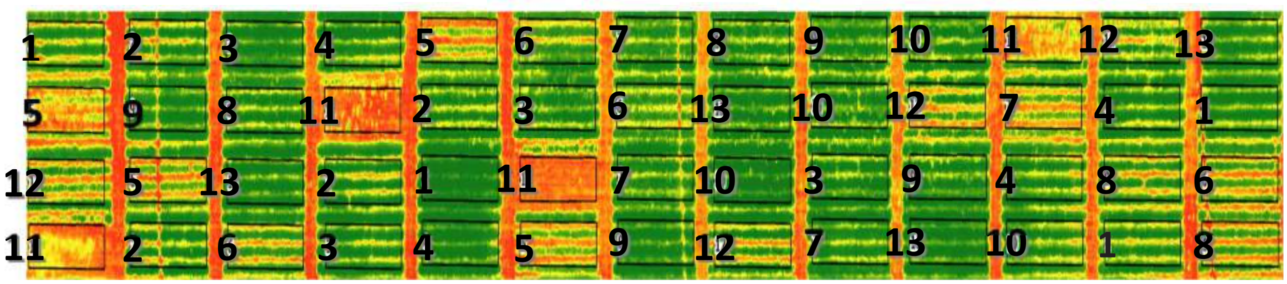

Fig. 1. Normalized difference vegetative index (NDVI) from treatments at 24 days after receiving a sublethal auxin herbicide rate on V5–V6 soybean.

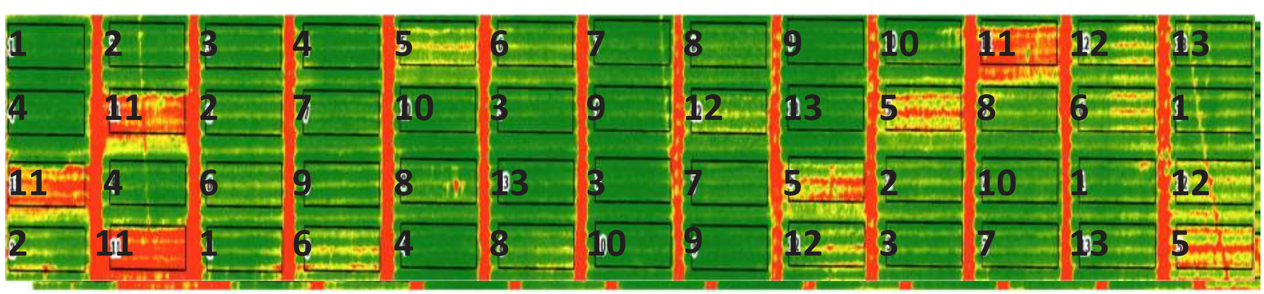

Fig. 2. Normalized difference vegetative index (NDVI) from treatments at 24 days after receiving a sublethal auxin herbicide rate on R2 soybean.

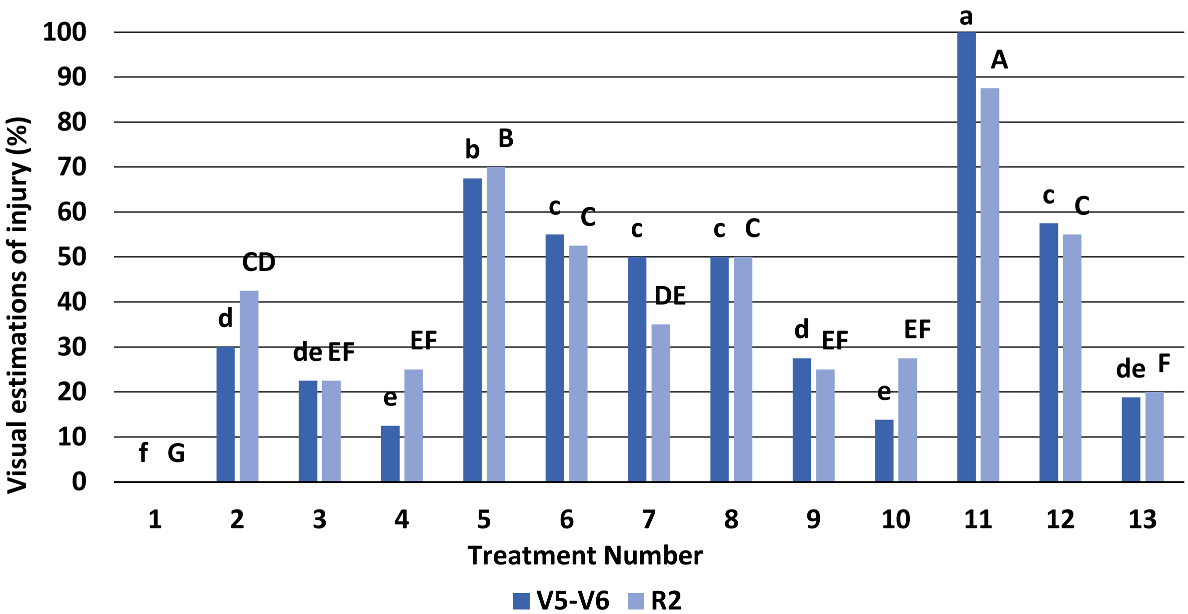

Fig. 3. Visual estimation of crop injury 21 days after application (DAA) of auxin herbicides on V5–V6 and R2 soybean. Treatments with the same letter within soybean growth stage application timing are not different according to Tukey's honestly significant difference test at α = 0.05.

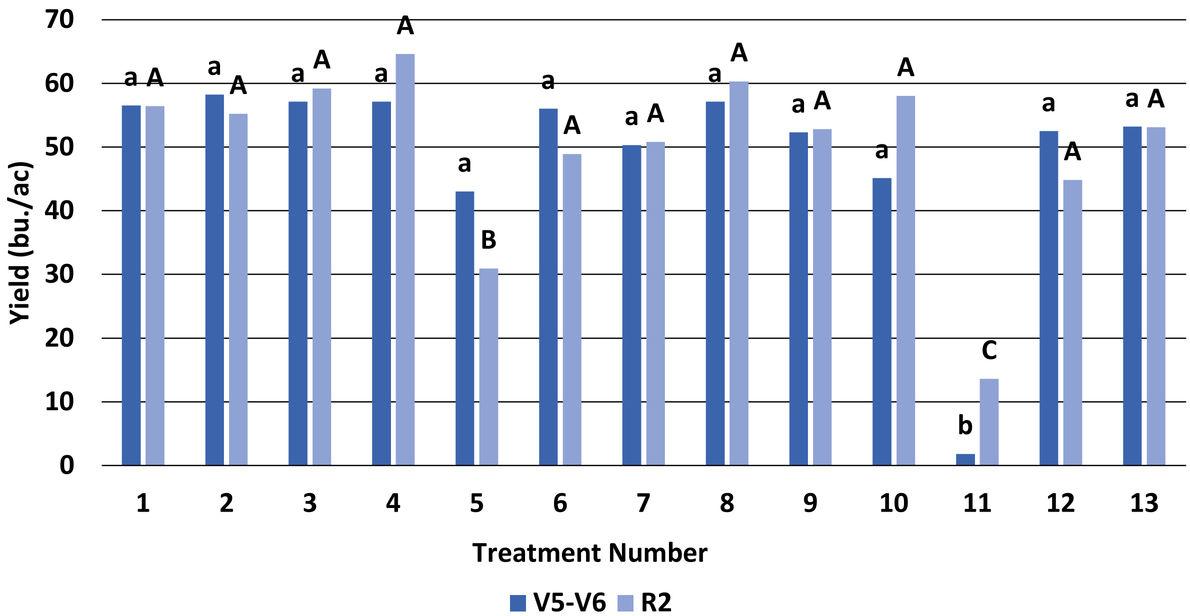

Fig. 4. Soybean yield in bushels per acre following applications of auxin herbicides at V5–V6 and R2 growth stages. Treatments with the same letter within soybean growth stage application timing are not different according to Tukey's honestly significant difference test at α = 0.05.

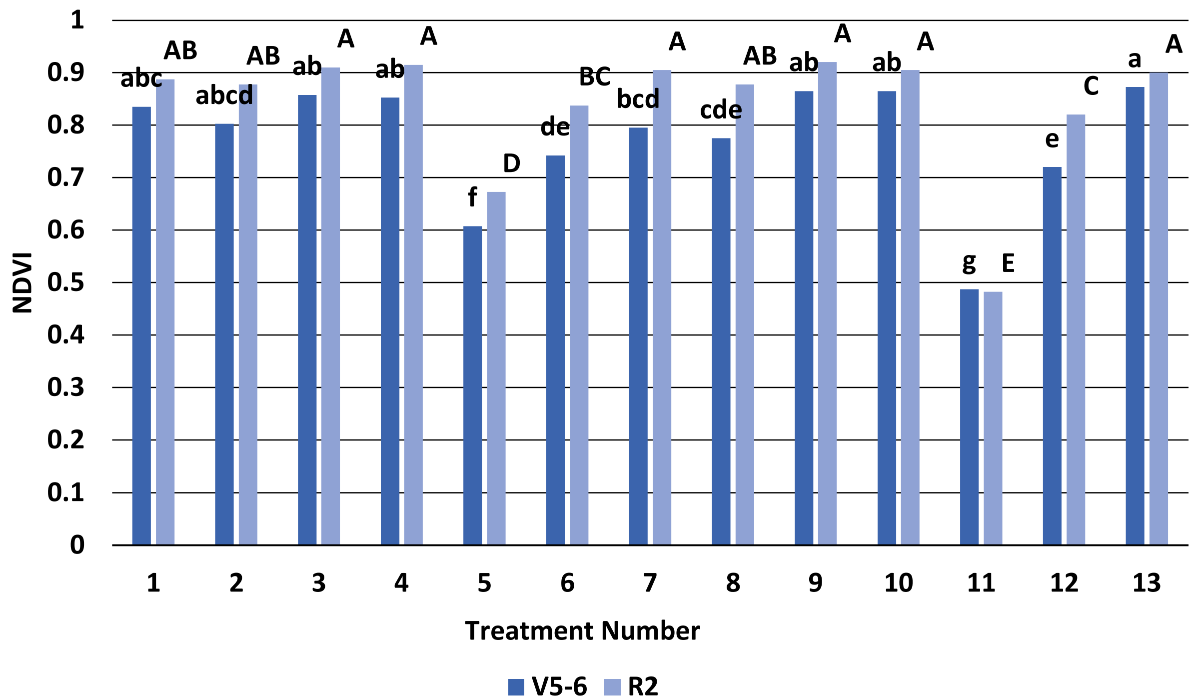

Fig. 5. Unmanned aerial system (UAS) normalized difference vegetative index (NDVI) measurements 24 days after application (DAA) on V5–V6 and R2 soybean. Treatments with the same letter within soybean growth stage application timing are not different according to Tukey's honestly significant difference test at α = 0.05.

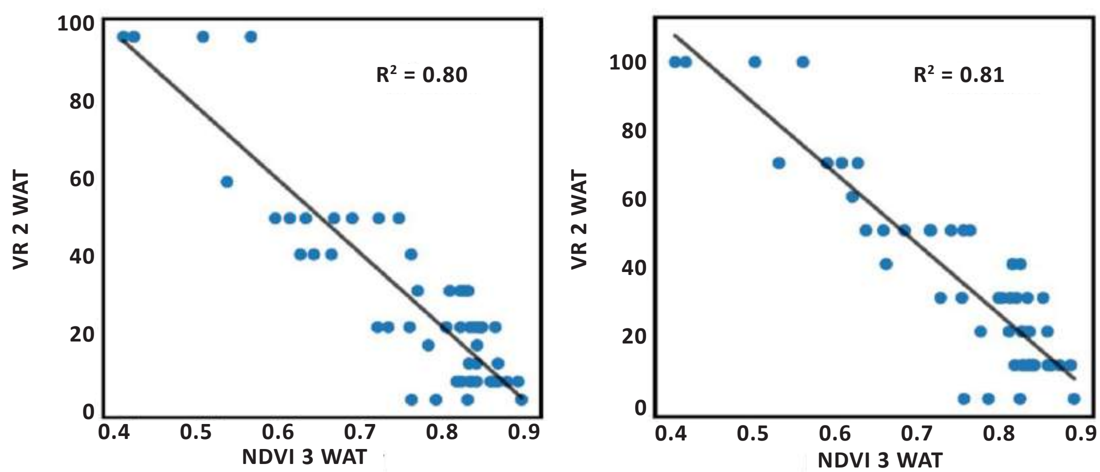

Fig. 6. Scatter plots with linear regression of normalized difference vegetative index (NDVI) 3 weeks after treatment (WAT) vs. visual estimations of injury (VR) 2 WAT (left) and 4 WAT (right) from plots receiving sublethal rates of auxin herbicide treatments on V5–V6 soybean.

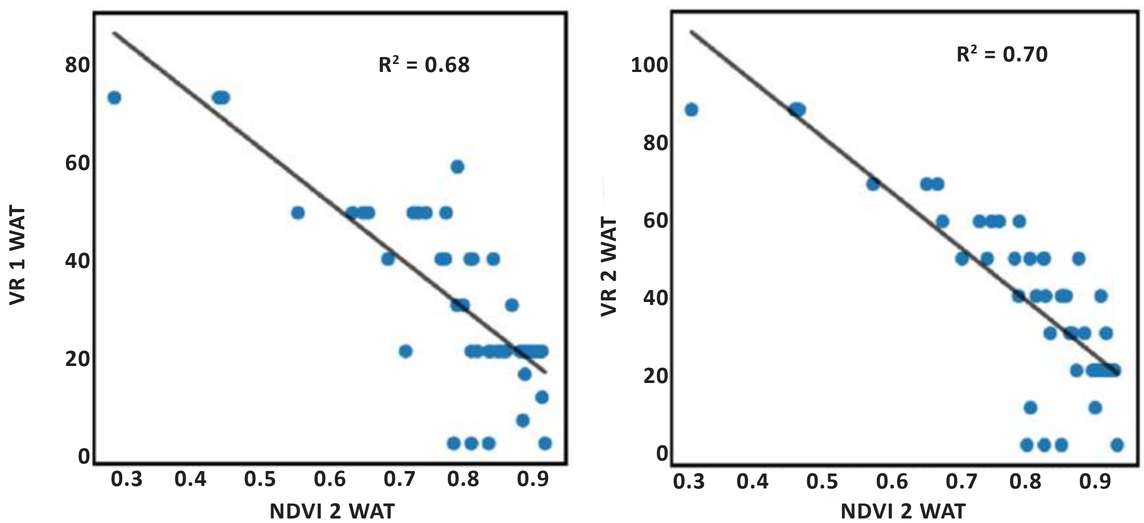

Fig. 7. Scatter plots with linear regression of normalized difference vegetative index (NDVI) 2 weeks after treatment (WAT) vs. visual estimations of injury (VR) 1 WAT (left) and 2 WAT (right) from plots receiving sublethal rates of auxin herbicide treatments on R2 soybean.

Evaluation of Residual Herbicides for Palmer Amaranth and Prickly Sida Control in Xtend® Soybean

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Abstract

The most problematic weed in mid-south soybean [*Glycine max* (L) Merr.] is Palmer amaranth (*Amaranthus palmeri* S. Wats.). While the shift to Xtend® soybean technology has provided another option of control for this weed, it has allowed for other troublesome weeds to be re-introduced to production soybean. One of those potentially yield-robbing weeds is prickly sida (*Sida spinosa* L.) also known as teaweed. A field study was conducted at the University of Arkansas System Division of Agriculture's Jackson County Extension Center near Newport, Ark. in 2020 to evaluate the efficacy and crop safety of preemergence (PRE) herbicides in Xtend® soybean. The study was a randomized complete block design with four replications and consisted of 10 total treatments: a nontreated control, a weed-free control, and 8 PRE herbicide treatments. A blanket postemergence (POST) application of Intact® (drift control aid) + Class Act Ridion® (adjuvant) + Tavium® plus Vaporgrip (dicamba + S-metolachlor) + Roundup® PowerMax® (glyphosate) was broadcast across the entire trial area 41 days after planting. All treatments provided equal control of Palmer amaranth 40 days after the PRE application. Prickly sida was controlled greater than 98% by all PRE treatments following the blanket POST application except for PRE treatments consisting of Boundary® (S-metolachlor + metribuzin) and BroadAxe® (sulfentrazone + *s*-metolachlor). There was no visual soybean injury observed with any treatments. Several PRE residual herbicides were shown to be effective at controlling both Palmer amaranth and prickly sida within Xtend soybean.

Introduction

Weed control in soybean [*Glycine max* (L.) Merr] production is increasingly problematic due to herbicide resistance (Heap, 2021). It is difficult to estimate the acreage that is currently infested with glyphosate-resistant weeds, particularly in the case of a rapidly evolving species such as Palmer amaranth (*Amaranthus palmeri* S. Wats.) (Carpenter and Gianessi, 2010). Weeds not only compete with soybean for nutrients, moisture, and light but also interfere with harvesting operations and may lower the quality of soybean seed (Indyk, 1957). Xtend® technology has provided another tool to aid with the control of Palmer amaranth, but it has also allowed other previously controlled weeds to reemerge from the seed bank. Prickly sida (*Sida spinosa* L.), also known as teaweed, has been shown to compete with soybean causing yield loss (Eaton et al., 1976), and has become problematic in Xtend soybean as neither glyphosate nor dicamba effectively controls this weed species (Barber et al., 2021). Since there are limited herbicide options for postemergence (POST) control, it is essential to select effective preemergence (PRE) herbicides. The objective of this research was to evaluate PRE herbicides for residual control of Palmer amaranth and prickly sida in Xtend soybean.

Procedures

A field study was conducted in the summer of 2020 at the University of Arkansas System Division of Agriculture's Jackson County Extension Center in Newport, Ark. Xtend soybean was planted in 30-in. row widths. The experimental design was a randomized complete block design with four replications and consisted of 10 total treatments: a nontreated control, a weed-free control, and PRE herbicide treatments. These included Boundary® (S-metolachlor + metribuzin), BroadAxe® (sulfentrazone + S-metolachlor), Fierce® XLT (chlorimuron + flumioxazin + pyroxasulfone), Sonic® (sulfentrazone + cloransulam-methyl), Zidua Pro® (saflufenacil + imazethapyr + pyroxasulfone), and three rates of an experimental herbicide (A23372) from Syngenta (Table 1). A single POST application of Intact® (drift control aid) (0.5% v/v) + Class Act Ridion® (adjuvant) (1% v/v) + Tavium® plus Vaporgrip® (dicamba + S-metolachlor) (3.53 pt/ac) + Roundup® PowerMax® (glyphosate, 32 oz/ac) was applied 41 days after plant-

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ing as a blanket across the entire trial. All treatments were applied using a Bowman MudMaster with a 10-ft multi-boom system calibrated to deliver 15 gallons per acre (GPA) at 3 mph. The PRE treatments were applied with AIXR 110015 nozzles and the POST treatment with TTI 110015 nozzles. Visual estimations of weed control and soybean injury were taken weekly. Weed control ratings were based on a scale of 0 (no control) to 100% (control). Soybean was harvested when the crop reached full maturity and yields were adjusted to 12.5% moisture. Data were subjected to analysis of variance (ANOVA) using ARM 2021, and means were separated using Fisher's protected least significant difference test at $\alpha = 0.05$.

Results and Discussion

Results showed no differences in Palmer amaranth control across PRE residual herbicide treatments 40 days after the PRE application, and all treatments achieved greater than or equal to 80% control (Fig. 1). The PRE herbicide treatments also provided equivalent control to the weed-free check. The low rate of A23372, Sonic, Fierce XLT, and Zidua Pro provided the greatest control of prickly sida (>94%) 40 days after the PRE application (Fig. 1).

All PRE treatments had greater than 96% control of Palmer amaranth 28 days following the blanket POST application, while all PRE treatments provided excellent control of prickly sida (>98%), excluding Boundary (60%) and BroadAxe (58%) (Fig 2). All herbicide treatments provided equivalent Palmer amaranth control as the weed-free check, and only Boundary and BroadAxe provided less control of prickly sida. No visual soybean injury was observed at any time from any of the PRE treatments evaluated. These results highlight the importance of using herbicides that contain multiple, effective sites of action. All PRE herbicides that successfully controlled both Palmer amaranth and prickly sida contained a combination of at least 2 sites-of-action from WSSA groups 2, 5, and 14.

Yield data from this research showed little difference amongst PRE treatments (Fig. 3). All PRE herbicide treatments and the weed-free check produced greater yield than the nontreated control. All PRE treatments were similar to the weed-free check, and only the low rate of A23372 and Boundary had reduced yields compared to Fierce XLT and Zidua Pro.

Practical Applications

Overall, several PRE residual herbicides were shown to be effective at controlling both Palmer amaranth and prickly sida within the Xtend® soybean system. When trying to effectively control multiple weed species, it is important to select a PRE residual herbicide that contains multiple, effective sites of action. Proper weed identification and knowledge of previous field history with subsequent appropriate herbicide selection are key for continued success at controlling these problematic weeds in Arkansas soybean production.

Acknowledgments

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Table 1. Treatment list for the evaluation of residual herbicides for Palmer amaranth (*Amaranthus palmeri*) and prickly sida (*Sida spinosa*) control in Xtend© soybean.

Treatment number	Trade name	Rate
		oz/ac
1	Untreated Check	
2	A23372	30.4
3	A23372	38.4
4	A23372	48
5	Boundary®	24
6	BroadAxe®	19
7	Sonic®	4.5
8	Fierce® XLT	3.75
9	Zidua Pro®	4.5
10	Weed-Free Check	

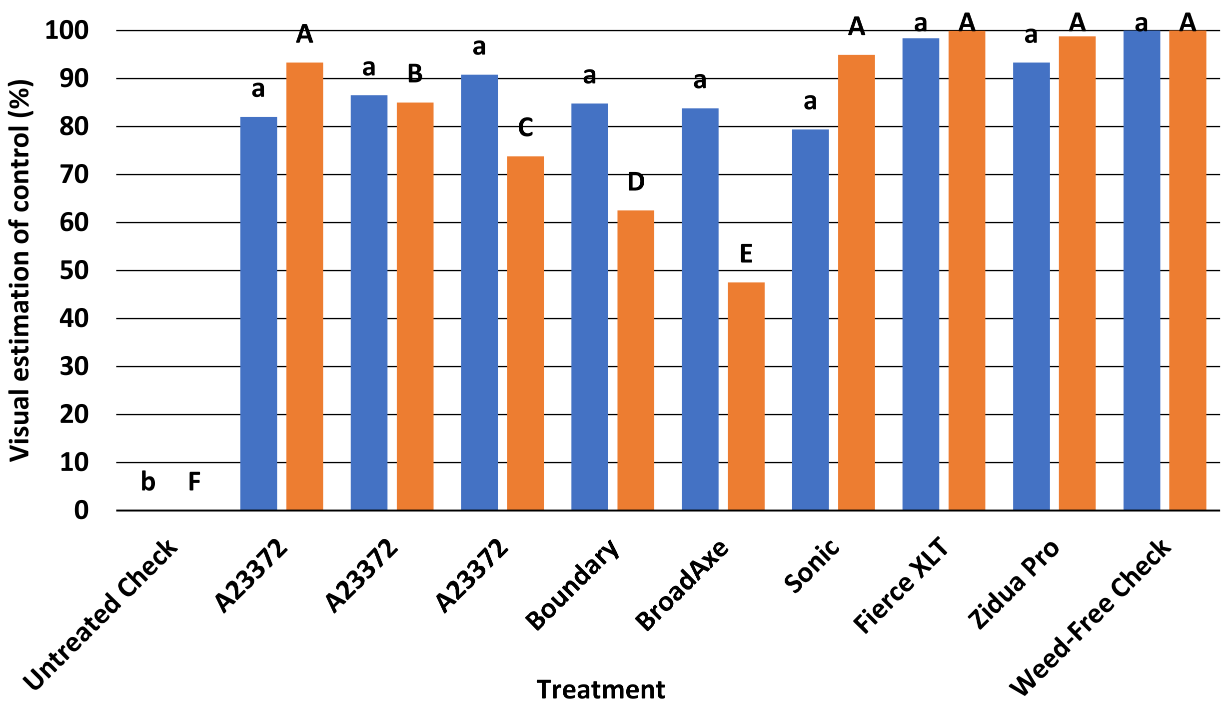

Fig. 1. Visual estimation of control of Palmer amaranth (*Amaranthus palmeri*) and prickly sida (*Sida spinosa*) 40 days after the preemergence application. Treatments with the same letter within weed species are not different according to Fisher's protected least significant difference test at α = 0.05.

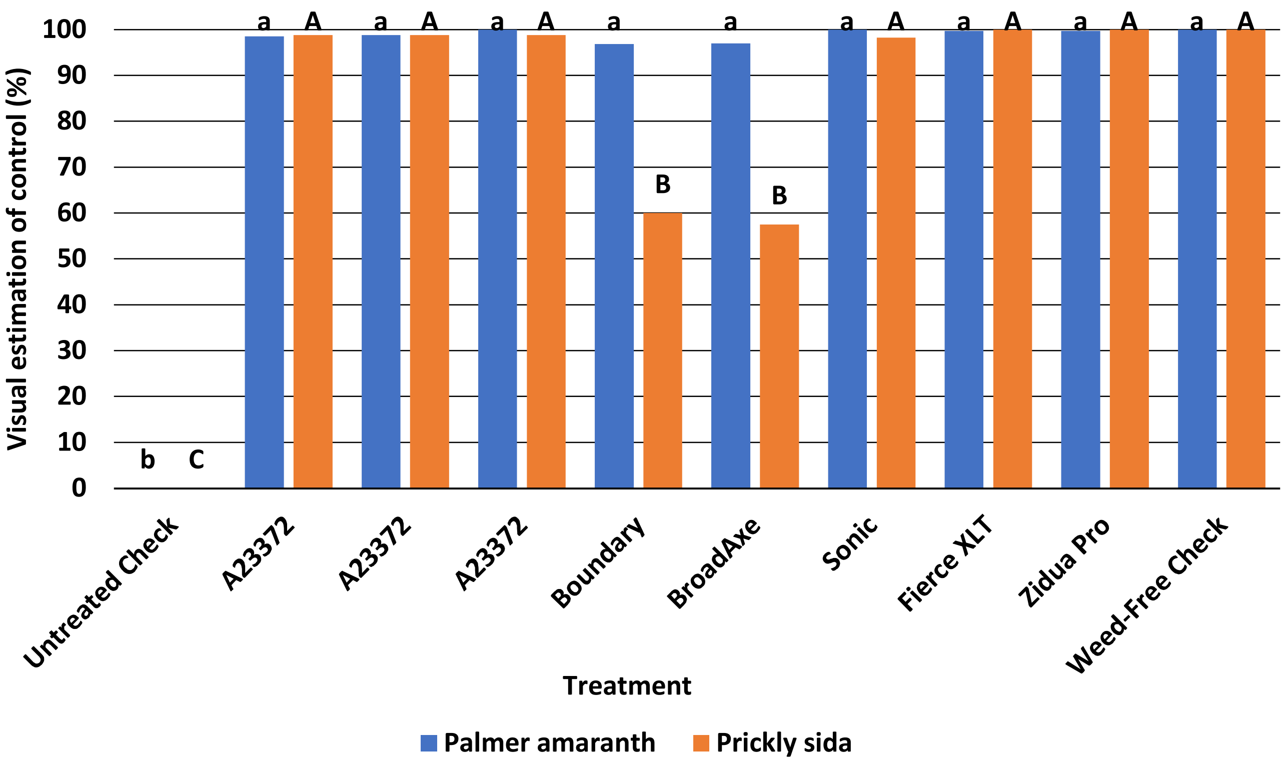

Fig. 2. Visual estimation of control of Palmer amaranth (*Amaranthus palmeri*) and prickly sida (*Sida spinosa*) 28 days after the blanket postemergence application. Treatments with the same letter within weed species are not different according to Fisher's protected least significant difference test at α = 0.05.

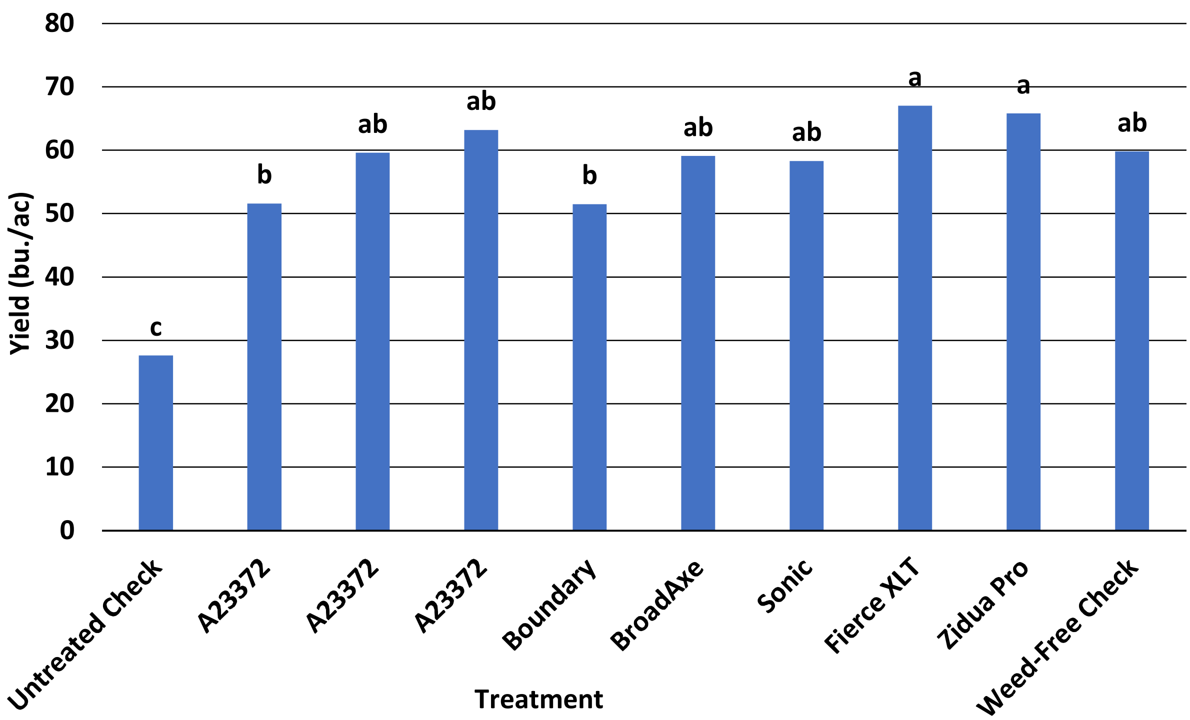

Fig. 3. Soybean yield as affected by preemergence herbicide treatments. Treatments with the same letter are not different according to Fisher's protected least significant difference test at α = 0.05.

Optimizing Palmer amaranth Control in the XtendFlex™ System

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Abstract

Dicamba formulations like Engenia®, Fexapan®, and Xtendimax® plus VaporGrip® are labeled for over-the-top use in the XtendFlex™ soybean [*Glycine max* (L.) Merr.] technology system; however, mixtures of dicamba and glufosinate cannot be utilized. In 2019, a field study was conducted in Crawfordsville, at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center near Keiser, and the Lon Mann Cotton Research Station near Marianna, Ark. In 2020, the same field study was conducted at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, and repeated near Keiser, and Marianna, Ark. to evaluate the efficacy of sequential applications of dicamba and glufosinate when applied at 0.2- (6 hours), 3-, 7-, 14-, and 21-day intervals from the initial application on native Palmer amaranth (*Amaranthus palmeri*) populations. Field experiments were conducted to determine if the time interval between sequential applications and/or sequence of herbicides could be optimized to improve Palmer amaranth control. Palmer amaranth control was optimized in the dicamba only and glufosinate only systems when sequential applications were made at the 14-, and 21- day-interval, and 7 day-interval, respectively. Palmer amaranth control was improved on larger-than-labeled weed sizes when dicamba was followed by glufosinate at the 14 day-interval. Only when dicamba was followed by glufosinate at the 14 day-interval on labeled weed sizes was 100% Palmer amaranth control achieved. These findings highlight the importance of utilizing both dicamba and glufosinate in-season and making the first application to labeled weed sizes.

Introduction

The commercial launch of XtendFlex™ soybean [*Glycine max* (L.) Merr.], resistant to dicamba, glufosinate, and glyphosate, enables producers to use these herbicides in-season. Current soybean technologies like Xtend™ or LibertyLink™ rely on a single site-of-action (SOA) postemergence (POST) to control Palmer amaranth with resistance to acetolactate synthase-, 5-enolpyruvyl shikimate-3-phosphate synthase-, and protoporphyrinogen oxidase-inhibiting herbicides (Heap, 2020). In the past, overreliance on an SOA perpetuated the evolution of herbicide resistance (Norsworthy et al., 2012). In 2021, producers have the option to plant XtendFlex™ soybean, thus allowing for separate applications of dicamba and glufosinate. Prior research has shown that utilizing two effective SOA in mixture or rotation will reduce the likelihood of the evolution of target-site herbicide resistance (Norsworthy et al., 2012). However, when combining herbicides with different SOA into a herbicide program, interactions can be considered additive, synergistic, or antagonistic. Some interactions between dicamba and glufosinate have been evaluated, such as glufosinate in mixture with dicamba (Chahal and Johnson, 2017; Vann et al., 2017). The results in the literature mentioned above were variable and exclusive to individual weed species. However, the label restrictions in XtendFlex soybean prohibit the mixture of dicamba and glufosinate (Anonymous, 2021). Therefore, additional research is needed to understand how to optimize the efficacy of dicamba and glufosinate when applied sequentially in the XtendFlex soybean technology.

Procedures

Field experiments were conducted in 2019, at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center near Keiser Ark., near Crawfordsville, Ark., and at the Lon Mann Cotton Research Station near Marianna, Ark. In 2020, the study was conducted at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, and repeated in Keiser, and near Marianna, Ark. Treatments applied in the experiments are shown in Table 1. Treatments were applied to native Palmer amaranth (*Amaranthus palmeri*) populations at each location without a crop present. Plot size at all locations was 12.6-ft wide and 20-ft long with 4 replications. Applications of each herbicide were made with separate hand-held CO_2-pressurized backpack sprayers to avoid any herbicide contamination. The hand-held sprayers were calibrated to deliver 20 gal/ac of

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spray solution at 3 mph. All dicamba applications were made with the TTI 110015-VP (TeeJet, Springfield, Ill. 62703) nozzle and glufosinate applications were made with an AIXR 110015-VP (TeeJet, Springfield, Ill. 62703). The mixture of dicamba + glufosinate, although off-label was included for research purposes, was made with the TTI 110015-VP nozzle. Before the first herbicide applications and every two weeks after treatments were applied *s*-metolachlor at 0.9 lb/ac was applied to reduce Palmer amaranth emergence. Subsequent applications of dimethenamid-P or *s*-metolachlor were made at a biweekly interval until all assessments were finished. Palmer amaranth control was visually evaluated using a scale of 0 to 100% at 28 days after the final application (DAFA).

Data were analyzed by Palmer amaranth size. Site-years were pooled if Palmer amaranth size at the time of the initial application was <4 in. or >4 in. Site-years including Crawfordsville in 2019 and Keiser in 2020 were pooled as labeled applications and site-years including Keiser in 2019, Marianna in 2019 and 2020, and Fayetteville in 2020 was pooled as weed size at the time of the initial application was greater than label requirements. A single-factor analysis of variance (ANOVA) was used to assess herbicide treatments in SAS 9.4 utilizing the PROC GLIMMIX function (SAS Institute Inc., Cary, N.C.). A beta distribution was assumed for Palmer amaranth control 28-DAFA.

Results and Discussion

Dicamba and glufosinate can both be incorporated into a POST herbicide program effectively if the sequence of the two herbicides and timing between the applications is optimized. Sequential applications increased Palmer amaranth control when compared to dicamba alone, glufosinate alone, or dicamba plus glufosinate (Figs. 1 and 2). Dicamba followed by (fb) glufosinate at the 14 day-interval provided better control of larger than labeled Palmer amaranth than sequential applications that utilized glufosinate only or glufosinate fb dicamba; comparable control was observed when dicamba fb glufosinate at the 21 day-interval or dicamba fb dicamba at the 14 and 21 day-interval was utilized (Fig. 2). Overall, when the time interval between sequential applications of dicamba fb glufosinate was increased to 14 days, Palmer amaranth efficacy was generally optimized (Figs. 1 and 2). The sequential application of dicamba fb glufosinate 14 days later provided equal or greater control than the dicamba or glufosinate system alone or the dicamba plus glufosinate tank-mixture and provided greater control than glufosinate followed by dicamba at all time intervals.

Practical Applications

Dicamba and glufosinate should not be applied in sequence of one another in a time interval shorter than 14 days. To increase Palmer amaranth efficacy and utilize 2 effective SOA, dicamba should be applied 14 days before a glufosinate application. Also, only when dicamba followed by glufosinate at the 14 day-interval was applied to labeled sized Palmer amaranth was 100% control observed. It is of the utmost importance to apply effective POST herbicides to labeled weed sizes in the XtendFlex™ system as well as using the aforementioned herbicide sequence and timing recommendations to achieve maximum control.

Acknowledgments

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Table 1. Experimental treatments, including herbicides, herbicide rate, and the time interval between the sequential herbicide applications.

Herbicide	Rate	Time interval between sequential applications
Nontreated	-	-
Dicamba[a]	22 fl/oz ac	-
Glufosinate[b]	32 fl/oz ac	-
Dicamba + glufosinate	32 fl oz/ac + 22 fl oz/ac	-
Dicamba fb[c] dicamba	22 fl oz/ac fb 22 fl/oz ac	7, 14, and 21 days
Glufosinate fb glufosinate	32 fl oz/ac fb 32 fl oz/ac	7, 14, and 21 days
Dicamba fb glufosinate	22 fl oz/ac fb 32 fl oz/ac	6 hours, 3, 7, 14, and 21 days
Glufosinate fb dicamba	32 fl oz/ac fb 22 fl/oz ac	6 hours, 3, 7, 14, and 21 days

[a] Xtendimax® plus VaporGrip® was the product used for all dicamba applications.
[b] Liberty™ was the product used for all glufosinate applications.
[c] fb = followed by.

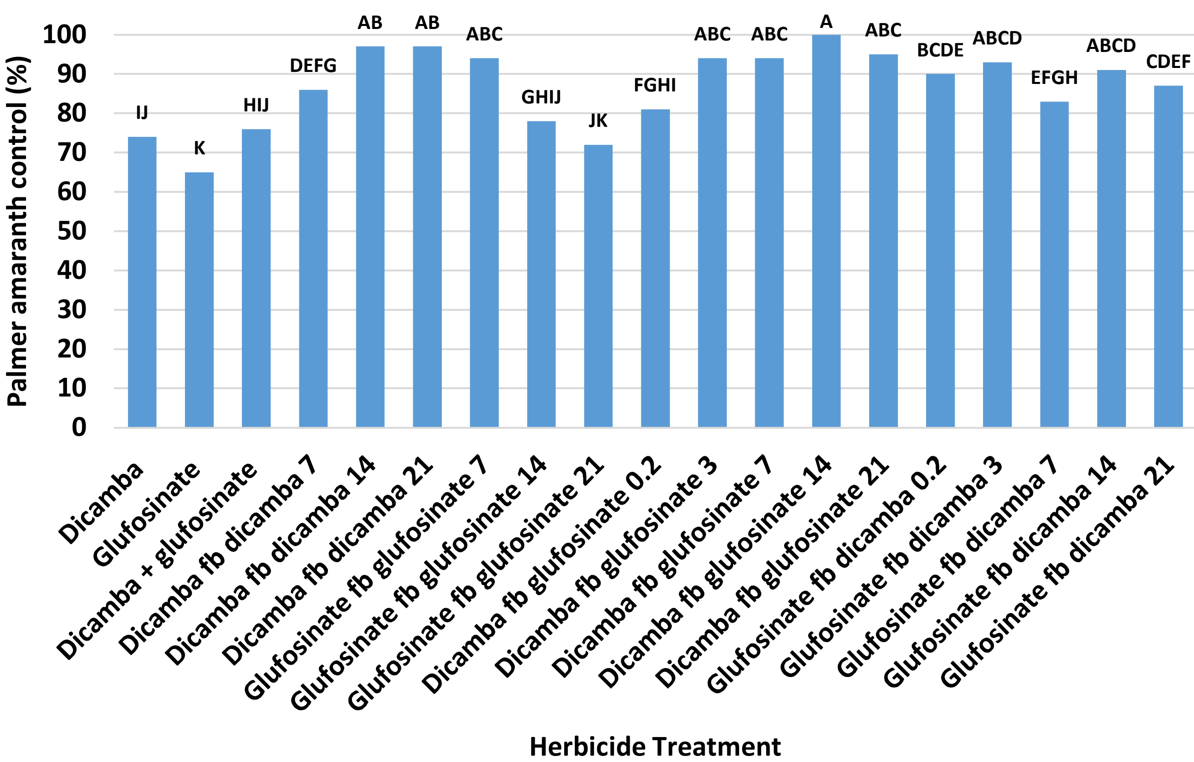

Fig. 1. Visual estimates of control of equal to or less than labeled size Palmer amaranth (*Amaranthus palmeri*) provided by treatments at Crawfordsville, Ark. in 2019, and at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center near Keiser, Ark. in 2020. The treatments are listed by herbicide A followed by (fb) herbicide B. The subsequent number represents the time interval in days between sequential applications.

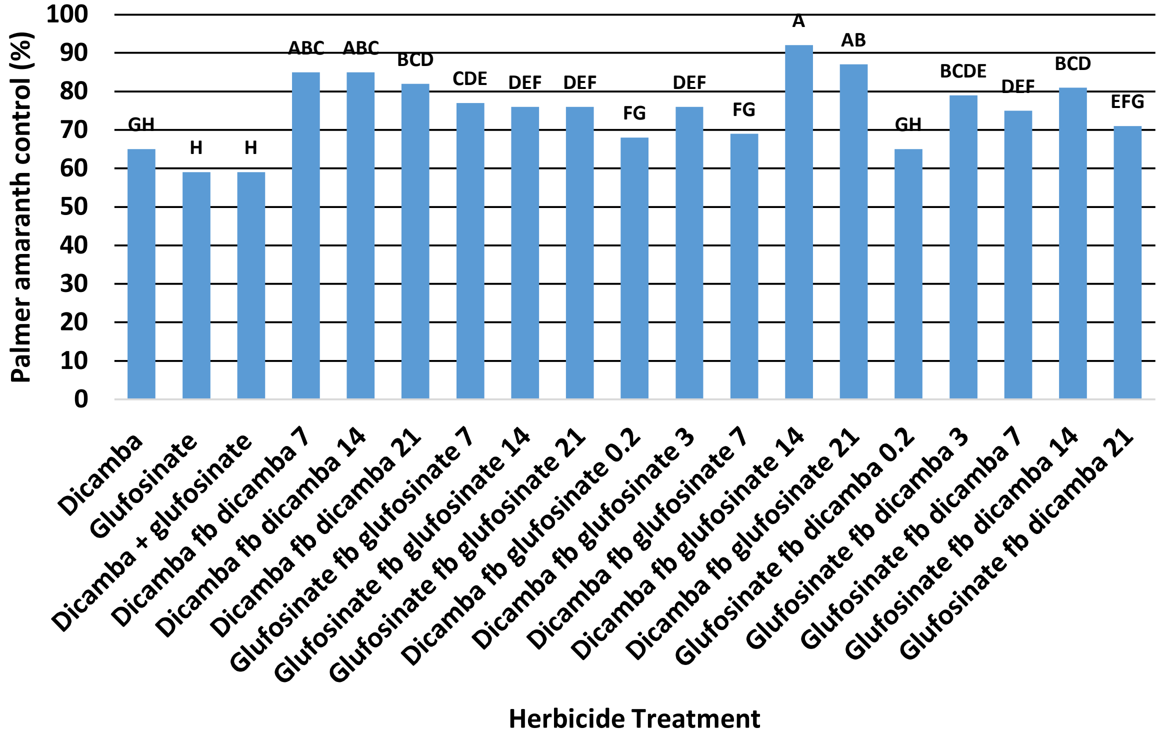

Fig. 2. Visual estimates of control of larger than labeled Palmer amaranth (*Amaranthus palmeri*) provided by treatments pooled over University of Arkansas System Division of Agriculture locations: Northeast Research and Extension Center near Keiser in 2019, Lonn Man Cotton Research Station near Marianna in 2019 and 2020, and Milo J. Shult Agricultural Research and Extension Center near Fayetteville in 2020. The treatments are listed by herbicide A followed by (fb) herbicide B. The subsequent number represents the time interval in days between sequential applications.

Evaluations of Palmer amaranth Susceptibility to Dicamba and Glufosinate

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Abstract

Dicamba and glufosinate have been effective herbicides used for postemergence weed control in XtendFlex® technology. The occurrence of Palmer amaranth (*Amaranthus palmeri* S. Wats.) escapes in fields that rely on these tools demonstrate the importance of monitoring the emergence and spread of herbicide resistance. For that purpose, Palmer amaranth accessions were collected from fields in regions where auxins (dicamba or 2,4-D) and glufosinate are heavily relied upon for weed control. Collections occurred in the fall of 2018, 2019, and 2020 from fields located in Mississippi, Missouri, Nebraska, Illinois, Louisiana, Tennessee, and Arkansas. Every state did not sample for Palmer amaranth each year. Herbicide treatments equivalent to a 0.5X or 1X rate of dicamba at 0.25 and 0.5 lb ae/ac or glufosinate at 0.26 and 0.53 lb ai/ac were applied to greenhouse-grown plants at the 5- to 6-leaf stage. Some accessions could not be thoroughly evaluated due to limited seed availability or lack of seed viability. For all samples reported, at least 100 plants were assessed. Thus far, the screening has evaluated 193 and 206 accessions to dicamba and 210 and 215 accessions to glufosinate at a 0.5 and 1X rate of each herbicide, respectively. Evaluations of the accessions showed a high variability of plant responses to the herbicide treatments. Dicamba and glufosinate applied at a 0.5X rate resulted in less than 60% mortality to 22 and 31 accessions, respectively. Nevertheless, a full labeled (1X) rate of dicamba and glufosinate provide at least 80% mortality of 193 and 194 Palmer amaranth accessions, respectively. Future experiments will be conducted to determine the mechanism for reduced susceptibility to these herbicides as well as alternative herbicides that can be used to control these troublesome accessions.

Introduction

According to crop consultants, extension agents, and weed scientists, Palmer amaranth (*Amaranthus palmeri* S. Wats.) is the most troublesome weed of soybean [*Glycine max* (L.) Merr.] production and other broadleaf crops (Van Wychen, 2019). One reason for the difficulty in controlling Palmer amaranth is the occurrence of multiple herbicide resistance (Heap, 2021). Palmer amaranth resistance to herbicides is increasing, with resistance now documented to group 2 [acetolactate synthase (ALS) inhibitors], group 4 (synthetic auxins), group 9 [5-enolpyruvylshikimate-3-phosphate synthase (EPSPS) inhibitors], group 14 [protoporphyrinogen oxygenase (PPO) inhibitors], group 15 [very-long-chain-fatty-acid (VLCFA) elongase inhibitors], and group 27 [4-hydroxyphenylpyruvate dioxygenase (HPPD) inhibitors].

The spread of herbicide resistance in Palmer amaranth demonstrates the importance of determining if chemical options are still effective in controlling this weed. Glufosinate and dicamba are 2 of the most pivotal herbicides for postemergence control in XtendFlex® soybean production. These herbicides form the basis of herbicide programs with multiple mechanisms of action, including glutamine synthetase (group 10) inhibition and growth regulator (group 4) activity that leads to the production of reactive oxygen species. However, recent reports confirmed cases of dicamba-resistant Palmer amaranth in Kansas and Tennessee (Peterson et al., 2019; Steckel 2020) and glufosinate resistance in Arkansas (Barber et al., 2021). Therefore, this research aimed to monitor the efficacy of dicamba and glufosinate for control of Palmer amaranth accessions collected from multiple locations across the United States soybean production regions where this weed is deemed problematic.

Procedures

Palmer amaranth seeds were collected from soybean fields in Nebraska, Missouri, Illinois, Indiana, Tennessee, Louisiana, Mississippi, and Arkansas, in one or more years during the fall of 2018, 2019, and 2020. Regions targeted in this survey had a history of utilizing herbicide programs that included dicamba or glufosinate. Seeds from 5 to 10 inflorescences collected at each site comprised an accession. Seeds were planted and seedlings transplanted at 4 to 7 days after emergence to 50-cell trays (Plug tray 50 Square, 21 by 11.5 in.; Hummert International, Earth City, Mo.) filled with potting soil (Sun Gro Horticulture, Seba Beach, Alberta, Canada). Seedlings were grown in a greenhouse until they reached the 5- to 6-leaf stage and were approximately 3 to 4 inches tall. Dicamba and glufosinate treatments were applied at 0.5

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and 1X rate, which was equivalent to 0.26 and 0.53 lb ai/ac for glufosinate (Liberty®, Bayer CropScience, Research Triangle Park, N.C.) and 0.25 and 0.5 lb ae/ac for dicamba (XtendiMax® with VaporGrip®, Bayer CropScience, St. Louis, Mo.). Herbicides were applied using a research track sprayer calibrated to deliver a constant volume of 20 gallons per acre (gal/ac) with two TP 1100067 TeeJet® (Spraying Systems, Wheaton, Ill.) nozzles, which produces a fine spray classification for a high degree of coverage. Quantitative data as live and death counts (mortality) were recorded 21 days after applications. Mortality assessments were conducted in 2 runs with 50 plants per accession each winter. Mortality data were used to generate box and whisker plots using JMP Pro 15 (SAS Institute Inc., Cary, N.C.). Outliers identified by the analysis would need further evaluation to determine whether resistance to either herbicide had occurred.

Results and Discussion

We received more than 260 accessions from fields collected in the fall of 2018, 2019, and 2020. Because of limited seed availability or lack of seed viability for some accessions, the number of screened accessions was less than the sample number received. Additionally, evaluations of some accessions collected in 2020 are still in progress. Currently, comprehensive assessments (with criteria based on 100 treated plants) have been made for 193 and 206 accessions to dicamba at 0.5X and 1X rate and 210 and 215 accessions for glufosinate, respectively, at the same rates.

Palmer amaranth average mortality in response to dicamba and glufosinate varied over time, with the herbicides being less efficacious in 2019 and 2020 versus the 2018 screening (Fig. 1). Herbicide treatments applied to the accessions collected in 2018 averaged 98% or more mortality for both herbicides. By 2019, dicamba resulted in 72% and 88% mortality of plants, while 2020 samples had 82% and 93% mortality for 0.5X and 1X rates, respectively. Glufosinate was more effective in 2019 (averaged 83% and 95% mortality for 0.5X and 1X rate, respectively) than in 2020 (67% and 88% mortality for 0.5X and 1X rate, respectively).

Evaluations of the Palmer amaranth accessions showed variability regarding percent mortality for the herbicides tested. The herbicide applications made in 2019 and 2020 showed a much greater variability in plant response with respect to mortality than results from accessions collected in 2018 (Fig. 2). Additionally, the accessions with low mortality (outliers) are critical for the survival of Palmer amaranth to dicamba and glufosinate applications. Further studies will be conducted with outlier accessions shown in Fig. 2 to determine whether these accessions exhibit resistance to the failed herbicides, and if so, the likely resistance mechanism and what herbicides are still effective in controlling these accessions will be investigated.

Overall, 22 and 31 accessions of the 0.5X rate treatments with dicamba and glufosinate, respectively, resulted in less than 60% mortality (Fig. 3). Results from the 1X rate indicated 4 and 10 accessions resulted in less than 60% mortality when treated with dicamba and glufosinate, respectively (Fig. 4). Dicamba and glufosinate are still effective herbicides causing more than 80% mortality of 193 and 194 accessions, respectively when treated with the 1X labeled rate of these herbicides under the conditions tested here. However, complete control (no survival) was only accomplished for 65 of 206 and 148 of 215 accessions resulting from treatment with the 1X rate of dicamba and glufosinate, respectively. It should also be noted that spray coverage with dicamba under field conditions when using an approved nozzle would be much less than achieved in this research.

Based on these findings, herbicide resistance to dicamba and glufosinate in Palmer amaranth could be already present in several locations. The recently confirmed dicamba resistance in Tennessee and glufosinate resistance in Arkansas was initially documented with samples included in this screening. The occurrence of resistance to these herbicides and likely resistance to 2,4-D due to its similarity to dicamba is of great concern because of the nature of the dioecious reproduction of Palmer amaranth, facilitating rapid evolution and dissemination of potential resistance across neighboring fields (Ward et al., 2013).

Practical Applications

Overall, these experiments showed that the Palmer amaranth collected from production fields in recent years has differential sensitivity among accessions to dicamba and glufosinate. Results indicated that plants survived 1X applications of dicamba and glufosinate, and these plants could survive field applications which is a concern for the sustainability of these herbicides and associated technologies. However, dicamba and glufosinate are still valuable tools to control Palmer amaranth since resistance is limited to a few accessions. Researchers, consultants, and specialists need to collaborate to help mitigate the spread of resistance by developing weed control recommendations focused on integrated weed management practices that bring additional attention to non-chemical tactics (crop rotation, tillage, cover crops, etc.) that are not being relied upon in current production systems.

Acknowledgments

The authors would like to express appreciation for the support from the United Soybean Board and the University of Arkansas System Division of Agriculture.

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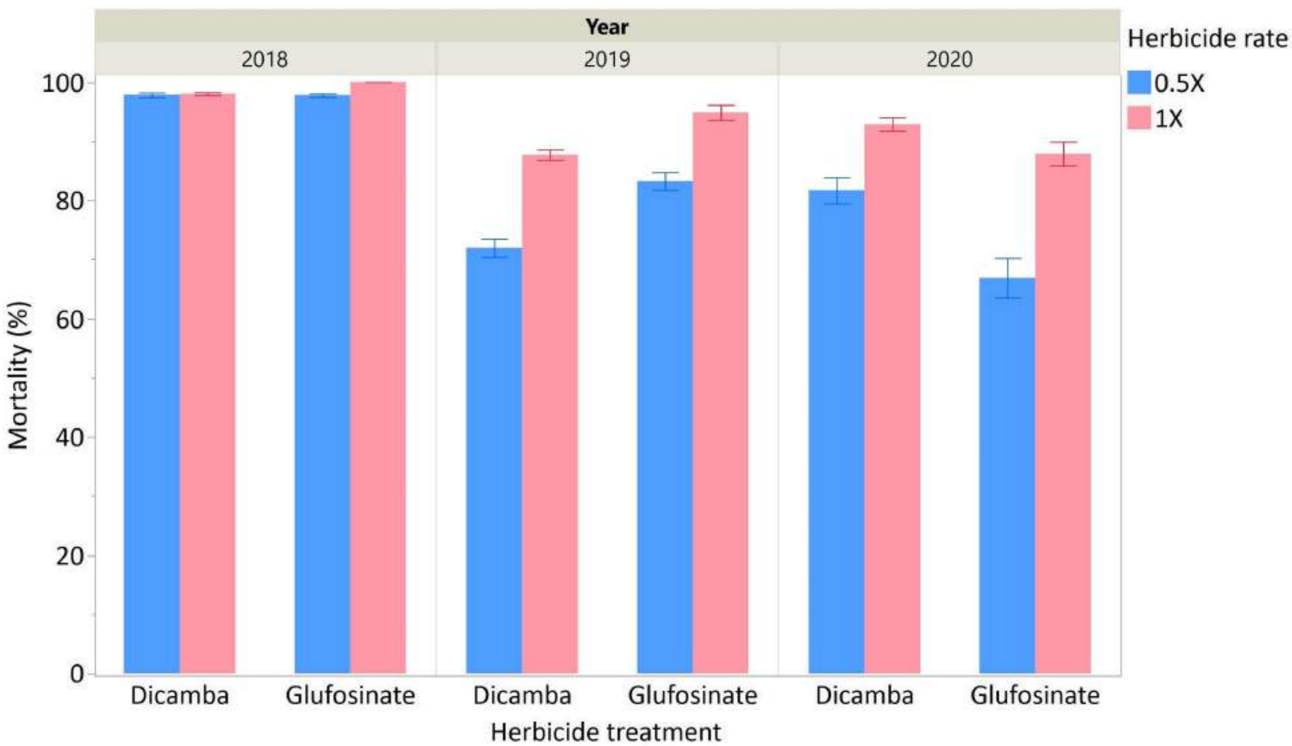

Fig. 1. Annual average mortality (%) across Palmer amaranth (*Amaranthus palmeri* S. Wats.) accessions treated with dicamba or glufosinate at 0.5 or 1X rates (blue and pink bars, respectively). Evaluations treated with 0.5X rate included 52 and 71 accessions from 2018, 68 and 67 accessions from 2019, and 73 and 72 accessions from 2020 applied with dicamba and glufosinate, respectively. Evaluations treated with 1X rate included 59 and 72 accessions from 2018, 62 and 66 accessions from 2019, and 85 and 77 accessions from 2020 applied with dicamba or glufosinate, respectively. Error bars were calculated based on one standard error of the means.

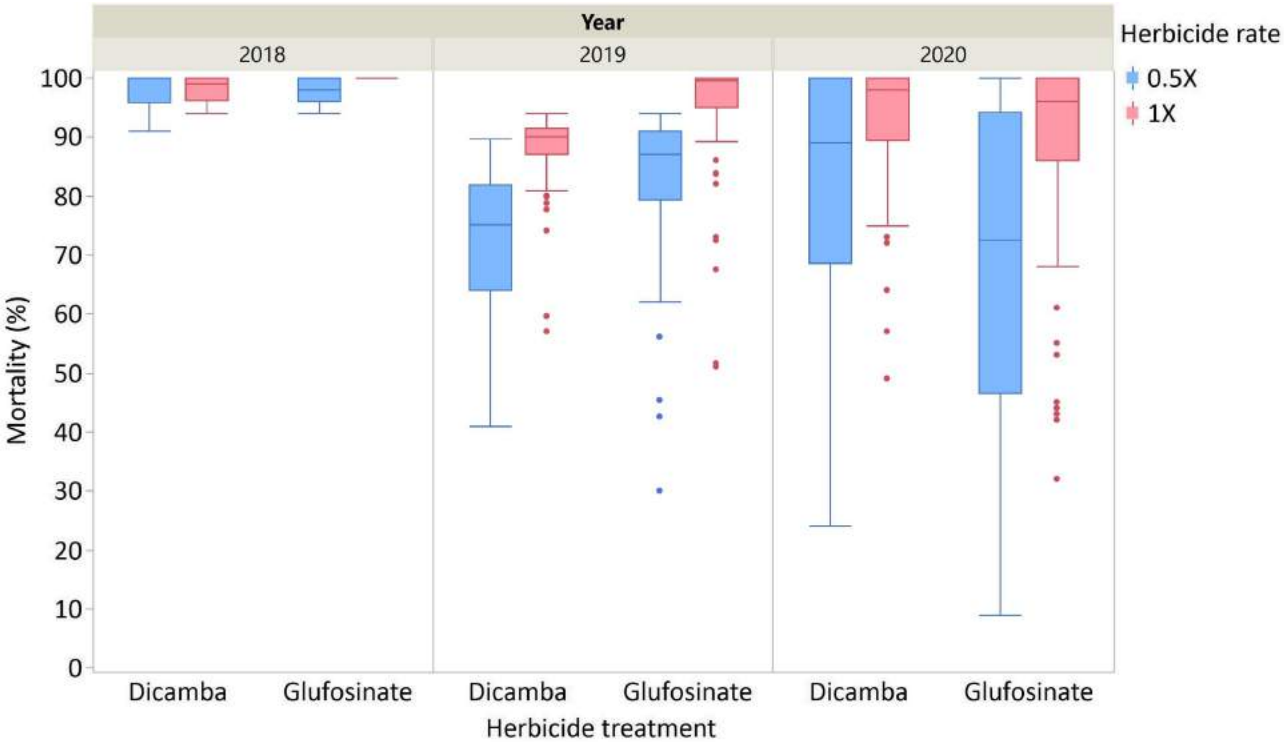

Fig. 2. Distribution of the annual mortality (%) of Palmer amaranth (*Amaranthus palmeri* S. Wats.) accessions treated with dicamba or glufosinate at 0.5 or 1X rates (blue and pink boxes, respectively). Boxes represent 50% quartile, the line is the median value, and the points represent the outliers. Evaluations treated with 0.5X rate consisted of 52 and 71 accessions from 2018, 68 and 67 accessions from 2019, and 73 and 72 accessions from 2020 sprayed with dicamba and glufosinate, respectively. Evaluations treated with 1X rate consisted of 59 and 72 accessions from 2018, 62 and 66 accessions from 2019, and 85 and 77 accessions from 2020 sprayed with dicamba or glufosinate, respectively.

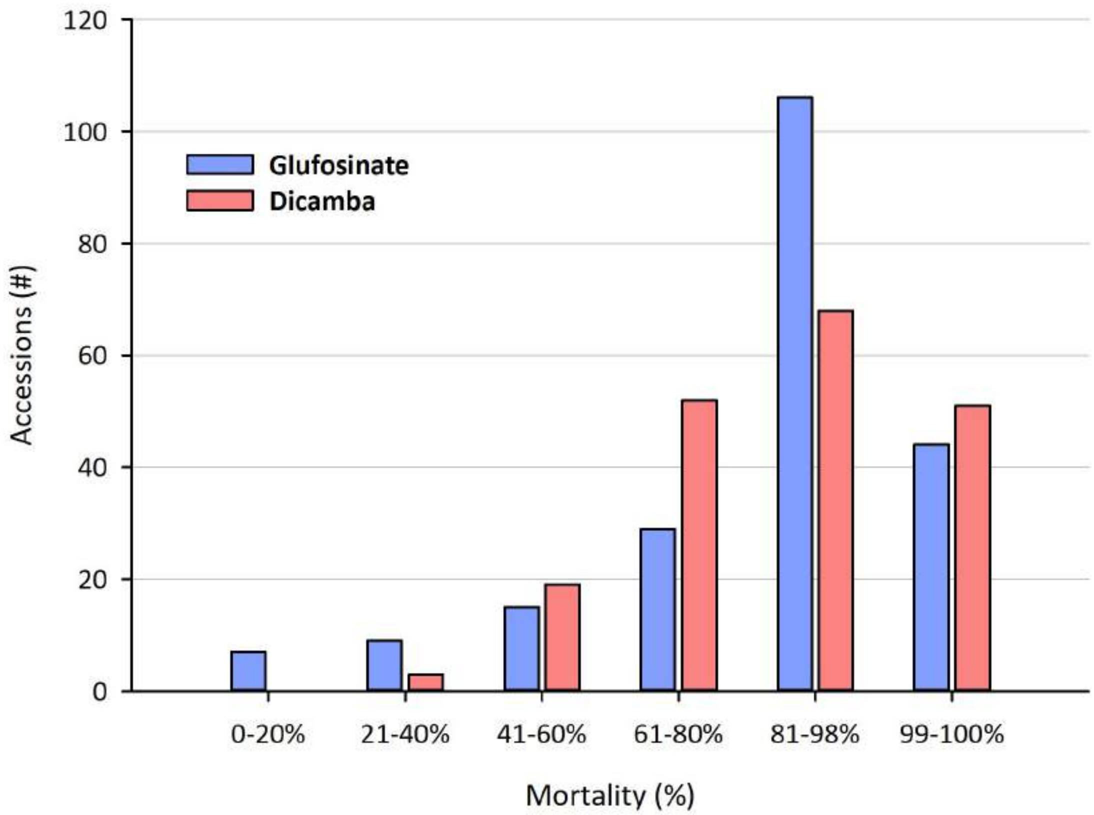

Fig. 3. Total Palmer amaranth (*Amaranthus palmeri* S. Wats.) accessions classified by mortality (%) after treatment with glufosinate or dicamba (blue and pink bars, respectively) at 0.5X rate, with data pooled over time.

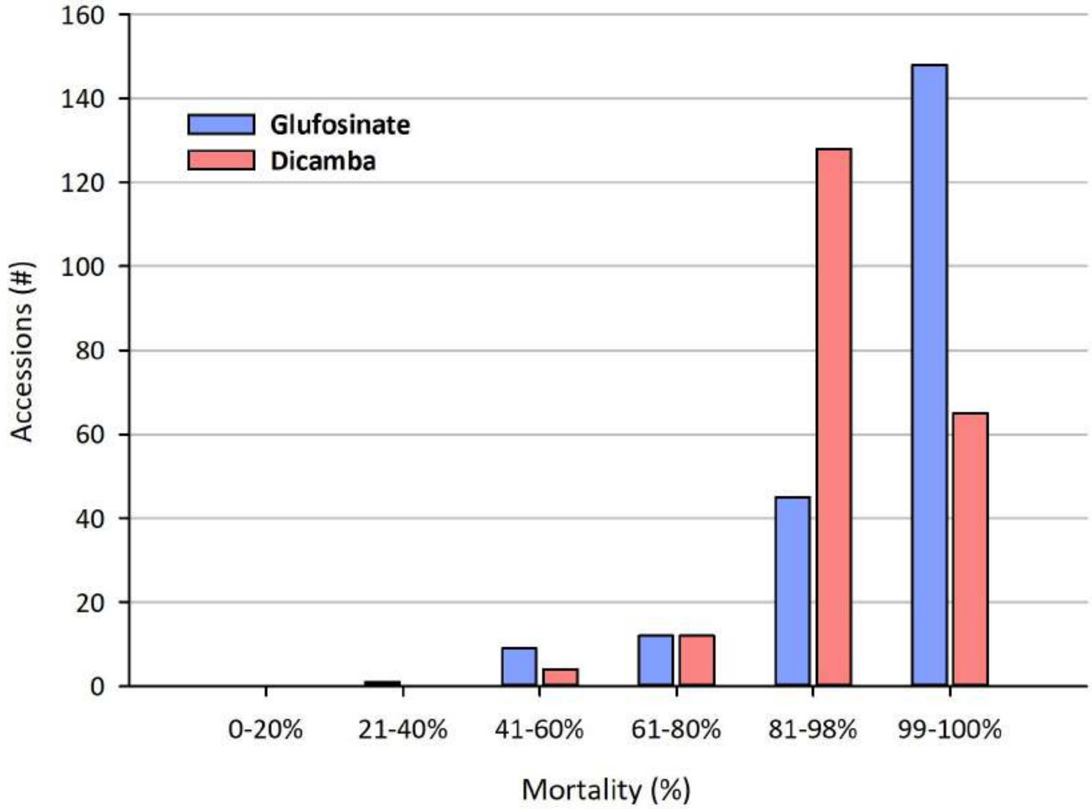

Fig. 4. Total Palmer amaranth (*Amaranthus palmeri* S. Wats.) accessions classified by mortality (%) after treatment with glufosinate or dicamba (blue and pink bars, respectively) at 1X labeled rate, with data pooled over time.

Economic Analysis of the 2020 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 before and within a crop growing season. The 2020 season results provide additional economic relationship insights among seasonal, herbicide, and irrigation production systems, especially concerning early- and late-season plantings. Early-season production system fields had yields that exceeded full-season by over 8 bu./ac and late-season by 26 bu. Early-season returns were almost $90/ac higher in net returns than full-season and $260/ac over late-season system fields. Roundup Ready Xtend® (RRX) herbicide production system fields had a 13 to 16 bu./ac yield advantage over Liberty Link® (LL) and Enlist E3© system fields leading to a $130/ac advantage in net returns across all program fields. Irrigated systems were far superior to non-irrigated ones in both yields and net returns. Total cost savings of $80/ac associated with non-irrigated system fields could not overcome yield and associated revenue disadvantages.

Introduction

The University of Arkansas System Division of Agriculture's Soybean Research Verification Program (SRVP) originated in 1983 with a University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) 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 data set. Among other goals, the program seeks to validate CES 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 regularly 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 CES State Extension Economist compiles the data into the spreadsheet used for the annual cost of production budget development. Measures of profitability and production efficiency are calculated for each cooperator's field and grouped by the soybean production system.

Procedures

Seventeen cooperating soybean producers from across Arkansas provided input quantities and production practices utilized in the 2020 growing season. A state average soybean market price was estimated by compiling daily forward booking and cash market prices for the 2020 crop. The collection period was 1 Jan. through 31 Oct. for the weekly soybean market report published on the Arkansas Row Crops Blog (Stark, 2021). Data was entered into the 2020 Arkansas soybean enterprise budgets for each respective production system (Watkins, 2020). Input prices and production practice charges were primarily estimated by the budget values. Missing values were estimated using a combination of industry representative quotes and values taken from the Mississippi State Budget Generator program for 2020 (Laughlin and Spurlock, 2016). Summary reports, by field, were generated and compiled to generate system results.

Results and Discussion

The 17 fields included in the 2020 Arkansas Soybean Research Verification Program (Elkins, 2020) spanned 9 different production systems based on combinations of seasonal, herbicide, and irrigation characteristics (Table 1). The system combination utilizing a full-season, Roundup Ready Xtend® (RRX) technology seed and furrow irrigation was most common with five fields. Three each used late-season, Liberty Link® (LL) seed, and furrow irrigation or late-season, Roundup Ready Xtend® (RRX) technology seed, and furrow irrigation systems. The remaining 6 combinations, respectfully, each occurred on only two or fewer fields. All economic comparisons were developed from the soybean forward book and cash market prices for the 2020 crop reported by Stark in weekly and monthly summary market reports (Stark, 2021). The soybean forward book and cash market price for the 2020 crop averaged $9.15/bu. over the period of 1 Jan. through 31 Oct. 2020. Market price multiplied by

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yield gave field revenues. No grade reductions or premiums were included. All yields were standardized to 13% moisture content. Readers should note that the small number of fields in total and numbers within groups of fields represented in this study do not permit standard statistical analysis. Yield and economic results are presented by grouping only for discussion purposes. Economic comparisons are drawn across seasonal, herbicide, and irrigation characteristics (Tables 2, 3, and 4). The values for yield, revenue, total variable cost, total fixed cost, total cost, and return to land & management are discussed.

Season Comparisons. Weather conditions for 2020 limited early-season production system fields for the cooperating producers in the program. The 17 fields were primarily classified as either full-season or late-season systems. Early planting was still validated as the two early-season fields had over 8.7 bu./ac higher average yields than the six full-season (Table 2). Revenue for the early-season fields was $80/ac higher than full-season fields. Returns to Land and Management was over $87/ac higher on early-season fields compared to full-season fields. These economic results are consistent with and support CES recommendations for early systems in Arkansas.

Herbicide Comparisons. The Roundup Ready Xtend® (RRX) herbicide system was most frequently used with 9 of the seventeen fields (Table 3). One field had conventional, non-transgenic seed. Yield comparisons by herbicide showed the RRX fields had a 14 bu./ac advantage overall systems except for the 1 conventional field. RRX fields in 2020 were $6/ac less expensive in variable costs, but $13/ac higher in fixed costs than all other systems. The lowest total cost per acre was $342.09 found in Enlist® (E3) except for 1 conventional field. Returns to Land and Management gave a $26/ac advantage to Roundup Ready Xtend herbicide over Liberty Link (LL) and Enlist E3 fields. Returns on the single conventional field were $50/ac higher than the RRX average.

Irrigation Comparisons. Heavy spring precipitation in 2020 seemed to be an advantage for the 2 early-season fields that were planted. Recorded yields on the 2 early-season fields were 8.7 bu./ac higher than all other 2020 SRVP fields. The $7/ac total cost savings provided another advantage. Irrigation systems employed by growers in the 2020 SRVP were predominantly furrow (15 fields). One field was split between center pivot and furrow. One was non-irrigated, and 1 used a flood system (Table 4). The 16 irrigated fields averaged 58.9 bu./ac compared to 34.0 bu./ac for the 1 non-irrigated field. Revenue was almost $150 higher per acre for irrigated fields, but a substantial $79/ac additional cost was again seen for irrigated over non-irrigated. Total variable costs averaged $260.10/ac overall irrigated fields compared to $222.87/ac on the 1 non-irrigated field. Total fixed costs differed similarly with irrigated fields at $97.63/ac and the non-irrigated field at $50.61/ac. The combination of costs left irrigated fields at an average Total Cost of $357.72/ac compared to $278.54/ac for non-irrigated. Return to Land and Management averaged $148.65 higher per acre for irrigated fields over non-irrigated.

Overall Comparisons. The 2020 SRVP fields had a 57.4 bu./ac statewide average yield, 2.2 bushels more than 2019, and over 7 bushels above the Arkansas state average yield of 50 bu./ac (USDA-NASS, 2020). Revenue averaged $525.53/ac generated from this production, an increase of over $73/ac. Total Variable Costs averaged $258.20/ac, a $4/ac increase, and Total Fixed Costs averaged $94.86/ac, more than $8/ac higher, for an average Total Cost per acre of $353.07/ac, slightly over $13/ac higher. These revenue and cost averages left producers with an average per acre Return to Land and Management of $172.47/ac across all production systems, an increase per acre of over $30 compared to 2019.

Practical Applications

The results of state research verification programs can provide valuable information to producers statewide. An illustration of the returns generated when optimum management practices are applied can facilitate the distribution of new techniques and validate the standard recommendations held by state row crop production specialists. Adoption of these practices can benefit producers currently growing soybeans and those contemplating production.

Acknowledgments

The author wishes to thank the Arkansas Soybean Promotion Board for the support provided by Arkansas soybean producers through checkoff funds administered by the board. Appreciation is given to the University of Arkansas System Division of Agriculture and the University of Arkansas at Monticello College of Forestry, Agriculture, & Natural Resources who provided funding and other support for this research project. Appreciation is especially extended to Chad Norton and Chris Elkins, 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.

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Table 1. Production System Combinations of the seventeen fields participating in the 2020 Soybean Research Verification Program.

Production System	Early	Full	Late	Late	Early	Late	Late	Late	Full
Herbicide	RRX	RRX	RRX	RRX	LL	LL	E3	E3	CON
Irrigation	Fur	Fur	Fur	CP	Fur	Fur	Fur	Dry	FL
Number of Fields	1	5	3*	1*	1	3	2	1	1

Production Systems: Full = Full-Season; Late = Late-Season; Early = Early-Season.
Herbicide: RRX = Roundup Ready Xtend®; LL = Liberty Link®; E3 = Enlist®; CON = Conventional.
Irrigation: Furrow = Furrow Irrigation; Dry = Non-Irrigation; CP = Center Pivot Irrigation; FL = Flood Irrigation
*Denotes that Perry County field was split with Furrow and Center Pivot irrigated areas.
Source*:* 2020 Arkansas Soybean Research Verification Program Report.

Table 2. Economic Results by Seasonal Production System for the 2020 Soybean Research Verification Program.

Production System	Early Season	Full Season	Late Season	All Fields
# Fields	2	6	9	17
Yield (bu.)	74.6	65.9	48.0	57.4
Revenue ($/ac)	682.59	602.70	439.30	525.53
Total Variable Costs ($/ac)	255.86	251.50	263.19	258.20
Total Fixed Costs ($/ac)	83.48	95.60	96.91	94.86
Total Costs ($/ac)	339.33	347.09	360.10	353.07
Returns to Land and Management ($/ac)	343.26	255.44	79.20	172.47

Source: 2020 Arkansas Soybean Research Verification Program Report.

Table 3. Economic Results by Herbicide System for the 2020 Soybean Research Verification Program.

Herbicide System	Roundup Ready Xtend®	Liberty Link®	Enlist® E3	Conventional	All Fields
# Fields	9	4	3	1	17
Yield (bu.)	63.4	49.8	47.4	64.5	57.4
Revenue ($/ac)	580.01	455.90	433.40	591.18	525.53
Total Variable Costs ($/ac)	253.98	274.15	260.12	226.65	258.20
Total Fixed Costs ($/ac)	103.60	85.95	81.95	90.63	94.86
Total Costs ($/ac)	357.58	360.10	342.09	317.27	353.07
Returns to Land and Management ($/ac)	222.43	95.80	91.32	272.90	172.47

Source: 2020 Arkansas Soybean Research Verification Program Report.

Table 4. Economic Results by Irrigation System for the 2020 Soybean Research Verification Program.

Irrigation Production System	Irrigated	Non-Irrigated	All Fields
# Fields	16	1	17
Yield (bu.)	58.9	34.0	57.4
Revenue ($/ac)	538.94	311.10	525.53
Total Variable Costs ($/ac)	260.10	227.87	258.20
Total Fixed Costs ($/ac)	97.63	50.61	94.86
Total Costs ($/ac)	357.72	278.54	353.07
Returns to Land and Management ($/ac)	181.21	32.56	172.47

Source: 2020 Arkansas Soybean Research Verification Program Report.

ECONOMICS

2020 Soybean Enterprise Budgets and Production Economic Analysis

B.J. Watkins[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 across all field crops. Production practices for base budgets represent the University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) recommendations from crop specialists and the Soybean Research Verification Program. Unique budgets can be customized by users based on either CES recommendations or information from producers for their production practices. The budget program is utilized to conduct an economic analysis of field data in the Soybean Research Verification Program. The crop enterprise budgets are designed to evaluate the solvency of various field activities associated with crop production. Costs and returns analysis with budgets are extended by production economics analysis to investigate factors impacting farm profitability.

Introduction

The availability of new technologies for soybean producers provides interesting and unique opportunities for producers across Arkansas. Commodity prices have increased in the past year allowing for a rise in revenue to offset steadily increasing input prices in comparison to the last 3 years. Soybean prices for 2020 were estimated at $8.15/bu. and appear to be the low for recent years. The objective of crop enterprise budgets is to develop an interactive computational program, which allows stakeholders of the soybean industry to evaluate numerous production methods for comparative costs and returns dependent upon a wide range of inputs.

Procedures

Crop enterprise budgets are developed based upon input from crop specialists across the state. Input prices are gathered directly from suppliers to create costs estimates unique to the production year. Input costs for fertilizers and chemicals are estimated by applying prices to typical input rates based upon crop specialists' recommendations. Equipment prices, custom hire rates, and fees are estimated with information from those within the agricultural industry in Arkansas. 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 the time requirements of an activity which is applied to an hourly wage rate for determining labor costs (USDA-NASS, 2019). Labor costs in crop enterprise budgets represent time devoted to specified field activities listed at the beginning of each budget.

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). One should note 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 October 2019. Representative prices for machinery and equipment are based on contacts with Arkansas dealers and industry list prices (Deere & Company, 2019; MSU, 2019). Revenue in crop enterprise budgets is the product of expected yields from following CES research verification practices and average commodity prices over the month the budgets are created.

Results and Discussion

The Department of Agricultural Economics and Agribusiness (AEAB) and Agriculture and Natural Resources (ANR) together develop 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 from the University of Arkansas System Division of Agriculture's Soybean Verification Program coordinators, farmers,

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CES county agents. Actual production practices vary greatly among individual farms due to management preferences. Analyses are for generalized circumstances with a focus on the consistent and coordinated application of budget methods for all field crops. This approach results in meaningful costs and returns comparisons for decision-making related to acreage allocations among field crops. Results should be regarded only as a guide and basis as individual farmers should develop budgets for their production practices, soil textures, and other unique circumstances within the budget tool to more accurately represent each unique operation.

Table 1 presents a summary of estimated 2020 costs and returns for Arkansas furrow-irrigated soybeans utilizing field activities associated with a Roundup Ready 2 Xtend® production system. 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 -$35.44 due to the expected price being $0.59/bu. lower than needed to break even. The budget program includes similar capabilities for center pivot irrigated and non-irrigated soybean production for Roundup Ready®, Roundup Ready 2 Xtend, Liberty Link®, Liberty Link GT27, Enlist® E3, and conventional varieties.

Crop insurance information in Table 1 associates input costs with alternative coverage levels for insurance. For example, with an APH yield of 54.0 bu./acre and an assumed projected price of $8.15/bu., input costs could be insured at selected coverage levels greater than 76%. Production expenses represent what is commonly termed as "out-of-pocket costs," and could be insured at coverage levels greater than 87%.

Practical Applications

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 and for planning production methods with the greatest potential for financial success. Flexible budgets enable farm financial outlooks to be revised during the production season as inputs, input prices, yields, and commodity prices change. Incorporating changing information and circumstances into budget analysis assists producers and lenders in making decisions that manage financial risks inherent in agricultural production.

Acknowledgments

This research is made possible by funding from the Arkansas Soybean Promotion Board. Support was also provided by the University of Arkansas System Division of Agriculture and Natural Resources Conservation Service, Arkansas Rice Research and Promotion Board, and the Arkansas Corn and Grain Sorghum Promotion Board.

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Table 1. 2020 Summary of revenue and expenses for furrow-irrigated Roundup Ready 2 Xtend® Soybeans, per acre and 1000 acres.

Summary of Revenue and Expenses			Crop Insurance Information	
Revenue	Per Acre	Farm		Per Acre
Acres	1	1000	**Enter for Farm**	
Yield (bu.)	60.00	60,000	APH Yield	54.0
Price ($/bu.)	8.15	8.15	Projected Price	8.15
Grower Share	100%	100%		
Total Crop Revenue	**489.00**	**489,000**	**Revenue**	**440.10**
Expenses			**Percent of Revenue**	
Seed	72.90	72,900		17%
Fertilizers & Nutrients	34.58	34,575		8%
Chemicals	154.37	154,365		35%
Custom Applications	16.00	16,000		4%
Diesel Fuel, Field Activities	18.23	18,226		4%
Irrigation Energy Costs	35.43	35,434		8%
Other Inputs	3.88	3880		1%
Input Costs	**335.38**	**335,380**		**76%**
Fees	7.00	7000		2%
Crop Insurance	7.21	7210		2%
Repairs & Maintenance, Includes Employee Labor	20.91	20,910		5%
Labor, Field Activities	10.42	10,425		2%
Production Expenses	**380.92**	**380,925**		**87%**
Interest	10.48	10,474		2%
Post-harvest Expenses	18.65	18,645		4%
Custom Harvest	0.00	0		0%
Total Operating Expenses	**410.05**	**410,045**		
Returns to Operating Expenses	**78.95**	**78,955**		
Cash Land Rent	0.00	0		0%
Capital Recovery & Fixed Costs	114.39	114,392		26%
Total Specified Expenses	**524.44**	**524,437**		
Returns to Specified Expenses	**-35.44**	**-35,427**		
Operating Expenses/bu.	6.83	6.83		
Total Specified Expenses/bu.	8.74	8.74		

Soybean Plant's Sap Flow And Crop Yields Relations

M. Ismanov,[1] C.G. Henry,[2] L. Espinoza,[1] and P.B. Francis[3]

Abstract

Plant water demands vary by soybean varieties and by climate and are specific to each region. Sap flow is a direct measure of plant transpiration, the primary component of evapotranspiration. Understanding the relationship between crop yield, plant biomass, soil moisture, amount of nutrients, and plant sap flow is critical to developing irrigation practices that result in higher water use efficiency in soybean (*Glycine max*. L. Merr.), especially during drought or lack of irrigation water. Sap flow was measured for maturity groups 3, 4, and 5 soybean varieties adapted to the mid-south. Measurements were taken during all reproductive growth stages using a Flow 32 K-1 system. Multiple linear regression sap flow sap equations were developed for R4-R8 growth stages using the solar radiation, air temperature, air relative humidity, dew point, and soil moisture.

Introduction

Soybean plant water use varies with growth stages and weather conditions (Payero and Irmak, 2013). Lower sap flow rates have been mostly reported for soybean grown in humid regions. Akihiro and Wang (2002) reported that soybean water use varies relative to climates and soil differences. Soil water resistance and hydraulic conductance of the plant regulate the amount of sap flow. Moreshet et al., (1990) reported that hydraulic conductance was the limiting factor to water flow in the soybean plant. Sap flow rate is a function of soil moisture, solar radiation, air temperatures, and vapor pressure deficits (Zhao et al., 2017).

Plant water demand for soybean is highest during the reproductive stages. About 65% of water use occurs from R1 (beginning flower) through maturity R8 (Kranz and Specht, 2012). Soybean is most sensitive to water stress during the middle to late-reproductive stages: pod development (R3 to R4) and seed fill (R5 to R6).

Estimates of sap flow were obtained during the major reproductive growth stages for soybean planted in a soil mapped as a Calhoun silt loam during the growing seasons of 2017–2019. A previous report showed a relationship between sap flow and yield across different planting dates (Ismanov et al., 2019). Understanding and identifying plant water use and crop yield relations could help to improve water use efficiency. This work aims to document the magnitude of water use by a soybean plant by growth stage and relate water use to grain yield.

Procedures

Sap flow experiments were planted with different soybean varieties (P31A06L, P35T75X, P37T09L, P40A03L, P40A47X, P48A60X, P55A49X, Dyna-Gro). Planting dates for the 3 years of the study were for the early term planting between 16 April and 6 May, the middle term planting between 28 May and 6 June, and late-term planting on 30 June. Experiments were conducted at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, near Marianna, Ark., during 2017–2020. Field preparation, fertilization, planting, and pest control were done following the University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations. Treatments included evapotranspiration (ET) and calendar-based irrigation scheduling, and rainfed dryland. ET-based irrigation was scheduled using alfalfa referenced atmometer recommendations (Henry et al., 2019, https://www.etgage.com). The calendar-based method was meant to simulate neighborhood farmers' irrigation practices and mainly was irrigated on the same day every week unless a significant effective amount of rain was experienced.

A Flow 32 1-K system implemented with SGA5-WS (5 mm) and SGB9-WS (9 mm) sap flow stem gages (Dynamax Inc, Houston Texas) was used to measure sap flow from R2 until the final growth stages. Each sensor was equipped with a heater and temperature sensors that recorded upcoming and outgoing sap (tissue) temperatures. Sap flow was calculated and recorded in 10-minute time intervals. A modified WatchDog 2900 ET weather station of Spectrum Technologies Inc, Aurora, Ill.) was used to record the weather data. Watermark® soil moisture sensors installed at 6, 12, 18, and 30 inches soil depths and Irrometer® 900M data logger (Irrometer Co. Inc., Riverside, Calif.) were used to record hourly soil moisture data during the season.

Additionally, gravimetric water content (GWC) soil moisture was measured to a depth of 30-in. in 6-in. incre-

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ments. Samples were measured several times to calibrate the soil moisture sensors and to calculate the soil water balance throughout the season. Collected variable data were analyzed using scattered diagram method, multiple linear regression analyses (RStudio, B-Corporations) to evaluate the functional relations between sap flow and weather data using SAS (SAS Inst., Cary, N.C.) and EXCEL data analyses ToolPak.

Results and Discussion

Aggregated data across the 4 years show that sap flow is related to growth stage, plant biomass, solar radiation, evapotranspiration, air temperature, and relative humidity. As expected, sap flow increases relative to increasing average daily maximum and minimum temperatures within the same growth stage. A relationship between solar radiation and air relative humidity was developed for R4, R5, and R6, where a large enough dataset existed. The sap flow (SF) multiple regression equation at the R4 growth stage is defined as:

$$S_F=17.86 + 0.039S_{RD} - 0.178H_M \qquad \textit{Eq. 1}$$

Here, SRD = solar radiation, and HMD = relative air humidity. The residual standard error for R4 was found to be 5.284 with 213 degrees of freedom (DF). Multiple R-squared goodness of fit was found to be 0.922, *P*-value < 0.001. The effect of S_{RD} and H_{MD} are shown in Fig. 1. Coefficients, standard deviations, and *P*-value of the variables of the multiple regression equations in R5 and R6 growth stages are given in Table 1.

Solar radiation efficiency (SRE) is defined as the hourly ratio between solar energy received by the plant and the amount of sap flow measured. As transpiration increases during the day, the soil matric potential measured by sensors near the root zone generally increases resulting in a lower SRE in afternoon periods. The daily high SRE is around 1 g/Wh^2 when saturated (-10 to -15 cb) and around 0.5 g/Wh^2 when matric potential is higher (-40 to -60 cb) for silty-loam soils. When SRE is less than 0.3-0.1 g/Wh^2 in dry soil (<-120 to -150 cb), sap flow is reduced. Daily soil water transpired at R4–R6.5 growth stages is up to 0.3 in./d in high (20–25% GWC) and less than 0.1 in./day in low (10%–15% GWC) soil moisture conditions at 0.2–0.25 in./d ET rates in silty-loam soils.

Higher average daily water use was observed for earlier planted soybeans than later planted. The daily water use period of early (from April to the first week of May) planted soybeans observed in late-R3 to R6.5 growth stages are shown in Fig 2. Daily water use was higher in early planted soybeans than later planted soybeans for the same R4–R6 growth stage. Water use is high in very early growth stages and is reduced around the R5 growth stages in late-term (late June) planted soybeans (Fig. 2)

A relationship between yield and sap flow was determined using the dataset. Thus, as yield increased, so did sap flow. An R^2 of 0.92 was observed between sap flow (x) and soybean yields (y) planted in different timings and irrigation treatments, including drylands within the same year: y = 4.3234x + 12.88 (bu.). (Fig. 3). The relationship between the sap flow during R4–R8 growth stages and soybean yields in 2017–2020 is given in Fig. 4. The trends indicate that one inch of plant sap flow in the R4–R8 growth stages is equivalent to 3.9 bushels of grain yield. The relationship between yield and sap flow could be useful to growers to predict crop water demand based on a projected yield goal. This would be useful at the end of the season when water supplies could be more limited.

Finally, a comparison of weekly irrigation versus ET-based irrigation was conducted in a separate experiment. Sap flow amounts during the R4–R8 growth stages in 2020 are shown in Table 2. Four more inches of irrigation (36% more net irrigation) were applied using the calendar-based method than the ET-based irrigation treatment. The plant sap flow amounts in the ET- and calendar-based irrigation plots were almost identical: 11.6 and 12 inches, respectively. In the dryland plots, sap flow was close to rainfall amounts and was between 57%–59% of the irrigated plots' sap flow. Like the ratio of sap flow amounts, the yield of dryland plots made 53%–56% of the irrigated plots' yield. These results indicate that ET-based scheduling can conserve irrigation water amounts compared to the calendar scheduling method. These results also confirm that the sap flow experiments were well watered.

Practical Applications

This data provides estimates of crop water demand by growth stage for Arkansas soybean growing in a silt loam soil. Crop water demand by growth stage can estimate irrigation timing more accurately, thus potentially increasing water use efficiency. Additionally, the regression model developed for R4–R7 growth stages could be used to estimate crop water demand of Arkansas soybean in non-average climate years or by scheduling tools. Water movement inside the plant (sap flow) is driven by weather conditions (solar radiation, air temperature, and relative humidity). Clearly understanding how these parameters affect sap flow can aid in the development of management practices that could increase plant sap flow by providing irrigation water only when needed and terminating irrigation when appropriate.

The trends of soybean water use during the different growth stages depending on the planting date. These data may allow us to define optimum planting dates and maturity groups based on specific weather forecasting in the upcoming season to optimize yield potential and water use efficiency in soybean production. The correlations between soybean plant sap flow and crop yield were identified. It was found that an ET-based irrigation program has the potential to reduce irrigation by 4 inches or 36% compared with a calendar-based irrigation program.

Acknowledgments

The authors would like to thank the Arkansas soybean growers for their financial support for this research provided through the soybean checkoff funds administered by the Arkansas Soybean Promotion Board. This material is based upon work that is supported by the National Institute of food and Agriculture, U.S. Department of Agriculture, 1014608.

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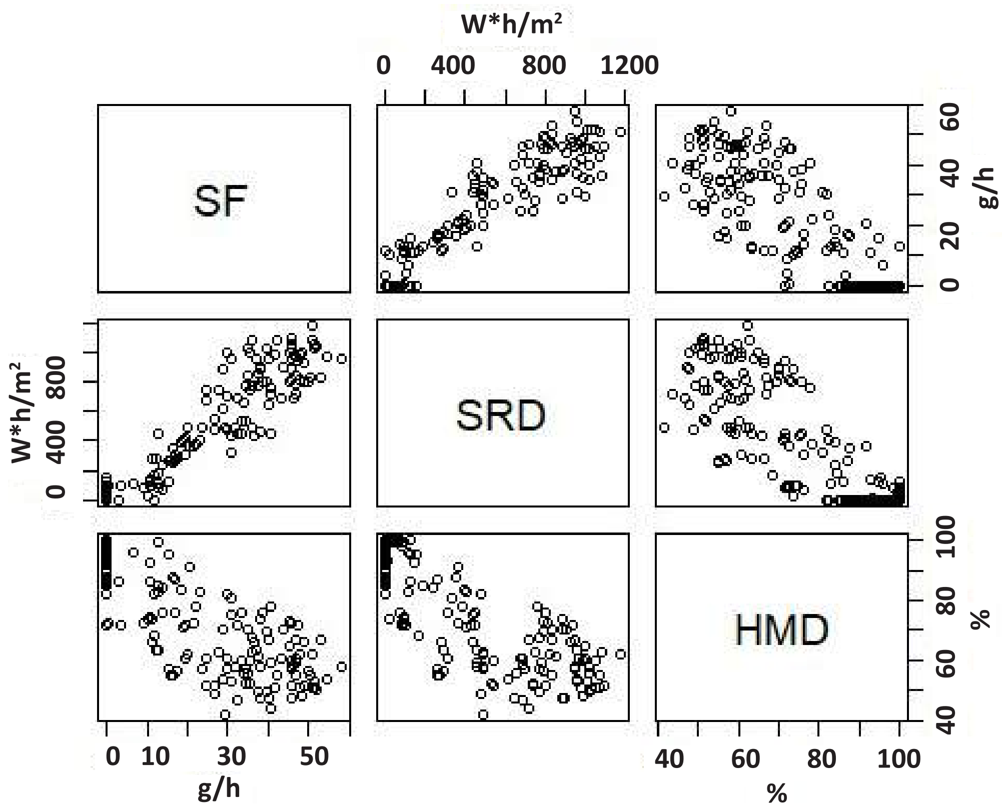

Fig. 1. SRD –solar radiation (W*h/m2) and HMD – relative air humidity (%) impact to the soybean [*Glycine max* (L.) Merr.] plant sap flow SF (g/h) at the R4 growth stage.

Table 1. Regression Slopes, Coefficients, standard deviation, Residual Standard Error, and probabilities for R5 and R6 growth stages of soybean [*Glycine max* (L.) Merr.].

	Growth stage									
	R5					R6				
Variables	Coef.	Std.dev	Error	t-value	Pr(>|t|)	Coef.	Std.dev.	Error	t-value	Pr(>|t|)
Intercept	12.981	3.367	3.855	$1.53e^{-4}$	***	21.565	3.045	7.082	$1.61e^{-11}$	***
SRD	0.034	0.002	22.167	$2e^{-16}$	***	0.028	$1.4e^{-03}$	19.288	$2e^{-16}$	***
HMD	-0.119	0.036	-3.322	$1.01e^{-03}$	**	-0.216	0.032	-6.706	$1.45e^{-10}$	***
Residual standard error: 4.652 on 213 degrees of freedom. Multiple R-squared: 0.898, F-statistic: 942.6 on 2 and 213 DF, *P*-value: < $2.2e^{-16}$						Residual standard error: 3.709 on 237 degrees of freedom. Multiple R-squared: 0.912, F-statistic: 1221 on 2 and 237 DF, *P*-value: < $2.2e^{-16}$				

Regression variables are significant at alpha of '***' 0.001 and '**' 0.01.

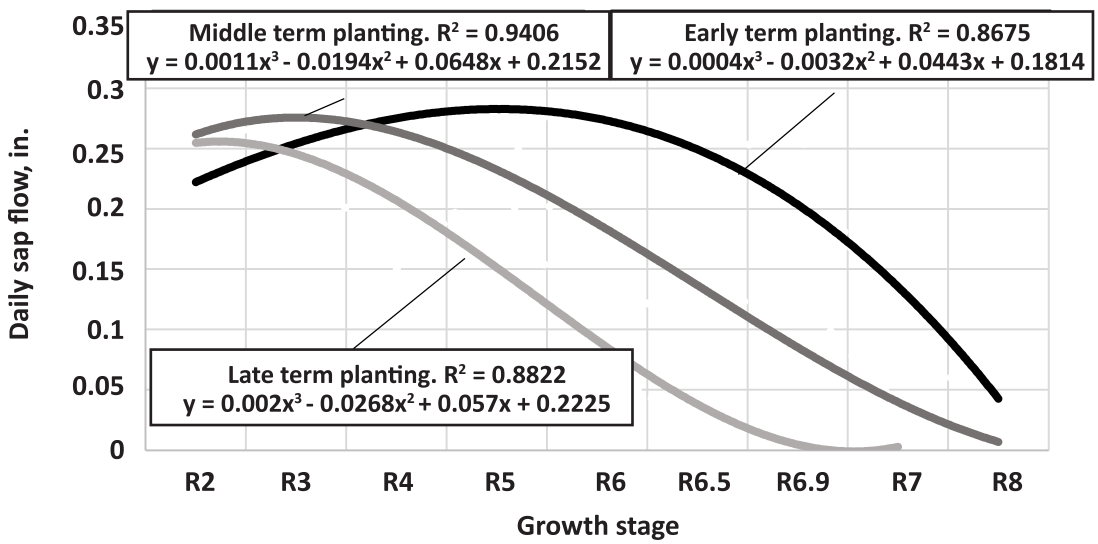

Fig. 2. Soybean [*Glycine max* (L.) Merr.] daily sap flow (water use) planted in different timings.

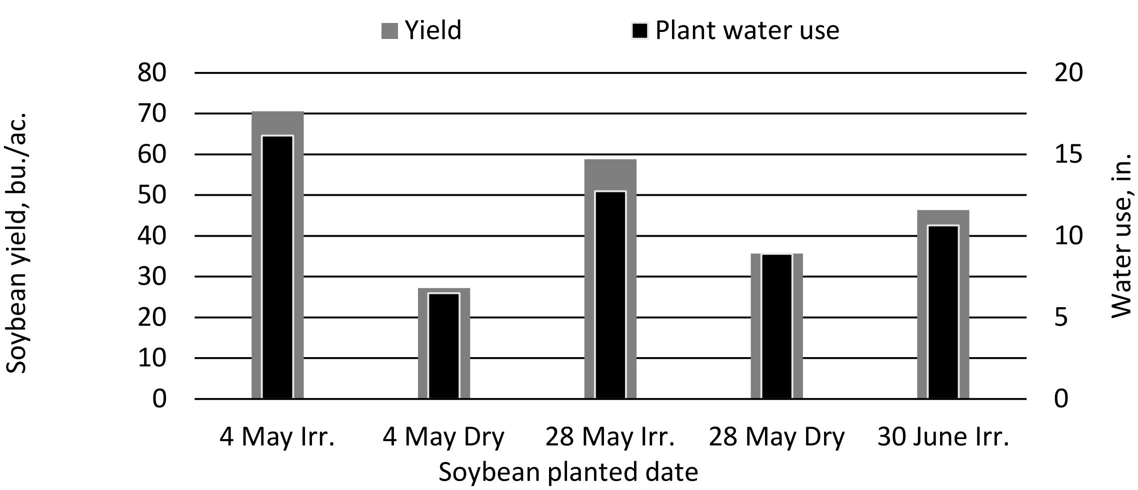

Fig. 3. Soybean [*Glycine max* (L.) Merr.] yield and plant water (sap flow) use when planted at different timings and with different irrigation treatments.

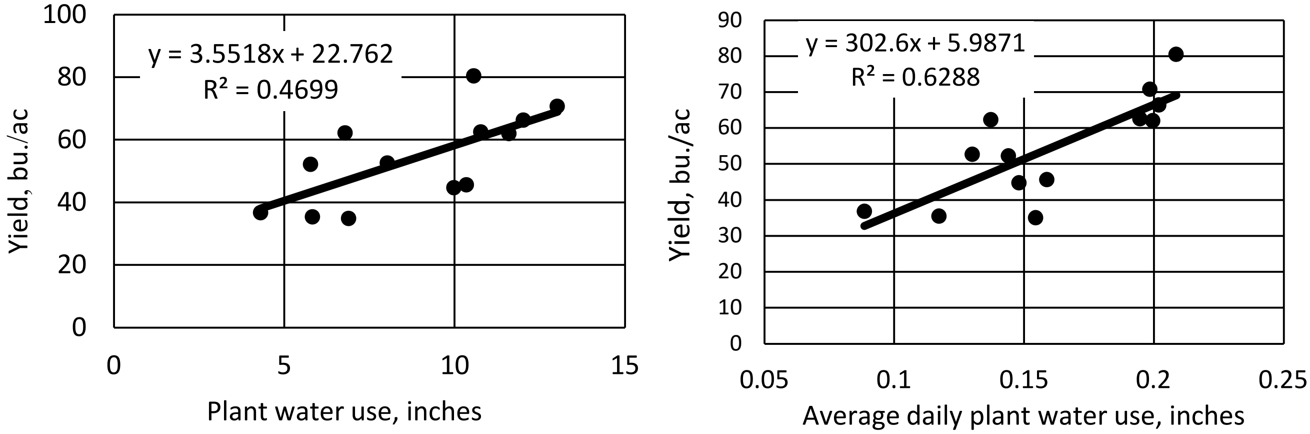

Fig. 4. Relations between yield and total and daily water (sap flow) use in soybean [*Glycine max* (L.) Merr.] growth stages R4–R8 of different soybean varieties planted in different timings and irrigation treatments in 2017–2020.

Table 2. Daily and cumulative plant sap flow amounts in different growth stages of soybean variety Pioneer P31A06L with different irrigation treatments.

Planted:	5/6/2020				5/6/2020				5/6/2020			
Harvested:	9/22/2020				9/22/2020				9/22/2020			
Days to R8:	112				123				123			
Irrigation:	Dryland				ET-based				Calendar-based			
Growth stages	**Days**	**Av.**	**Sum**	**Cum.**	**Days**	**Av.**	**Sum**	**Cum.**	**Days**	**Av.**	**Sum**	**Cum.**
R2	6				9				9			
R3	9				11				11			
R4	9	0.08	0.74	0.74	11	0.29	3.17	3.17	11	0.33	3.6	3.6
R5	8	0.26	2.04	2.78	12	0.26	3.08	6.26	12	0.28	3.3	6.9
R6	9	0.18	1.64	4.42	8	0.29	2.34	8.59	8	0.3	2.42	9.32
R6.5	5	0.18	0.92	5.33	7	0.26	1.81	10.4	7	0.21	1.46	10.8
R6.9	3	0.17	0.51	5.84	3	0.2	0.61	11	3	0.18	0.54	11.3
R7	5	0.19	0.96	6.8	6	0.1	0.58	11.6	6	0.11	0.68	12
R8	4	0.02	0.09	6.89	5	0	0.01	11.6	5	0.01	0.02	12
Rain + Irr., in.			7.1			14.2				18.2		
ET, in.			10.1			11.1				11.1		
Yield, bu./acre			35.0			62.1				66.4		
Standard dev.			5.99			6.38				2.56		

Results from Three Years of the University of Arkansas System Division of Agriculture Soybean Irrigation Yield Contest

C.G. Henry,[1] T. Clark,[1] Greg D. Simpson,[1] P.N. Gahr,[1] and J.P. Pimentel[2]

Abstract

The University of Arkansas System Division of Agriculture Irrigation Yield Contest was conducted in 2018, 2019, and 2020. The contest was designed to promote better use of irrigation water as well as to record data on water use and water use efficiency for various crops. Unlike yield contests where winners are decided by yield alone, the irrigation contest results are decided by the highest calculated total water use efficiency (WUE) achieved by a producer. The contest consists of 3 categories: corn, rice, and soybeans. All fields entered were required to show a history of irrigation and production on the field. Irrigation water was recorded by using 8-in. and 10-in. portable mechanical flow meters. Rainfall totals were calculated using Farmlogs™. The contest average water use efficiency of 2018–2020 for soybean was 3.2 bu./in. The winning WUEs were 4.37 bu./in. for 2020, 4.31 bu./in. for 2019, and 3.92 bu./in. for 2018. Adoption of Irrigation Water Management (IWM) practices such as Computerized Hole Selection (CHS), surge irrigation, soil moisture sensors are increasing. Soybean contest participants from 2018–2020 reported using on average 8.9 ac-in./ac of irrigation.

Introduction

According to data from 2015 reported by the United States Geological Survey (USGS), Arkansas ranks 3rd in the United States for irrigation water use and 2nd for groundwater use (Dieter et al., 2018). For comparison, Arkansas ranked 18th in 2017 in total crop production value (USDA-NASS, 2017). Of the groundwater used for irrigation, 96% comes from the Mississippi River Alluvial Aquifer (Kresse et al., 2014). One study of the aquifer found that 29% of the wells in the aquifer, that were tested, had dropped in water level between 2009 and 2019 (Arkansas Department of Agriculture Natural Resource Division, 2019).

A study was conducted from 2013 to 2017 in primarily corn and soybean fields to assess the water-saving potential of implementing 3 irrigation water management (IWM) tools: computerized hole selection, surge irrigation, and soil moisture sensors (Spencer et al., 2019). Paired fields were set up with 1 using the IWM tools and 1 using conventional irrigation methods. It was found that the implementation of all 3 IWM tools reduced water use in the soybean fields by 21% while not reducing yields. This increased water use efficiency (WUE) by 36%. For the cornfields, a 40% reduction in water use was observed and WUE went up by 51%. For soybeans, when the cost of the new IWM tools was incorporated, no significant difference in net returns was found, but in corn, net returns were improved by adopting IWM.

The University of Arkansas System Division of Agriculture's Irrigation Yield Contest was designed as a novel way of encouraging the use of water-saving methods by Arkansas producers. The competition aimed to promote water-reducing management practices by educating producers on the benefits of irrigation water management tools, providing feedback to participants on how they compared to other producers, documenting the highest achievable water use efficiency in multiple crop types under irrigated production in Arkansas, and by recognizing producers who achieved a high-water use efficiency.

Procedures

Rules for a soybean irrigation yield contest were developed in 2018. The influence was taken from already existing yield contests (Arkansas Soybean Association, 2014; National Corn Growers Association, 2015; National Wheat Foundation, 2018; University of California Cooperative Extension, 2018). The rules were designed to be as unobtrusive as possible to normal planting and harvesting operations. Fields were at least 30 acres in size. A yield minimum of 60 bu./ac was required to qualify.

A portable propeller-style mechanical flow meter was used to record water use. All flow meters were checked for proper installation and sealed using poly-pipe tape and serialized tamper-proof cables. Rainfall was recorded using Farmlogs™, an online software that provides rainfall data for a given location. Rainfall amounts were totaled from the date of emergence to the date of physiological maturity. Emergence was assumed as 7 days after the planting date provided on the entry form. For physiological maturity, the seed companies published days to maturity was used. Rainfall was adjusted for extreme events.

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The harvest operations were observed by a third-party observer, often an Extension agent, Natural Resource Conservation Service employee, or Division of Agriculture staff. For the yield estimate, a minimum of 3 acres was harvested from the contest field.

The equation used for calculating WUE for the contest was: WUE = Y/(Pe + IRR) where, WUE = water use efficiency in bushels per inch, Y = yield estimate from harvest in bushels per acre, Pe = effective precipitation in inches, and IRR = irrigation application in ac-inches/ac (Irmak et al., 2011). Statistical analysis was performed using Microsoft Excel and JMP 15 (Cary, N.C.).

Results and Discussion

Detailed results are published on the contest website (www.uaex.uada.edu/irrigation) for each year of the contest. Over the 3 years that the competition has been conducted, there have been 42 fields entered for soybean. The average WUE over the 3 years was 3.2 bu./in. By year, the average WUE was: 3.51 bu./in. for 2020 with 17 contestants, 2.94 bu./in. for 2019 with 13 contestants, and 2.86 bu./in. for 2018 with 12 contestants (Table 1). The winning WUE was higher in 2020 than in 2018 and 2019. The winning WUE for each year was: 4.37 bu./in. for 2020, 4.31 bu./in. for 2019, and 3.92 bu./in. for 2018.

It is a common belief that a higher or lower yield will help obtain a better WUE. By plotting WUE on one axis and yield on the other, the best fit line can be calculated. The line calculated has a coefficient of determination of $R^2 = 0.3882$ where $R^2 < 0.95$ shows no relationship or correlation exists. There is no discernable relationship between yield and WUE in the soybean dataset. Another commonly held belief by contestants is that a higher amount of rainfall will help to increase WUE. By plotting rainfall against WUE, linear regression was used to determine if there was a linear relationship. The coefficient of determination was determined to be $R^2 = 0.15$. There is no discernable relationship between WUE and precipitation. The lack of relationships suggests that neither precipitation nor yield is a factor in achieving high WUE and achieving high WUE is due to irrigation management.

In 2015, a survey was conducted across the mid-South to determine the adoption rate of various IWM tools (Henry 2019). On the entry form for the contest, a similar survey was included to assess the usage of IWM tools among the participants. In the 2015 survey, 40% reported using computerized hole selection and 66% of the Arkansas growers reported using computerized hole selection. 24% of respondents said they used soil moisture sensors in the region on their farm and only 9% of Arkansas irrigators reported using soil moisture sensors.

Contestants were asked about their adoption of IWM tools when they entered the contest. In total, 64% of the participants across all 3 categories included responses in their entry form. The IWM tool that was most widely adopted was computerized hole selection. The average use among respondents was 89% across all 3 years with 88% in 2018, 72% in 2019, and 100% in 2020. Fifty-four percent of respondents from all 3 years said that they used soil moisture sensors on their farms, with 60% in 2018, 67% in 2019, and 42% in 2020. Surge valves were the least used IWM tool with 28% of respondents from all 3 years saying they used surge valves. This included 44% from 2018, 28% from 2019, and 16% from 2020.

Practical Applications

Irrigation water use efficiency (WUE) of working farms is not a common metric available in the literature, and it is not a metric familiar to soybean farmers. The data recorded from the Arkansas Irrigation Yield Contest provides direct feedback to irrigators about their irrigation performance in maintaining high yields and low irrigation water use. Such direct feedback of Arkansas soybean farmers will likely provide many with a competitive advantage when water resources become scarcer. It provides a mechanism for soybean farmers to evaluate the potential for water savings by adopting water-saving techniques or management changes.

On average, soybean growers in the contest across the 3 years averaged 8.9 ac-in./ac applied, and total water use of 24.8 in. of total water for soybean.

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Table 1. Maximum, average, and minimum for 2018, 2019, and 2020 of various water and yield data points for soybean from the Arkansas Irrigation Yield Contest.

		Water Use Efficiency	Yield	Adjusted Rainfall	Irrigation Water	Total Water
		bu./in.	bu./ac	in.	ac-in./ac	in.
2020	Maximum	4.37	106	15.9	20.8	34.1
	Average	3.51	79	13.4	10.1	23.4
	Minimum	1.80	45	9.8	3.8	14.7
2019	Maximum	4.31	112	30.4	13.1	34.7
	Average	2.94	74	19.9	6.0	26.0
	Minimum	1.80	46	15.1	2.0	19.8
2018	Maximum	3.92	103	17.6	17.4	30.6
	Average	2.86	72	15.0	10.3	25.3
	Minimum	2.24	53	11.6	4.9	19.3
3 Yr.	Average	3.15	76	15.9	8.9	24.8

Evaluation of Selected Soybean Foliar Fertilizer Products

W.J Ross,[1] R.D. Elam,[1] and R.G. Miller[1]

Abstract

Many soybean [*Glycine max* (L.) Merr.] producers apply foliar products containing elemental nutrients as a routine practice during soybean reproductive growth. Many times, these products are used in addition to routine soil testing and recommended fertilizer applications. Due to increased production costs and narrowing profit margins, many soybean producers have questioned if foliar nutrient products increase soybean grain yield and if these products are profitable. In 2020, Arkansas collaborated with 16 other Universities to compare the soybean grain yield response to six commercially available foliar nutrient products. Soybean grain yields were not statistically different for the 6 products evaluated when compared to the untreated check at the 2 Arkansas locations. Based on these findings, along with previous work, using these foliar nutrient products as a routine production practice is not currently recommended.

Introduction

Soybean [*Glycine max* (L.) Merr.] producers in Arkansas rely on routine soil testing and field history to determine fertilizer and lime applications rates to maximize soybean grain yield. Compared to corn (*Zea mays*) and rice (*Oryza sativa*), soybean requires relatively larger amounts of nitrogen (N), phosphorus (P), and potassium (K) to maximize grain yield (Slaton et al., 2013). A majority of the required elemental nutrients needed to maximize soybean grain yield are supplied by soil available nutrients, biological fixation, or by fertilizer products. Recently, many companies have been marketing foliar nutrient products as a routine practice for soybean production. Soybean producers often apply these products in combination with fungicide and/or insecticide applications during reproductive growth. Some producers believe there is a yield gain with applications of N and K at the R3 growth stage. Others believe that micronutrients such as boron (B), manganese (Mn), and iron (Fe) are increasing soybean yield. Due to tight profit margins, knowing if these foliar nutrient products increase soybean yield and if there is an economic return to the producer is needed.

In 2020, 16 states tested 6 foliar nutrient products in 26 environments. These products were commercially available and selected with the input of industry professionals. The objectives for this study were to 1. identify yield response in soybean to foliar nutrient applications, 2. conduct economic analyses on the value of these products (data not shown), and 3. extend these results to soybean producers through the University of Arkansas System Division of Agriculture's Cooperative Extension Service networks. This paper will only focus on the 2 locations that were established in Arkansas and only report the yield comparisons of the products tested in 2020.

Procedures

Research trials to evaluate 6 foliar nutrient products were established at the University of Arkansas System Division of Agriculture's Jackson County Extension Center (JCEC), Newport, Ark., and at the Pine Tree Research Station (PTRS), near Colt, Ark. in 2020. The soybean variety Credenz CZ 4539 GTLL (BASF; Ludwigshafen, Germany) was used for each trial which was a 4.5 maturity group LibertyLink® GT27™ soybean variety seeded at a rate of 150,000 seed/ac. Plots consisted of four rows spaced 15-in. by 30-ft. long. Trials were planted using a Precision Kincaid Vacuum Plot Planter (Kincaid Equipment Manufacturing; Haven, Kan.) at both the JCEC and PTRS on 2 June and 16 June 2020, respectively. After planting, composite soil samples were taken from each plot. The average values of selected soil chemical properties are listed in Table 1. Foliar nutrient products used in this– study were selected with the input of industry representatives and the associated application rates are provided in Table 2. Treatments were applied at the R3 growth stage (University of Wisconsin-Extension, 2020) using a backpack sprayer with a 3-nozzle boom calibrated to deliver a constant carrier volume of 20 gal/ac. Nutrient amounts for each product at the application rate are listed in Table 2. Foliar tissue samples were taken immediately before applications and 14 days after the application for nutrient analysis (data not shown). Management for irrigation, fertility, and late-season pest control closely followed recommendations from the University of Arkansas System Division of Agriculture's Cooperative Extension Service for soybean production. In each trial, soybean was irrigated as needed using flood irrigation at both locations. At maturity, plots were harvested, and moisture content and weight of the grain were determined. Grain yield was adjusted to 13% moisture and reported as bu./ac for each trial.

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Within each test, treatments were arranged as a randomized complete block design with six replications. Data were subjected to analysis of variance (ANOVA), using ARM 2020 (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 0.10.

Results and Discussion

Soybean grain yields varied across the two locations tested in Arkansas in 2020; therefore, statistical analyses were conducted by location. At the JCEC location, the average soybean grain yield for the foliar nutrient products applied ranged from 54.5–57.5 bu./ac. Soybean grain yields from each treatment were not significantly different from the untreated check (56.7 bu./ac) (Table 3; Fig. 1). The FertiRain treatment had the highest numerical grain yield (57.5 bu./ac) of all the treatments. Similar results were observed with the same nutrient products when tested in 2019 at the JCEC locations (Ross et al., 2020).

Results from the 2020 PTRS locations were similar to those observed at the JCEC location. Soybean grain yields of the treatments were not significantly different from the untreated control (63.0 bu./ac) (Table 3; Fig. 2). Average grain yields for the foliar nutrient products at the PTRS location ranged from 60.2–66.6 bu./ac. SureK had the highest grain yield (66.6 bu./ac) of any treatment. These results were similar to the findings when these same products were evaluated in 2019 (Ross et al., 2020).

At both locations in 2020, the recommended pre-plant fertilizer was applied according to soil analysis. Therefore, this study evaluated the effect of selected foliar nutrient products where adequate fertilizer had been applied to maximize soybean grain yield. Results from these trials indicated that additional foliar nutrient products did not significantly increase soybean grain yield where proper pre-plant fertilizer was applied.

The 2020 results observed in Arkansas were similar to the results seen in the other states that conducted this study (Matcham et al., 2021). Of the 26 sites in 2020, no treatment significantly increased grain yield when compared to the untreated control. During the 2 years these 6 products were tested, only one product at one location in 2019 showed a significant yield increase compared to the untreated control (Matcham et al., 2020).

Practical Applications

Findings from the 2019 and 2020 studies indicate that under normal soybean production where soil testing is utilized and recommended fertilizer rates are applied, the additional application of foliar nutrient products does not increase soybean grain yield. These products could potentially be beneficial in situations where nutrient deficiencies are observed but should not be used as a routine practice. Due to increased production costs and variable market prices, foliar nutrient products do not significantly increase soybean yields and do not have a positive return based on product and application costs.

Acknowledgments

The authors would like to thank the Arkansas Soybean Promotion Board for their funding of this research. We would also like to thank the personnel at the Jackson County Extension Center and the Pine Tree Research Station for their help and support with our fieldwork. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Selected soil chemical property means from the 0-4 in. depth for the nutrient product trials conducted in 2020.[a]

Location[b]	Soil Series	pH	P	K	Ca	Mg	SOM
			------------------------ppm------------------------				%
JCEC	Dexter silt loam	5.5	36	114	957	100	1.9
PTRS	Calhoun silt loam	7.1	18	99	1324	264	2.2

[a] P = Phosphorus; K = Potassium; Ca = Calcium; Mg = Magnesium; SOM – Soil Organic Matter.
[b] JCEC = Jackson County Extension Center, Newport, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.

Table 2. Amounts of nutrients applied for each product tested at the given rates in 2020.[a]

Treatment	Company	Rate	N	P	K	S	Mn	Fe	Mo	Zn	B	Other
			--------------------------------------lb/ac--------------------------------------									
FertiRain	AgroLiquid	3 gal/ac	3.5	0.9	0.9	0.5	0.02	0.03	--	0.03	--	--
SureK	AgroLiquid	3 gal/ac	0.6	0.3	1.7	--	--	--	--	--	--	--
HarvestMore Ureamate	Stoller	2.5 lbs/ac	0.1	0.25	--	--	0.01	--	0.002	0.01	0.004	Ca, Mg, Co, Cu
Smart B-Mo	Brandt	1 pt/ac	--	--	--	--	--	--	0.006	--	0.07	--
Smart Quarto Plus	Brandt	1 qt/ac	--	--	--	0.04	0.08	--	0.003	0.08	0.06	--
Maximum NPact K	Nutrien	1.5 gal/ac	1.9	--	1.9	--	--	--	--	--	--	--

[a] N = Nitrogen; P = Phosphorus; K = Potassium; S = Sulfur; = Mn = Manganese; Fe = Iron; Mo = Molybdenum; Zn = Zinc; B = Boron.

Table 3. Mean soybean grain yield (standard deviation) for selected foliar nutrient products at 2 locations in 2020.

Location[a]	UTC[b]	FertiRain	SureK	HarvestMore UreaMate	Smart B-Mo	Smart Quarto Plus	Maximum NPact K	
	--Yield (bu./ac)--							
JCEC	56.7 (9.8)	57.5 (8.4)	54.5 (5.2)	56.7 (9.2)	55.6 (6.7)	57.2 (7.3)	57.3 (7.3)	NS[c]
PTRS	63.0 (3.6)	62.0 (1.8)	66.6 (2.2)	60.2 (2.3)	65.0 (3.1)	65.0 (2.6)	63.6 (3.8)	NS

[a] JCEC = Jackson County Extension Center, Newport, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.
[b] UTC = untreated check.
[c] No statistical difference was seen between the untreated control and the foliar nutrient products evaluated at an alpha level = 0.10.

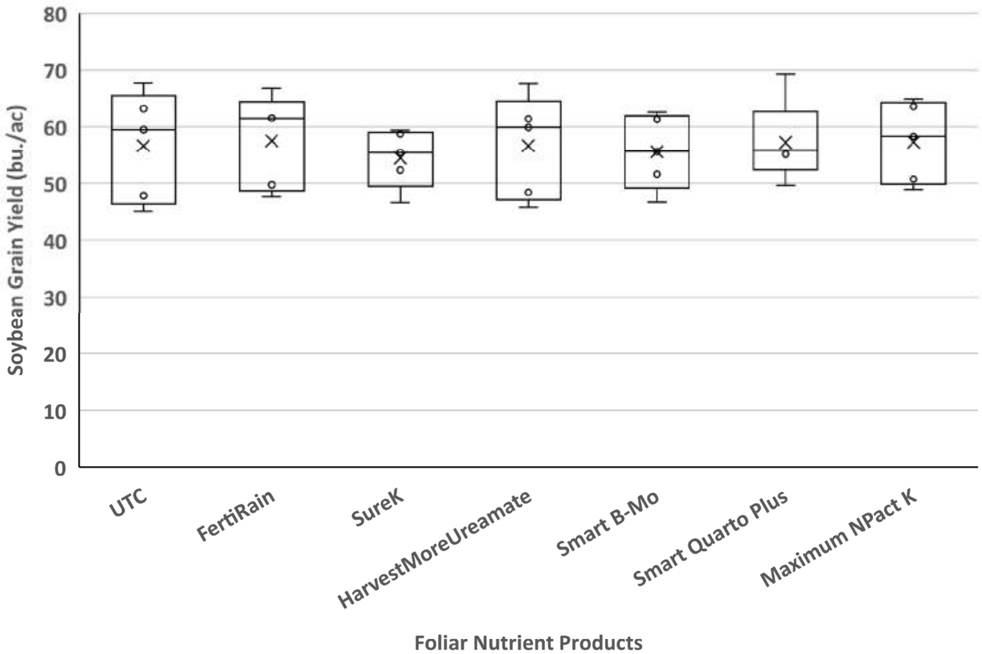

Fig. 1. Mean soybean yield (bu./ac) for each foliar nutrient product, 2020, at the University of Arkansas System Division of Agriculture's Jackson County Extension Center, near Newport, Ark. Boxes represent 50% quartile; "X" within each box depicts means, and the line within the box is the mean value. UTC = untreated check.

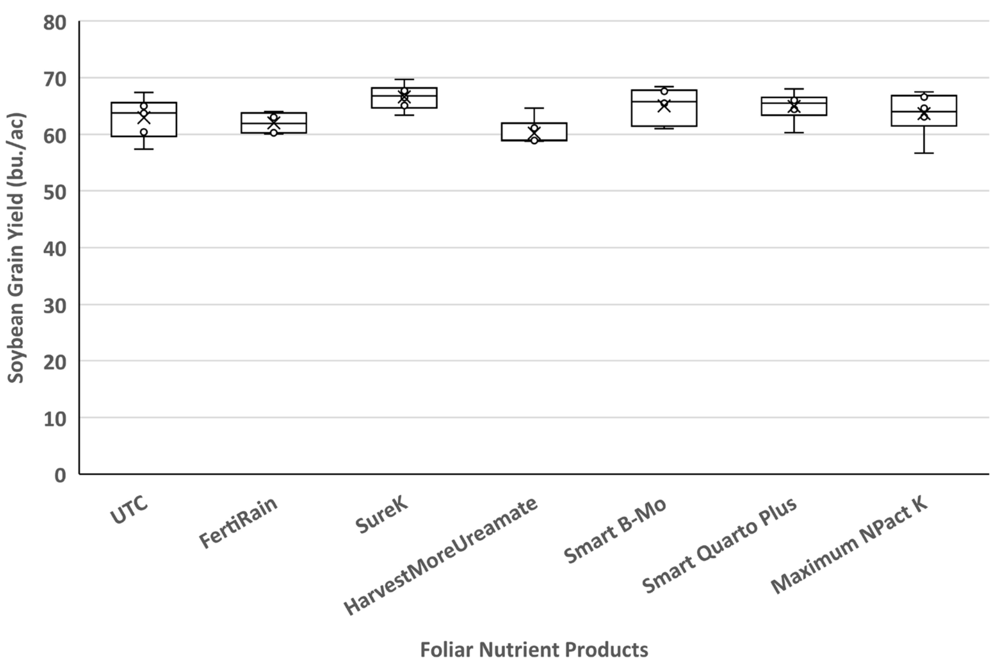

Fig. 2. Mean soybean yield (bu./ac) for each foliar nutrient product, 2020, at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark. Boxes represent 50% quartile; "X" within the box depicts means, and the line within the box is the median value. UTC = untreated check.

Soybean Response to Sulfur Fertilization

W.J. Ross,[1] R.D. Elam,[1] and R.G. Miller[1]

Abstract

Small-plot trials to evaluate sulfur fertilization source and rate were conducted at two locations in Arkansas during 2020. The locations for this trial were the University of Arkansas System Division of Agriculture's Jackson County Extension Center (JCEC) near Newport, Ark., and the Pine Tree Research Station (PTRS) near Colt, Ark. The studies conducted in Arkansas were a part of a national project that evaluated the same treatments at 22 locations in 9 other soybean-producing states in the United States. Sulfur is one of the essential macronutrients needed by soybean and is important in the production of some proteins. Sulfur deficiencies in soybean are becoming more common due to increased crop removal and lack of sulfur deposition from the atmosphere. Results from the studies conducted in Arkansas in 2020 showed no significant yield increase from the application of any of the fertility treatments, and these results were similar to the findings from 2019.

Introduction

Sulfur (S) is an essential nutrient element that soybean plants require to build proteins and other molecules. Sulfur ranks 4th in the importance of the essential elements behind nitrogen (N), phosphorus (P), and potassium (K) (Slaton et al., 2013). Row crop producers are reporting more observations of crops with S deficiencies due to increased removal associated with higher yields and the reductions of S input from atmospheric deposition. Some researchers are concerned that S could be the next limiting nutrient in U.S. soybean production. Atmospheric deposition previously accounted for a portion of the plant available S, but this input has been greatly reduced due to the implementation of the Clean Air Act.

A majority of the plant available S in the soil comes from the decomposition of soil organic matter (SOM). The S form released by the decomposition of SOM is a sulfate ion., which can be taken up by the soybean plant. However, the sulfate ion is also vulnerable to loss in the soil due to leaching. Soil with high sand content and low SOM are at the greatest risk for having plants develop S deficiencies. Under normal production conditions, soybean plants often do not respond to S fertilization, but yield responses to the addition of S-containing fertilizers can be substantial in cases where soil S levels are deficient (Slaton et al., 2013).

Soybean producers have questioned the potential for S fertilization to increase soybean yield and profitability. However, the effect of additional sulfur-containing fertilizers on soybean yield and economic return is important to understand to maintain farm profitability. In 2020, Arkansas collaborated with 9 other soybean production states on a multi-state project to evaluate the response of soybean to S fertilization. The objectives of this study were to 1.) identify yield response in soybean to S fertilizer applications, 2.) conduct economic analyses on the value of these applications, and 3.) extend results to soybean producers through Extension platforms. This paper will only focus on the two locations where this study was conducted in Arkansas and only report the yield responses of the fertilizer treatments tested in 2020.

Procedures

Research trials to evaluate the S treatments were established at the University of Arkansas System Division of Agriculture's Jackson County Extension Center (JCEC) near Newport, Ark., and the Pine Tree Research Station (PTRS), near Colt, Ark. in 2020. The soybean variety Credenz CZ 4539 GTLL (BASF; Ludwigshafen, Germany) was used for each trial which was a 4.5 maturity group LibertyLink® GT27™ soybean variety seeded at a rate of 150,000 seed/ac. Plots consisted of four rows spaced 15-in. by 30-ft. long. Trials were planted using a Precision Kincaid Vacuum Plot Planter (Kincaid Equipment Manufacturing; Haven, Kan.) at both the JCEC and PTRS on 2 June and 16 June 2020, respectively. After planting, composite soil samples were taken from each plot. The average values of selected soil chemical properties are listed in Table 1. Fertilizer products and rates used for this study are listed in Table 2. A non-S N treatment was used to separate any S response from N-containing S products. Treatments were applied by hand immediately after planting. Management for irrigation, fertility, and late-season pest control closely followed recommendations from the University of Arkansas System Division of Agriculture's Cooperative Extension Service for soybean production. In

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each trial, soybean was irrigated as needed using flood irrigation at both locations. At maturity, plots were harvested, and moisture content and weight of the grain were determined. Grain yield was adjusted to 13% moisture and reported as bu./ac for each trial. Grain samples were collected from each plot for protein and oil analysis (data not shown)

Within each test, treatments were arranged as a randomized complete block design with five replications. Data were subjected to analysis of variance (ANOVA), using ARM 2020 (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 0.10.

Results and Discussion

Statistical analysis for soybean grain yield was conducted for each location, and mean soybean grain yields for each treatment are reported in Table 3. When compared to the untreated control (UTC) (no additional fertilizer), mean grain yields for all treatments were not statistically different at either of the two locations. At the JCEC location, the mean yield for the UTC was 57.0 bu./ac, with treatment mean yields ranging from 58.0–64.1 bu./ac. Although not significant, all treatments had numerically higher grain yields than the UTC. Mean yields at the PTRS were from 70.6 to 75.1 bu./ac compared to the UTC mean yield of 71.8 bu./ac. At the PTRS locations, all but one treatment had numerically greater yields compared to the UTC.

The results from the 2 studies are not surprising due to both locations having sufficient amounts of soil available S as indicated by the soil analysis results presented in Table 1. Sulfur soil test values were 13 and 16 ppm at the JCEC and PTRS locations, respectively. Soybean plants are very efficient at scavenging soil available nutrients, and a response to additional S fertilizers would not be expected at these S soil test levels.

Similar results were observed when these same treatments were evaluated in 2019 in Arkansas (Ross et al., 2020). During 2019 and 2020, these treatments were evaluated in 9 states in 43 small-plot studies. When analyzed across all locations, 11 out of the 43 locations had a significant difference in yield among the treatments, but no product or rate consistently increased yield at all locations (Conley et al., 2020; Conley et al., 2021). Upon completion of the grain analysis (data not shown), a final report will be developed that includes yield, grain composition, and soil properties for all locations during 2019 and 2020.

Practical Applications

Results from this study and previous studies conducted in Arkansas and other soybean-producing states indicated that many times additional S fertilizers do not increase soybean grain yield in environments similar to the ones where these tests were conducted. However, some soils testing very low in soil-test S (>5 ppm) and expressing S deficiencies could benefit from additional S fertilization. Fields with a coarse soil texture and with low SOM could potentially have soil-test S levels low enough to show S deficiencies. Routine soil testing will be required to identify these fields, and supplemental S-containing fertilizers may be required.

Acknowledgments

The authors would like to thank the Arkansas Soybean Promotion Board for their funding of this research. We would also like to thank the personnel at the Jackson County Extension Center and the Pine Tree Research Station for their help and support with our fieldwork. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Selected soil chemical property means (n = 50) from the 0–4 in. depth for the sulfur fertilization trials conducted in 2020.[a]

Location[a]	Soil Series	pH	P[b]	K	Ca	Mg	S	B	Mn	Zn
			ppm							
JCEC	Dexter silt loam	5.7	56	120	960	97	13	0.23	200	2.9
PTRS	Calhoun silt loam	7.2	24	110	1900	300	16	0.30	170	2.6

[a] JCEC = Jackson County Extension Center, Newport, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.
[b] P = Phosphorus; K = Potassium; Ca = Calcium; Mg = Magnesium; S = Sulfur; B = Boron; Mn = Manganese; Zn = Zinc.

Table 2. List of sources and rates of sulfur (S) and nitrogen (N) containing fertilizers evaluated in 2020.

Product[a]	Application Rate	Supplied S	Supplied N
	lb/ac		
Untreated Control		0	0
Ammonium Sulfate	42	10	9
Ammonium Sulfate	83	20	18
Ammonium Sulfate	125	30	26
Gypsum	63	10	0
Gypsum	125	20	0
Gypsum	188	30	0
Urea	19	0	9
Urea	39	0	18
Urea	56	0	26

[a] Ammonium Sulfate (21% N; 24% S); Gypsum (16% S); Urea (46% N).

Table 3. Soybean grain yield response to sulfur (S) fertilizer products in 2020.

		Location[a]	
Product	Application Rate	JCEC	PTRS
	lb/ac	Yield (bu./ac)	
Untreated Control		57.0	71.8
Ammonium Sulfate	42	58.0	73.2
Ammonium Sulfate	83	61.1	73.9
Ammonium Sulfate	125	60.5	74.1
Gypsum	63	58.1	71.9
Gypsum	125	62.8	72.0
Gypsum	188	60.4	70.6
Urea	19	64.1	74.4
Urea	39	64.0	73.9
Urea	56	61.3	75.1
		NS[b]	NS

[a] JCEC = Jackson County Extension Center, Newport, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.
[b] No statistical difference was seen between the untreated control and the S fertilizer treatments at an alpha level = 0.10.

APPENDIX

2020-2021 Soybean Research Proposals

Principal Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
B. Bluhm		Accelerated Development of Bioherbicides to Control Palmer Amaranth (Pigweed): Phase II	1 of 3	35,000
T. Butts	T. Barber, J. Norsworthy, N. Burgos	A Team Approach to Weed Management	1 of 3	211,256
J. Carlin	G. Bathke	Purification and Production of Pre-foundation Seed of UADA Soybean Lines	3 of 3	46,669
M. Daniels	A. Sharpley	The Arkansas Discovery Farm Program	2 of 3	24,808
T. Faske	T. Spurlock and K. Korth	Comprehensive Disease Screening of Soybean Varieties in Arkansas	3 of 3	127,834
T. Faske	A. Rojas	Integrated Management of Soybean Nematodes in Arkansas	1 of 3	67,822
T. Faske	K. Korth	Development of an Effective Program to Manage Fungicide-Resistant Diseases of Soybean in Arkansas	2 of 3	49,437
B. Watkins	V. Ford	Soybean Enterprise Budgets and Production Economic Analysis	1 of 3	10,266
C. Henry	L. Espinoza, P. Francis, T. Spurlock	Promoting Irrigation Water Management for Soybeans	1 of 3	148,504
J. Kelley	J. Ross	Developing Profitable Irrigated Rotational Cropping Systems for Arkansas	2 of 3	16,000
K. Korth	L. Mozzoni and N. Slaton	Utilizing Chloride-Tolerance Markers and Phenotypes to Develop Improved Varieties	3 of 3	49,901
G. Lorenz	B. Thrash and N. Bateman	Educating Growers and Consultants on Insect Monitoring and Control	3 of 3	5,000
L. Mozzoni		Utilization of Chile for Winter-Nursery Progeny Rows to Supplement MG4 Soybean Variety Development	2 of 3	31,000
L. Mozzoni		Breeding New and Improved Soybean Cultivars with High Yield and Local Adaptation	1 of 3	195,772
L. Mozzoni		Soybean Germplasm Enhancement Using Genetic Diversity	1 of 3	155,382
L. Mozzoni	L. Purcell and C. Henry	Breeding Soybean under Reduced Irrigation Conditions	2 of 2	44,630
J. Norsworthy	J. Ross	Screening for Soybean Tolerance to Metribuzin	2 of 3	14,182
L. Purcell	L. Mozzoni	Evaluation and Identification of Early-Maturing Soybean with Drought and Heat Tolerance	1 of 3	72,197
T. Roberts	J. Ross and J. Carlin	Field-based Determination of Chloride Tolerance in Soybean	1 of 3	42,077
T. Roberts	J. Ross	Influence of Cover Crops and Soil Health on Soybean	1 of 3	54,840

Continued

2020-2021 Soybean Research Proposals, continued.

Principal Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
T. Roberts	J. Ross	Fertilization of Soybean	1 of 3	65,644
J. Robinson	K. Ballard	Soybean Science Challenge	2 of 3	79,582
J. Ross		Improving Technology Transfer for Profitable and Sustainable Soybean Production	1 of 3	32,530
J. Ross		Investigating Emerging Production Recommendations for Sustainable Soybean Production	1 of 3	214,115
J. Ross	C. Norton and C. Elkins	Soybean Research Verification Program	1 of 3	197,448
J. Rupe	A. Rojas	Cover Crops and the Control of Soybean Diseases	2 of 3	41,000
T. Spurlock	N. Bateman, J. Rupe, A. Rojas, and C. Stark	Determining the Impact of Disease and Stinkbug Feeding on Soybean Quality	2 of 3	85,203
T. Spurlock	A. Rojas	Understanding Taproot Decline; A Soybean Disease of Increasing Importance in Arkansas	1 of 3	37,039
T. Spurlock		Determining the Value of Fungicide Applications on Regional, Whole-farm, Field Level, and Within-Field Scales	1 of 3	32,834
C. Stark		Economic Analysis of Soybean Production and Marketing Practices	1 of 2	7,034
B. Thrash	G. Lorenz, N. Bateman, G. Studebaker, and N. Joshi	Development of Integrated Management Strategies for Insects in Soybean	2 of 3	69,995
			Total:	**2,265,001**

DIVISION OF AGRICULTURE

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