Arkansas
Soybean Research Studies 2021

Jeremy Ross, Editor

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Cover photo: Soybean breeding staff bring their own shade to make crosses in soybean breeding plots at the Milo J. Shult Agricultural Research and Extension Center. (U of A System Division of Agriculture photo by Fred Miller).

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Preface

The 2021 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 Checkoff 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

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Introduction

Arkansas is the leading soybean-producing state in the mid-southern United States. Arkansas ranked 11th in soybean production in 2021 compared to the other soybean-producing states in the U.S. The state represented 3.49% of the total U.S. soybean production and 3.49% of the total acres planted in soybean in 2021. The 2021 state soybean average yield was 52.0 bushels per acre, setting a new state record and surpassing the previous yield record of 51.5 bushels per acre set in 2020. The top five soybean-producing counties in 2021 were Mississippi, Phillips, Crittenden, Poinsett, and Arkansas (Table 1). These five counties accounted for over 35% of the soybean production in Arkansas in 2021.

Weather events during the early portion of the 2021 growing season were much improved compared to those during 2020. However, frequent rain events hampered preplant tillage and delayed planting for some portions of the state. On 19 and 20 April 2021, a cold front moved across the state and set daily record low temperatures for several locations in the state. Soybean planting during 2021 was ahead of the previous year and the 5-year average for planting progress. According to the 6 June 2021 USDA-NASS Arkansas Crop Progress and Condition Report (USDA-NASS, 2021), 86% of the soybean acreage had been planted as of 1 June compared to 75% and 81% for the 2020 and the 5-year average planting progress, respectively. With improved weather conditions and higher commodity prices, Arkansas soybean producers planted 3.04 million acres in 2021. This was an increase in acreage compared to 2020 and back to over 3 million acres planted compared to the last two years. The most significant event in Arkansas during the 2021 growing season was several rounds of heavy rainfall in southeast Arkansas during June. In 48 hours on 8 and 9 June 2021, Rohwer in Desha County received 19.22 inches of rain. This rain event was the second-highest 48-hour total on record in Arkansas. Approximately 600,000 acres of cropland in the southeastern portion of the state were affected by the flooding, with an estimated 300,000 acres fully submerged from 1 to 2 weeks. Most of the soybean acreage in this portion of the state was in early reproduction. Due to the flooding, many fields were abandoned or replanted. Yields were significantly reduced due to replants occurring in late June and into July.

Overall, except for Armyworms, disease and insect issues were not a problem in 2021. Armyworm infestations were seen across the entire state during 2021 in many row crops and pastures. However, soybean fields were the least affected commodity by this pest. 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 2021 growing season was the fifth year where dicamba was labeled for over-the-top applications on dicamba-tolerant soybean. Even with application restrictions, 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, 2020-2021[a]

	Acres Planted		Acres Harvested		Yield		Production	
	2020	2021	2020	2021	2020	2021	2020	2021
County	------------acres-----------		----------acres----------		---bu./ac---		-----------bu.-----------	
Arkansas	162,500	168,500	161,800	167,500	59.2	58.2	9,573,000	9,749,000
Ashley	49,200	45,800	49,000	45,400	55.4	61.6	2,715,000	2,795,000
Benton	*	600	*	600	*	41.2	*	24,700
Chicot	164,500	164,000	163,100	163,200	53.9	54.1	8,796,000	8,829,000
Clay	101,500	105,000	101,200	104,400	53.3	44.1	5,398,000	4,600,000
Conway	16,400	14,600	16,200	14,500	33.2	32.4	538,000	470,000
Craighead	78,900	*	78,200	*	48.7	*	3,810,000	*
Crittenden	197,000	212,500	196,200	212,000	50.4	51.2	9,898,000	10,854,000
Cross	130,000	152,000	129,300	151,200	50.4	53.3	6,522,000	8,059,000
Desha	144,500	162,000	144,100	154,200	57.3	50.8	8,257,000	7,833,000
Drew	28,500	28,300	28,400	27,600	56.7	57.4	1,610,000	1,584,000
Faulkner	7,900	7,400	7,800	7,360	33.6	32.5	262,000	239,000
Franklin	2,300	*	2,300	*	37.3	*	85,800	*
Greene	66,400	*	66,100	*	46.9	*	3,100,000	*
Independence	22,600	*	22,400	*	43.1	*	965,000	*
Jackson	94,500	106,000	93,900	105,300	40.6	45.7	3,816,000	4,812,000
Jefferson	78,600	94,300	78,300	92,300	55.8	55.7	4,369,000	5,141,000
Johnson	3,600	*	3,600	*	34.7	*	125,000	*
Lafayette	6,200	*	6,180	*	53.1	*	328,000	*
Lawrence	48,200	*	48,000	*	42.9	*	2,059,000	*
Lee	112,000	110,500	111,500	109,800	55.6	52.5	6,198,000	5,765,000
Lincoln	52,400	65,200	51,300	64,700	54.6	52.0	2,803,000	3,364,000
Logan	5,800	5,700	5,710	5,680	37.5	35.4	214,000	201,000
Lonoke	92,000	92,300	91,400	91,600	47.6	46.4	4,351,000	4,250,000
Mississippi	256,000	*	255,000	*	53.4	*	13,610,000	*
Monroe	79,200	83,200	78,900	81,400	50.9	42.6	4,014,000	3,468,000
Phillips	180,000	197,000	179,100	195,500	55.5	57.7	9,940,000	11,280,000
Poinsett	163,000	185,500	161,600	184,500	51.9	53.2	8,392,000	9,815,000
Prairie	100,500	102,000	100,100	101,300	50.0	54.4	5,005,000	5,511,000
Pulaski	17,500	17,900	16,000	16,300	35.9	40.5	575,000	660,000
Randolph	25,300	*	25,200	*	45.3	*	1,142,000	*
Saint Francis	138,500	139,500	138,000	138,600	50.2	50.6	6,926,000	7,013,000
Sebastian	3,900	*	3,900	*	33.3	*	130,000	*
White	21,400	32,000	21,300	31,800	47.9	44.5	1,020,000	1,415,000
Woodruff	116,000	117,000	115,500	116,200	50.8	47.0	5,867,000	5,461,000
Yell	6,600	6,700	6,500	6,560	42.5	36.9	276,000	242,000
Other Counties	46,600	624,500	42,910	620,500	35.2	48.5	1,510,200	30,075,300
State Totals	2,820,000	3,040,000	2,800,000	3,000,000	51.5	52.0	144,200,000	156,000,000

[a]Data obtained from USDA-NASS; 2022.

*Included in "Other Counties."

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VERIFICATION

2021 Soybean Research Verification Program

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Abstract

The 2021 Soybean Research Verification Program (SRVP) was conducted on 19 commercial soybean fields across the state. Counties participating in the program included Arkansas, Chicot, Clay, Conway, Cross, Desha, Drew, Faulkner, Independence, Jefferson, Lafayette, Lawrence, Lee, Mississippi, Perry, Poinsett, St. Francis, White, and Woodruff, for a total of 1170 acres. Grain yield in the 2021 SRVP averaged 62.6 bu./ac ranging from 30.1 to 78.0 bu./ac. The 2021 SRVP average yield was 11.6 bu./ac, greater than the estimated Arkansas state average of 51 bu./ac. The highest yielding field was in Desha County, with a grain yield of 78 bu./ac. The lowest yielding field was in Perry County and produced 30.1 bu./ac.

Introduction

In 1983, the University of Arkansas System Divison 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 the 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 678 commercial soybean fields in 41 soybean-producing counties in Arkansas. SRVP has typically averaged 10 bu./ac better than the state average yield. This increased yield can mainly be attributed to intensive cultural and integrated pest management practices.

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 promptly from planting to harvest. Each county's designated County Extension Agent 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 2021 the following counties participated in the SRVP, Arkansas, Chicot, Clay, Conway, Cross, Desha, Drew, Faulkner, Independence, Jefferson, Lafayette, Lawrence, Lee, Mississippi, Perry, Poinsett, St. Francis, White, and Woodruff. The 19 SRVP fields totaled 1170 acres. Five Roundup Ready 2 Xtend® varieties (Armor 46-D09, Asgrow AG46X6, Asgrow AG48X9, NK S44-C7X, and Pioneer P43A42X), five Roundup Ready 2 XtendFlex® varieties (Asgrow AG38XF1, Asgrow AG45XF0, Asgrow AG47XF0, Asgrow AG48XF0, and Local Seed LS4606XFS), 3 Enlist E3® varieties (Delta Grow DG47E20, Local Seed ZS4694E3S, and Progeny P4775E3S), 1 LibertyLink® variety (Pioneer P49A41L), and 1 Roundup Ready® variety (Pioneer P46A16R) 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).

Results and Discussion

Yield

The average 2021 SRVP grain yield was 62.6 bu./ac ranging from 30.1 to 78.0 bu./ac (Table 2). The SRVP aver-

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age yield was 11.6 bu./ac higher than the estimated 2021 state average yield of 51 bu./ac (USDA, 2022). The difference has been attained many times since the program began and can be attributed partly to intensive management practices and utilization of CES recommendations. The highest soybean grain yield, 78.0 bu./ac, was planted with Asgrow AG46X6 in Desha County.

Planting and Emergence

Planting was initiated with Clay County on 3 April and concluded on 20 June in Perry County with an average planting date of 9 May. The average seeding rate across all SRVP fields was 143,000 seeds/ac ranging from 120,000 to 165,000 seeds/ac. The average emergence date was 18 May ranging from 16 April to 30 June. On average, across all SRVP fields, 9 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 the 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. In addition, all irrigated fields utilized computerized hole selection programs such as PHAUCET or Pipeplanner to maximize irrigation efficiency. Thirteen of the 19 SRVP fields were furrow irrigated, 3 were flood irrigated, 2 were pivot irrigated, and one was non-irrigated.

Practical Applications

Data collected from the 2021 SRVP reflected higher soybean yields and maintained above-average returns in the 2021 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, 2021).

Acknowledgments

We appreciate the cooperation of all participating soybean producers. We 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 Arkansas Agricultural Experiment Station and Cooperative Extension Service, along with the district administration, for their support.

Literature Cited

Watkins, B. 2021. University of Arkansas System Division of Agriculture Cooperative Extension Service Enterprise Crop Budgets. Accessed: 21 April 2022. Available at https://www.uaex.uada.edu/farm-ranch/economics-marketing/farm-planning/budgets/crop-budgets.aspx

USDA National Agricultural Statistics Service. 2021 Census of Agriculture. Accessed: 21 April 2022. Available at www.nass.usda.gov/AgCensus

Table 1. Agronomic Information for 2021 Soybean Research Verification Fields.

County	Variety	Field size	Previous crop[a]	Production system[b]	Seeding rate	Stand density
		ac			seed/ac	plants/ac
Arkansas	Pioneer P46A16R	30	Corn	ESI	125K	114K
Chicot	NK S44-C7X	40	Soybean	ESI	140K	84K
Clay	Asgrow AG38XF1	32	Corn	ESI	140K	131K
Conway	Local Seed ZS4694E3S	69	Corn	LSI	150K	115K
Cross	Asgrow AG48X9	115	Rice	FSI	165K	113K
Desha	Asgrow AG46X6	71	Soybean	ESI	160K	143K
Drew	Armor 46-D09	73	Rice	ESI	155K	137K
Faulkner	Progeny P4775E3S	50	Soybean	LSI	140K	104K
Independence	Progeny P4775E3S	55	Soybean	ESNI	160K	106K
Jefferson	Pioneer P43A42X	40	Soybean	ESI	125K	108K
Lafayette	Asgrow AG47XF0	73	Corn	ESI	120K	114K
Lawrence	Delta Grow DG 47E20	72	Rice	FSI	151K	118K
Lee	Asgrow AG45XF0	54	Corn	ESI	140K	115K
Mississippi	Asgrow AG48XF0	32	Corn	FSI	140K	107K
Perry	Local Seed LS4606XFS	52	Soybean	LSI	140K	83K
Poinsett	Armor 46-D09	145	Rice	FSI	165K	72K
St. Francis	Asgrow AG47XF0	64	Rice	FSI	130K	104K
White	Asgrow AG48X9	44	Corn	FSI	120K	83K
Woodruff	Pioneer P49A41L	59	Soybean	LSI	150K	117K
Average		**61.6**			**143K**	**109K**

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

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

Table 2. Planting, Emergence, and Harvest Dates and Adjusted Soybean Grain Yield for 2021 Soybean Research Verification Program Fields.

County	Planting date	Emergence date	Harvest date	Yield adj. to 13% moisture
	-----------------------------	-----date-----	-----------------------------	(bu./ac)[a]
Arkansas	4/19	4/28	9/4	59.5
Chicot	4/6	4/22	9/14	55.0
Clay	4/3	4/16	9/24	75.7
Conway	6/13	6/19	10/13	64.4
Cross	5/22	5/29	10/19	65.1
Desha	4/19	4/27	9/28	78.0
Drew	4/20	4/28	10/9	75.9
Faulkner	6/18	6/25	10/21	40.5
Independence	4/19	4/30	9/29	47.9
Jefferson	4/13	4/26	9/15	76.8
Lafayette	4/13	4/26	9/20	71.6
Lawrence	5/21	5/26	10/15	52.5
Lee	4/20	5/1	10/12	68.8
Mississippi	5/21	5/28	10/15	78.7
Perry	6/20	6/30	11/17	30.1
Poinsett	5/15	5/25	10/9	64.3
St. Francis	5/16	5/25	10/13	74.7
White	5/24	5/31	10/12	65.3
Woodruff	6/17	6/22	11/5	50.5
Average	**5/9**	**5/18**	**10/8**	**62.6**

[a] 2021 Arkansas state soybean average yield was 51.0 bu./ac (UADA, 2022).

Table 3. Soil Test Results, Fertilizer Applied and Soil Classification for 2021 Soybean Research Verification Fields.

County	Soil Test Results pH	 P	 K	Pre-plant applied fertilizer N-P-K	Soil Classification
	---------ppm-----------			lb/ac	
Arkansas	6.0	19	62	0-64-140	Ethel, Dewitt silt loam
Chicot	6.7	17	68	0-74-112	Perry clay, Galion silt loam
Clay	6.0	31	152	0-45-120	Foley silt loam
Conway	7.1	46	138	0-0-0	Gallion silt loam
Cross	6.8	19	63	0-50-120	Crowley and Hillemann silt loam
Desha	6.5	38	92	0-0-90	Sharkey and Desha clays
Drew	6.3	34	176	0-0-0	Rilla, Portman silt loam, Portland clay
Faulkner	6.8	17	210	0-0-0	Perry Clay
Independence	7.7	26	116	0-0-75	Sturkie silt loam & Wideman loamy fine sand
Jefferson	6.4	38	96	0-0-75	Rilla, Hebert silt loam, Perry clay
Lafayette	6.7	40	182	0-0-0	Rilla, Caspiana silt loam
Lawrence	7.1	32	131	0-40-60	Crowley silt loam & Jackport silty clay
Lee	6.1	34	78	0-0-90	Loring, Falaya, Calloway silt loam
Mississippi	6.2	79	157	0-0-0	Dundee silt loam
Perry	6.2	29	236	0-0-0	Perry Clay
Poinsett	7.0	23	76	0-60-90	Henry & Hillemann silt loam
St. Francis	7.2	11	84	0-70-120	Henry & Calloway silt loam
White	7.1	54	140	0-0-120	Calhoun & Calloway silt loam
Woodruff	6.3	17	67	1.5 ton Poultry Litter	McCrory fine sandy loam

Table 4. Herbicide Rates and Timing for 2021 Soybean Research Verification Program Fields.

	Herbicide (rates/ac)	
County	**Burndown/Preemergence (Pre)**	**Post-emergence**
Arkansas	Burndown: 1 qt Cornerstone® Pre: 3 pt gramoxone + 6 oz metribuzin	1 qt Cornerstone + 1.5 pt Me-Too-Lachlor®
Chicot	Burndown: 1 pt Select® + 18 oz 2,4-D + 25.6 oz Cornerstone Pre: 24 oz Anteras Complete® + 1 pt gramoxone	1 qt Prefix + 6 oz Flexstar® + 22 oz Roundup Powermax
Clay	Pre: 1 qt glyphosate + 0.5 oz First Shot® + 1 pt *S*-metolachlor	1 qt Liberty + 3.25 oz Zidua
Conway	Burndown: 1 qt Roundup PowerMax® + 2 oz Valor + 0.28 lb Metribuzin Pre: 40 oz paraquat + 1.25 pt *S*-metolachlor	1st: 1 qt Roundup PowerMax + 1 qt Enlist One® + 1 pt *S*-metolachlor 2nd: 1 qt Roundup PowerMax + 1 qt Enlist One
Cross	Pre: 5 oz Verdict® + 10 oz Outlook®	1 qt glyphosate
Desha		1st: 22 oz Roundup Powermax + 1.5 pt Me-Too-Lachlor 2nd: 22 oz Roundup Powermax + 1.5 pt Me-Too Lachlor
Drew		1st: 3.5 pt Sequence® 2nd: 1 qt Cornerstone + 0.3 oz First Rate® + 1.3 pt Dual Magnum® II
Faulkner	Pre: 1 qt glyphosate + 1 oz Sharpen® + 1.5 pts. Ledger®	1st: 1 qt Interline® + 1 qt Enlist One 2nd 1 qt glyphosate + 1 qt Enlist One
Independence	Pre: 2 oz Valor®	1st: 1 qt glyphosate 2nd: 1 qt Liberty® + 1.25 pt *S*-metolachlor 3rd: 1 qt glyphosate
Jefferson	Burndown: 1 qt Cornerstone + 1 pt 2,4-D Pre: 1 qt Cornerstone + 1 qt Boundary®	1st: 1 qt Cornerstone + 3.25 oz Zidua SC 2nd: 1 qt Cornerstone + 0.3 oz First Rate + 1.2 pt Dual Magnum II
Lafayette	Pre: 24 oz Anteras Complete	1st: 1 qt Cornerstone + 3.25 oz Zidua SC 2nd: 22 oz Roundup PowerMax + 1.3 pt Charger Basic
Lawrence	Pre: 1 qt Roundup PowerMax + 1 pt *S*-metolachlor	1st: 1 qt Enlist One + 1 qt Liberty 2nd: 1 qt Liberty
Lee	Burndown: 8 oz dicamba + 1 qt Cornerstone + 0.6 oz First Shot Pre: 5 oz metribuzin + 1 qt Gramoxone® + 3.25 oz Zidua SC	1 qt Liberty + 12.8 oz Outlook®
Mississippi	Pre: 1 qt Gramoxone + 1 qt Intimadator® + 2 oz Zidua	12.8 oz Engenia® + pH buffering agent
Perry	Pre: 40 oz paraquat + 1 pt S-metolachlor	1 qt Liberty + 1 qt glyphosate
Poinsett	Pre: 1 qt glyphosate + 5 oz Verdict + 3.25 oz Zidua®	1st: 8 oz Select® + 2 pt Prefix® 2nd: 8 oz Select
St. Francis		1st: 1 qt Liberty + 1 qt glyphosate + 1.25 pt *S*-metolachlor 2nd: 1 qt glyphosate
White	Pre: 1 qt glyphosate + 1.25 pt *S*-metolachlor	1st: 12.8 oz Engenia + pH buffering agent 2nd: 1 qt glyphosate
Woodruff	Pre: 40 oz paraquat + 5 oz metribuzin + 3.25 Zidua	1 qt Liberty + 1.25 pt Dual Magnum

Table 5. Fungicide and Insecticide Applications for 2021 Soybean Research Verification Program Fields.

County	Aerial Web Blight	Frogeye Leaf Spot	Bollworms/Defoliators	Stink Bugs
Arkansas	--	--	--	--
Chicot	--	--	--	--
Clay	--	--	--	--
Conway	--	--	--	--
Cross	--	--	--	4.5 oz/ac Endigo
Desha	--	--	--	--
Drew	--	--	--	--
Faulkner	--	--	--	3.84 oz/ac Lambda Cy-Ag
Independence	--	--	--	--
Jefferson	--	--	--	6.4 oz./ac Sniper + 0.33 lb/ac acephate
Lafayette	--	--	--	--
Lawrence	--	--	--	--
Lee	--	--	--	--
Mississippi	--	--	1.92 oz/ac Lambda Cyhalothrin	--
Perry	--	--	--	1.92 oz/ac Lambda Cyhalothrin
Poinsett	--	--	--	--
St. Francis	--	--	--	--
White	--	--	--	--
Woodruff	--	--	14 oz/ac Prevathon	--

AGRONOMY

Soybean Science Challenge: Growing Soybean Education Beyond Our Borders

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. It aligns with the Next Generation Science Standards (NGSS). Junior high and high-school students are engaged in active learning and the co-creation of knowledge through the 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 an original NGSS-aligned curriculum in 7E and GRC-3D format and a continuum of educational methods, which include: teacher workshops, online and virtual live stream education, virtual NGSS aligned mini-lessons for the science classroom, community gardens, personal mentoring, student-led research and corresponding award recognition, and partnerships with state and national educators, agencies and the popular media. The COVID19 global pandemic continued to alter the educational landscape in 2021, despite increased in-person instruction. The Soybean Science Challenge (SSC), by nature of its existing design and methodology, launched online Next Generation Science Standards (NGSS) aligned Gathering Reasoning and Communicating (GRC)-3D and 7E lesson plans for teachers. An online course was added, including NGSS-aligned mini-lesson videos for the science classroom, and additional virtual field trips were added to the list on the Soybean Science Challenge website. The Challenge also sponsored the Arkansas Science Teacher Association Conference in October 2021, and the SSC Coordinator Diedre Young conducted a workshop on bringing agriculturally based lessons into the science classroom. The Soybean Science Challenge was also active in science fairs across the state, judging participants at both the regional and state levels. The SSC is in its second year of the 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 into the classroom and students' homes. The SSC has learned that not only do Arkansas teachers and students benefit from these additional resources but teachers and students from other states benefit as well. In 2021, the SSC program reached over 3,000 students and teachers through in-person, digital, virtual, and print methods.

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 Soybean Science Challenge 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 to develop 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 Soybean Science Challenge has also worked with students through mentorship and the online course.

Procedures

The Soybean Science Challenge is 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 Soybean Science Challenge Award competition at these fairs, students must submit for judging a project that is either soybean-based or an agriculturally sustainable project and have passed the 6-module SSC online course. In addition, students must receive an 80% or better on each quiz before progressing 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.

Program administrators recorded the number of students enrolled in the SSC online course and the number of fair participants over the last year to determine the outcome and impact of the SSC. The results are documented in Table 1. These numbers include Spring of 2022, based on the funding cycle. Community Garden and online course numbers are reported to date at the time of article submission.

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Results and Discussion

A series of key factors contribute to the evidence of real learning-based results in the Soybean Science Challenge Program. For 2021–2022, in the Soybean Science Challenge Pretest, student learning and knowledge averaged 32%; however, the post-test average was 90%, a marked increase in student knowledge of soybeans 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 2021–2022 was 81 (Table 2). The reduced participation could be due to many factors, including the more time-consuming nature of hybrid teaching, causing teachers to narrow their choices for the classroom. There is also an overall shortage of teachers due to COVID-19. Sixty-six percent of students completed the course with a 90% or higher total score. This score strongly indicates that the course is successful at teaching students about soybeans.

Along with the online course, the Soybean Science Challenge student research awards presented at Arkansas regional and state science fairs significantly increased 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, 1 regional fair was virtual, 1 fair was canceled with 0 projects submitted, and except for the Central Arkansas Regional Science and Engineering fair, all the fairs saw a drop of over 50% in entries. Each fair had at least 1 or more entries in the Soybean Science Challenge. Despite COVID-19 issues and challenges, SSC had 7 projects enter the state science fair. Judges were provided an abstract and in-person interview with each student researcher explaining their project. This year, SSC had 3 regional Soybean Science Challenge winners who received 'Best of Fair' or second place overall and were awarded a spot at the International Science and Engineering Fair (ISEF). This continues to demonstrate an increase in the quality and rigor of projects competing for the Soybean Science Challenge award in the area of soybean and agricultural sustainability and suggests that the Soybean Science Challenge 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 $10,200 this year in student research awards for science projects with a soybean-related focus and operational support costs for regional science fairs. This recognition raised the educational profile of 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 15 student awards presented on behalf of the ASPB.

The Soybean Science Challenge has also chosen this year 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. These standards included lessons to be written in the new GRC-3D format. To this end, the SSC now has 11 different soybean and agriculturally based lessons written in the standard 7E format and the new GRC-3D format for teacher use. The Soybean Science Challenge also has 14 different Virtual Field Trips (VFT) with NGSS Aligned manuals for teachers. All are available in paper form and online at the https://www.uaex.uada.edu/soywhatsup website. Over 500 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 covering a variety of subjects that are NGSS aligned and bring an agricultural bend to everyday science concepts to the SOYWhatsUP website.

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 lingering COVID19 restrictions. Three of the regional winners were awarded the ISEF Finalist position, showing the increased quality and caliber of projects judged. The Science Fair 101 online course had 13 participants enrolled, and the Science Fair 101 Resources online course had 12 enrolled. The online teacher in-service course had 12 participants enroll this year. These enrollment numbers are positive considering the course length and the strain teachers are under. The SSC's online educational tools have shown to be a strong asset in helping teachers be successful in virtual and in-person classrooms.

The numbers show that the SSC is making an impact (Table 3), 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. Several teachers, especially junior high teachers, have told the SSC team 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 emailed and called my parents and told them how much the SSC had influenced their child's decision regarding future careers in agriculture. These stories cannot be quantified, but they demonstrate some of the impacts the SSC is having in the classroom and at home. It shows people noticed 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. 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 to succeed, helping youth discover the world of agriculture.

Acknowledgments

The Arkansas Soybean Promotion Board supported this educational project through a partnership with the University of Arkansas System Division of Agriculture and the Cooperative Extension Service.

Literature Cited

Ballard, K.K. and L. Wilson. 2018. Soybean Science Challenge: From the Ground Up. In: J. Ross (ed.). Arkansas Soybean Research Studies 2016. University of Arkansas System Division of Agriculture Agricultural Experiment Station Research Series 648:86-88. Fayetteville.

Table 1. Year to Date Soybean Science Challenge Online Course Enrollment: 1 April 2021–22 February 2022.

Student Enrollment	Current Student Course Completion	Average Student Pre-Test Score	Average Student Post-Test Score	Teacher In-Service Enrollment
123	81	32%	90%	12

Table 2. 2022 Soybean Science Challenge Regional and State Science Fair Winners.

Science and Engineering Fair	Winner(s) Name and High School	Project Title
Southwestern Energy Arkansas State Science & Engineering Fair Conway – University of Central Arkansas, March 31	First Place: Abby Berger, Arkansas School for Math, Science and the Arts	*The Potential of Forage Soybeans as a Grazing Source for Cattle*
	Second Place: Sydney Wolf, The Academies at Jonesboro High School	*Does overcrowding affect the growth of soybeans?*
	Honorable Mention: Cameryn Berryhill, Arkansas School for Math, Science, and the Arts	*Using Stream Bacteria to Promote Soybean Growth*
Virtual Arkansas School for Mathematics, Science and the Arts: Hot Springs – Sciences and the Arts Science Fair, February 25	Abby Berger, ASMSA	*The Potential of Forage Soybeans as a Grazing Source for Cattle*
Ouachita Mountains Regional Science & Engineering Fair Hot Springs – Mid-America Museum, March 4	Emily Hudnall, Mt Pine High School	*Can plants stop soil erosion?*
Central Arkansas Regional Science & Engineering Fair Little Rock – University of Arkansas-Little Rock, March 4	Senior Level: Rebekah Caffey, Little Rock Central High School	*The Effects of Defoliation and Fungicide Treatment on soybean seeds*
	Junior Level: Aakash Bhattacharyya, Lisa Academy West Middle School	*Electronic Soil Moisture Sensors: Save Water, Save the Future.*
Virtual Northwest Arkansas Regional Science & Engineering Fair Fayetteville – University of Arkansas-Fayetteville, April 1	Senior Level: McKenzie Butler, Alma High School	*Drought Resistant*
	Junior Level: Alex Pagliani, Fayetteville Christian School	*Soybean Pollen Viability under Low Temperature Stress*
Southeast Arkansas Regional Science Fair Monticello – University of Arkansas - Monticello	*FAIR WAS CANCELLED*	
Northeast Arkansas Regional Science Fair Jonesboro – Arkansas State University, March 11	Senior Level: Sydney Wolf, The Academies at Jonesboro High School	*Does overcrowding affect the growth of soybeans?*
	Junior Level: Jailyn Strong, Salem High School	*Save the soybeans*

Continued

Table 2. Continued.

Southwest Arkansas Regional Science Fair Magnolia – Southern Arkansas University, March 11	Senior Level: Ayla Buford, Taylor High School	*How drinks affect plant growth*
	Junior Level: Noah Beard, Bearden High School	*Poop for plants*
State FFA Agriscience Fair Hot Springs – April 26	Senior Level: Hannah and Hadleigh Baker, Mountain Home High School	*Measuring early soybean growth response to commercial fertilizer and turkey litter*
	Junior Level: Jenny Garcia-Torres, SW Jr High School	*Does Temperature matter for Soybean Germination?*

Table 3. Soybean Science Challenge Products, Audience, Activities, and Impact 2021-2022.

Product	Target Audience	Activities and Impact
Soybean Science Challenge (SSC) student online course	6–12th grade	**123** Students enrolled; **81** completed.
Soybean Science Challenge Online Course–Teacher In-Service (7 Hrs.)	Science Teachers	**12** Teachers enrolled; **12** completed.
Soybean Science Challenge Online Course – Teacher Resources	Science Teachers	**13** Users.
Partnering with 7 regional science fairs, the FFA Agriscience Fair and the Arkansas State Science Fair, **2021–2022** Attended and judged 8 Arkansas science fairs	Science Teachers/Students Science Fairs	**40** articles published or posted in newspapers or on websites; **41** individual student projects with **27** student awards; awards totaled **$6,200 for the 2022 fairs.**
It's Never Too Early to Plant the Seeds of Science Education – Soybean Science Challenge Announcement Flyers (2)	Science Teachers/Students	Released multiple times to ARSTEM List Serve; ASTA List Serve, AR Educational Cooperatives, personal emails; mailed to over **2,000** science and ag teachers each year for 2021–2022.
Arkansas Science Teachers Association (ASTA) Conference October 2021	6–12th grade Science teachers and students	Sponsored and presented at the conference; **60 Participants** from across the state attended the event; the SSC presentation focused on soybean research, educational lesson plans, and the online course.
Farm Bureau Meeting, December 2021	AG Science Teachers and Students	Handed out SSC materials to **over 100 students and teachers,** such as seeds, promotional items, lesson plans, and resource information.
Virtual Science Fair In-Service Workshop, September 2021	6–12th grade math and science teachers	Discussed Soybean Science Challenge materials such as lessons, VFT Manuals, resource guides, and SSC promotional items. **Mailed over 30 folders** to teachers with lessons, manuals, and guides.
FFA Agri-Science Teacher In-Service Day, July 2021	9–12th Grade science teachers received material	SSC presentation focused on soybean research, educational lesson plans, and the online course. **Over 100** Teachers received lessons, VFT manuals, and guides.

Continued

Table 3. Continued.

National Ag in the Classroom Conference and workshop, June 2021	3–12th Grade School Teachers	**500** Participants from across the nation attended this conference. Lessons and manuals were handed out to everyone interested in using the SSC material in the classroom.
Soybean Science Challenge Seed Store announcement	Junior High and High School Students/Teachers	ASTA List Serve; Arkansas Educational Cooperatives, personal emails; SOYWhatsUP CES web page; workshops; teacher conferences; mailed to over **500** Arkansas science and ag teachers.
Soybean Science Challenge Brochure	6–12th Grade High School Students/ Teachers	ARSTEM List Serve; ASTA List Serve; Arkansas Educational Cooperatives; personal emails; SOYWhatsUP CES web page; conferences; field trips, STEM days and teacher workshops.
EAS Field trip, University of Arkansas Fayetteville, September 2021	9–12th grade Science Teachers	**Over 90 students** attended from the Fayetteville area with the SSC presentation focusing on soybean research, educational lesson plans, and careers in Agriculture.
Soy Science Scholars Booklet; Soybean Science Challenge Progress Report	ASPB; CES schools	Mailed to ASPB and CES. Booklets were also mailed to students, teachers, and administration of all winning participants' schools, and handed out at conferences.
Soy What's Up? Flier on resources found on the CES Soybean Science Challenge webpage – www.uaex.uada.edu/soywhatsup	Science Teachers/Students	ASTA List Serve; Arkansas Educational Cooperatives; personal emails; SOYWhatsUP CES web page; workshops, mailed to **over 500** Arkansas Science and AG Teachers and **1400** teachers across the nation.
Media Coverage of Soybean Science Challenge Events	Science Research, Agriculture Educators, and General Public	**35** articles in newspapers, magazines, and other publications, including YouTube.
Arkansas High School Science Project Development Guide	Science Teachers/Students	Several **were** handed out to teachers and students; posted on SOYWhatsUP CES webpage.

Continued

Table 3. Continued.

SSC Direct Contacts regarding online courses/events/activities	Science Teachers/Students Other partners, i.e., ADE, STEM, Educational Coops	**Over 20,000** direct contacts through Constant Contact, ARSTEM Science List Serve, Arkansas Educational Cooperatives, and individual science teacher/student emails.
Soil and Water Conservation research-based Virtual Field Trips with NGSS Aligned Lesson Manuals, plus 11 lessons for the classroom. Developed/produced a new ag-based Algebra II lesson. 11 different Soybean/Agriculturally based NGSS Aligned Virtual Mini lessons for classroom use. Produced Science Fair 101 mini-course.	Science Teachers/Students	Handed out **over 500** different lessons, field trip manuals, and resource guides at workshops, conferences, and via email to interested teachers.
Soybean Science Challenge Community Gardens	Science teachers, students, County Agents, Master Gardeners, and Community Garden Participants	**Over 100 gardens** across Arkansas and the United States as of 28 April 2022. Advertising through Constant Contact, email, and on the SOYWhatsUP website, reaching over 2,000 contacts.
National Science Teachers Association STEM Convention, Houston, Texas. 31 March–2 April 2022	Science teachers from across the nation and multiple countries.	There were **over 2,000 teachers** attending this conference. Over 500 science teachers from across the nation stopped by our booth and received information about the SSC. Also talked to teachers from Israel, India, Mexico, Sweden, and Turkey. Wards Science Company showed interest in partnering our lessons with their plant department, and MAGNITUDE.IO showed interest in using our soybeans in an experiment on the International Space Station in 2023–2024.

CES = University of Arkansas System Division of Agriculture's Cooperative Extension Service; STEM = Science, Technology, Engineering, and Math; ASPB = Arkansas Soybean Promotion Board; FT = Virtual Field Trips; NGSS = Next Generation Science Standards.

AGRONOMY

Irrigated Rotational Cropping Systems, 2014–2021 Summary

J.P. Kelley,[1] T.D. Keene,[1] C. Kennedy,[2] and C. Treat[2]

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 2013–2021 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station near Marianna, Arkansas. Yields of early planted (April) group 4 soybean yields were 5 and 7 bu./ac higher when planted following corn and grain sorghum, respectively, compared to continuous soybean. Crop rotation impacted June-planted, double-crop soybean yield 2 out of 8 years, and average yields were 4 bu./ac greater following corn or grain sorghum than a previous double-crop soybean crop. Corn yields were impacted by the previous crop 2 out of 8 years, where corn following corn yield was 26 bu./ac lower than when following early planted soybean in 2016. On average, corn following corn yielded 6 and 7 bu./ac less than following early planted soybean or double-crop soybean, respectively. The previous crop impacted wheat yields in 5 out of 7 years of the trial. Wheat following full-season grain sorghum across all years yielded 9 bu./ac less than when following early planted soybean and 5 and 6 bu./ac less than following corn and double-crop soybean, respectively. Full-season grain sorghum was always planted following early 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 86 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 planted 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 (*Gossypium hirsutum*), and rice (*Oryza sativa*), 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 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 than 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 growing 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 8 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 2013. The following 8 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 the corn harvest, then double-crop soybean planted in June after the 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 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.

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5. *Continuous Corn*. Corn 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 early planted group 4 soybean planted in April the following year.

8. *Early Soybean/Wheat/Double-Crop Grain Sorghum/Soybean*. Early planted (April) 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), 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. The plot size was 25-ft wide (8 rows wide) by 200-ft long with 38-in. row spacing. Before planting summer crops each year, plots were conventionally tilled, including 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 6-in. row spacing with a seeding rate of 120 lb of seed/ac.

Soybean varieties planted changed throughout the trial. For early planted group 4 soybean, maturity ranged from 4.6 to 4.9 each year. Double-crop soybeans planted each year had a maturity range of 4.6 to 4.9. Corn hybrids planted varied by year, but maturity ranged from 112 to 117 days. Full-season grain sorghum was Pioneer 84P80 from 2014–2018 and DKS51-01 from 2019–2021. Double-crop grain sorghum hybrids that were grown varied over the duration of the trial but included: Sorghum Partners 7715, DKS 37-07, and DKS 44-07, which are sugarcane aphid-tolerant hybrids. The soft red winter wheat variety Pioneer 26R41 was planted each year except for the fall of 2020 when the variety Progeny #Bullet was planted.

Summer crops were furrow irrigated according to the University of Arkansas System Division of Agriculture's Cooperative Extension Services' (CES) irrigation scheduler program. Normal crop production practices such as planting dates, seeding rates, weed control, insect control, and fertilizer recommendations followed current CES recommendations. Harvest yield data were collected from the center 2 rows of each 8-row wide plot at crop maturity. The remaining standing crops were harvested with a commercial combine, and the crop residue was deposited back onto the plots. 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, Arkansas, for analysis. Soybean-cyst nematode was the only nematode that was found to be above economic threshold levels during the course of this trial. No root-knot nematodes were found in the trial area.

Results and Discussion

Soybean

Early planted group 4 soybean yields were good each year with an average yield of 55 to 62 bu./ac depending on rotation over the 8 yr period (Table 1). However, the yield of early planted group 4 soybean was statistically impacted by previous crops in 4 out of 8 years of the trial. On average, continuously grown soybean without rotation yielded 55 bu./ac, while soybean rotated with corn or full-season grain sorghum the previous year yielded 60 and 62 bu./ac, respectively (Table 1). Similar trends were noted with double-crop soybean yields when following wheat. When double-crop soybean followed a previous wheat/double-crop soybean, yields on average were only 42 bu./ac, while yields increased to 46 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 2 out of 8 years (Table 2). Early planted group 4 soybean averaged 59.3 bu./ac averaged across rotations, and double-crop soybeans averaged 44.7 bu./ac averaged across rotations. The 14.6 bu./ac difference between April soybean and June planted double-crop soybean is similar to what many Arkansas soybean producers see on their farms between the early planted production system and the double-crop system.

Differences in early-planted and double-crop soybean yields between crop rotations can likely be partially attributed to lower soybean cyst nematode (SCN) numbers following corn or grain sorghum. Soybean cyst nematode egg numbers from soil samples collected in October 2021 after soybean harvest were highest in the double-crop soybean plots. Plots where double-crop soybean was grown each year had the highest level of SCN eggs with 1060 eggs/100 cc of soil, while plots that had been planted with corn or grain sorghum the previous year had SCN egg levels of 648 and 536 eggs/100 cc of soil, respectively. Early planted soybean plots showed variable SCN levels and averaged 518 SCN eggs/100 cc of soil and no consistent SCN egg number differences between rotations. In comparison, the analysis showed that plots that had been continuously planted with corn since 2013 resulted in no SCN eggs detected. The general trend of lower SCN egg numbers in the double-crop soybean plots in 2021 indicates that rotation to a non-host for 1 year can reduce numbers temporarily but will not eliminate SCN.

Corn

Corn yields were generally good over the 8 years and averaged 202–209 bu./ac depending on rotation (Table 3). Yields were statistically influenced by rotation in 2 out of 8 years, with corn following corn yielding 26 bu./ac less than when following early 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 8-yr period, corn following early planted group 4 soybean and double-crop soybean yielded 6 and 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 grown without rotation (Sindelar et al., 2015). As corn is grown continuously for more years without rotation, yields may decline, but that trend is not evident after 8 years of this trial.

Wheat

Wheat yields were generally good, with an average yield of 65 to 74 bu./ac (Table 4), depending on rotation. Wheat yield was influenced by the previous crop in 5 out of 7 years. Averaged across all years, wheat yield following early planted soybean was 74 bu./ac, 9 bu./ac greater than wheat following full-season grain sorghum. The reason for lower wheat yields following full-season grain sorghum is unclear; however, fall and early winter growth was visibly reduced in most 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 for 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, 4 bu./ac less than when following early planted soybean and 1 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 early planted group 4 soybean or double-crop soybean treatments over the 8 yr period. State average grain sorghum yields generally range from 80–95 bu./ac (Table 5). Double-crop grain sorghum planted following wheat averaged 86 bu./ac (Table 5.)

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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Literature Cited

Reddy, K.N., R.M. Zablotowiez, and L.J. Krutz. 2013. Corn and Soybean Rotation under Reduced Tillage Management: Impacts on Soil Properties, Yield, and Net Return. Am. J. Plant Sci. 2013, 4:10-17. Accessed 1 April 2021. Available at: https://www.scirp.org/html/2-2600731_32242.htm

Sindelar, A., M. Schmer, V. Jin, B. Wienhold, and G. Varvel. 2015. Long-Term Corn and Soybean Response to Crop Rotation and Tillage. Agron. J. 107. Accessed 25 Oct. 2022. Available at: https://dx.doi.org/10.2134/agronj15.0085

Howard, D.D., A.Y. Chambers, and G.M. Lessman. 1998. Rotation and Fertilization Effects on Corn and Soybean Yields and Soybean Cyst Nematode Populations in a No-Tillage System. Agron. J. 90. Accessed 25 Oct 2022. Available at: https://dx.doi.org/10.2134/agronj1998.00021962009000040013x

Table 1. The effect of the previous crop on the yield of early planted (April), irrigated group 4 soybean yield grown at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas, 2014–2021.

	Early Planted Soybean Grain Yield								
Previous Crop	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**Avg.**
	(bu./ac)								
Early Planted Soybean	43	49	47	65	56	62	62	56	55
Corn	64	49	52	71	67	58	62	60	60
Full-Season Grain Sorghum	64	51	56	74	64	62	61	62	62
Wheat/Double-Crop Sorghum	--	50	54	71	65	58	66	58	60
$LSD_{0.05}$	13	NSD[a]	NSD	6	6	NSD	NSD	4	--

[a] NSD = no significant difference at α = 0.05.

Table 2. The effect of the previous crop on the yield of irrigated double-crop soybean grown following wheat at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas, 2014–2021.

	Double-Crop Soybean Grain Yield								
Previous Crop	**2014**	**2015**	**2016[a]**	**2017**	**2018**	**2019**	**2020**	**2021**	**Avg.**
	(bu./ac)								
Double-Crop Soybean/Wheat	30	38	46	46	43	45	46	45	42
Corn/Wheat	39	43	49	48	46	47	47	47	46
Grain Sorghum/Wheat	40	42	50	48	46	46	46	50	46
$LSD_{0.05}$	4	NSD[b]	NSD	NSD	NSD	NSD	NSD	3	--

[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. The effect of the previous crop on the yield of irrigated corn grown at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas, 2014–2021.

	Corn Grain Yield								
Previous Crop	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**Avg.**
	(bu./ac)								
Early Planted Soybean	250	221	207	205	196	181	194	216	209
Wheat/Double-Crop Soybean	250	214	198	207	199	186	196	216	208
Corn	245	224	181	201	191	173	196	205	202
$LSD_{0.05}$	NSD[a]	NSD	20	NSD	NSD	NSD	NSD	9	--

[a] NSD = no significant difference at $\alpha = 0.05$.

Table 4. The effect of the previous crop on the yield of winter wheat grown at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas, 2014–2021.

	Wheat Grain Yield								
Previous Crop	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**Avg.**
	(bu./ac)								
Early Planted Soybean	75	72	--	76	67	69	80	78	74
Double-Crop Soybean	75	69	--	73	64	64	75	75	71
Corn	72	68	--	74	69	61	65	79	70
Full-Season Grain Sorghum	69	73	--	56	62	65	64	68	65
$LSD_{0.05}$	NSD[a]	4	--	12	6	NSD	8	10	--

[a] NSD = no significant difference at $\alpha = 0.05$.

Table 5. The 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, 2014–2021.

	Grain Sorghum Grain Yield								
Crop	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**Avg.**
	(bu./ac)								
Full-Season Grain Sorghum	143	123	113	99	98	106	118	111	114
Double-Crop Sorghum	--	88	92	86	87	81	88	85	86

AGRONOMY

Classification of Soybean Chloride Sensitivity Using Leaf Chloride Concentration of Field-Grown Soybean: 2021 Trial Results

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Abstract

Soybean [*Glycine max* (L.) Merr.] varieties are currently categorized as 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 150 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's location of the 2021 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 53, 11, 31, 40, and 15 varieties, respectively. The detailed rating system provides producers with more information regarding the relative Cl tolerance of available soybean varieties

Introduction

Soybean [*Glycine max* (L.) Merr.] varieties have historically been categorized as 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. A more robust system is needed to describe soybean tolerance to Cl accurately. Abel (1969) concluded that a single gene-controlled Cl inclusion attributes of soybean, which contributed to oversimplifying 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) supported this hypothesis and highlighted 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 the Cl sensitivity of soybean varieties involve short greenhouse trials (completed before reproductive growth begins) with a limited number of plants (5–10), limiting the results' scope and applicability. Our research objective was to examine the 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 into the Arkansas Soybean Variety Performance trials were sampled at the Rohwer Research Station in 2021. The trial included late 3, early 4, late 4, and 5 maturity group categories ranging from 3.5 to 5.9. Soybean was planted on 7 May 2021 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 4 times based on an irrigation scheduling program and managed using the University of Arkansas System Division of Agriculture's Cooperative Extension guidelines for furrow-irrigated soybean. Based on the information provided by the originating company or institution, varieties were divided into 3 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 3 replications. Additional details of this trial, along with yield data, are available from Carlin et al. (2021). 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.

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A composite sample comprised of 1 recently matured (top 3 nodes) trifoliolate leaflet (no petiole) was 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 was 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

On 8–9 June 2021, the Rohwer Research Station received 19.2 in. of rainfall, roughly 3 times the 10-year average rainfall for June. There was a significant amount of standing water for several days, but the volume of water itself may have lowered the overall Cl concentrations in the plant tissue due to dilution or leaching from the soil. The mean leaflet-Cl concentrations ranged from 57 to 3028 ppm Cl across the 150 varieties (Tables 1–4). The standard deviation increased linearly as the mean Cl concentration increased, suggesting greater variability in Cl concentrations for mixed and includer varieties. The late-3 and early-4 tests had the lowest total varieties with 18 entries. Within this group, 2 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 4. This number of varieties is similar to the 2020 data, indicating that most varieties in the late-3 and early-4 maturity groups were shifting towards a "mixed" population rather than an includer (Roberts et al., 2020). 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 included in the trial with a rating of 3 or lower.

The late-4 class of varieties had the most overall entries with 98 and mean Cl concentrations ranging from 76–1232 ppm. Within this maturity group range, 35 varieties were identified as being strong excluders which all fell within a range of Cl concentrations (Tables 2–3. 76–188 ppm Cl). There were only 2 varieties that fell within ranking 2 as moderate excluders. Fifteen varieties fell within category 3 or mixed trait varieties. The moderate and strong includers were similar to the strong excluder category, with 42 total varieties falling under Cl rankings of 4 or 5. These results indicate 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 34 entries, and the mean Cl concentration ranged from 57–866 ppm across this group of varieties. Similar to the late-4 class of varieties, there were a significant number of varieties (16) identified as strong excluders (Table 4), which is a major shift from previous years where most varieties tended to be rated as includers 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 excluders. There are an increasing number of varieties with 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 ratings 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 year to year. The overall Cl concentrations presented in the 2021 field trial results are much smaller than the values reported for 2020 but similar to 2019. The field location in 2021 was the same field used in 2019. Our results from several years of implementing field-based assessment of Cl tolerance indicate 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 the years.

Practical Applications

Accurate variety Cl sensitivity ratings are important for growers with 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 three-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 searching for 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 2 varieties. The new rating system will especially benefit growers with marginal irrigation water high in Cl concentration.

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Literature Cited

Abel, G.H. 1969. Inheritance of the capacity for chloride inclusion and chloride exclusion by soybeans. Crop Sci. 9:697–698.

Carlin, J.F., R.B. Morgan and R.D. Bond. 2021. Arkansas Soybean Performance Tests 2021. University of Arkansas Agricultural Experiment Station Research Series 682. Univ. of Arkansas, Fayetteville, Ark. Accessed 20 April 2022. Available at: https://wordpressua.uark.edu/aaes/files/2022/10/682_Arkansas_Soybean_Performance_Tests_2021.pdf

Cox, D.D. 2017. Characterization of the relationships between soybean yield, trifoliolate leaf chloride concentration, and cultivar chloride inclusion/exclusion rating. Master's Thesis. University of Arkansas, Fayetteville.

Cox, D.D., N.A. Slaton, W.J. Ross, and T.L. Roberts. 2018. Trifoliolate leaflet chloride concentrations for characterizing soybean yield loss from chloride toxicity. Agron. J. 10:1589-1599.

Liu, L., 1998. Determination of chloride in plant tissue. pp. 111–113. In: Y.P. Kalra, editor, Handbook of reference methods for plant analysis. CRC Press, Boca Raton, Fla.

Roberts, T.L., A. Smartt, L. Martin, C. Scott, S. Williamson, J. Carlin, R.D. Bond, and R.B. Morgan. 2021. Classification of Soybean Chloride Sensitivity using Leaf Chloride Concentration of Field-Grown Soybean. pp. 19–25. In: J.Ross (ed.) Arkansas Soybean Research Studies 2020. University of Arkansas System Division of Agriculture Agricultural Experiment Station Research Series 680.

Zeng, A., L. Lara, P. Chen, X. Luan, F. Hancock, K. Korth, K. Brye, A. Pereira, and C. Wu. 2017. Quantitative trait loci for chloride tolerance in 'Osage' soybean. Crop Sci. 57:2345-2353.

Table 1. Mean leaflet chloride (Cl) concentrations and preliminary rating for "Late Group 3 and Early 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 2021. A rating of 1 means strong excluder and a rating of 5 means strong includer.

Variety[a]	Mean	Rating[b]
	ppm	
Dyna-Gro S43XS70	203	1
S17-2243C	104	1
R18-14147	344	2
Progeny P4431E3	304	2
Local LS4324E3	892	3
R18-14229	719	3
R18-14287	686	3
Amp 4448X	765	3
Armor 44-D49	1112	3
Local LS4415XF	861	3
Asgrow AG43XF2	1349	4
NK 42-T5XF	1623	4
Asgrow AG42XF0	1451	4
NK 43-V8XF	1413	4
DG45E10	1729	4
R18C-1450	3028	5
NK 44-J4XFS	2103	5
NK S44-C7X	2019	5

[a] Abbreviation key: S = University of Missouri; R = University of Arkansas System Division of Agriculture; NK = NK Seeds; DG = Delta Grow.

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

Table 2. Mean and leaflet chloride (Cl) concentrations and preliminary rating of 1 for "Late 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 2021. A rating of 1 means strong excluder and a rating of 5 means strong includer.

Variety[a]	Mean	Rating[b]	Variety[a]	Mean	Rating[b]
	ppm			ppm	
Dyna-Gro S45ES10	191	1	Pioneer P47A64X	100	1
Armor 46-D09	134	1	Progeny P4775E3S	95	1
Axis 4611ES	123	1	Armor 48-D25	88	1
DG46E10	115	1	Armor 48-E82	102	1
DG46X65/STS	80	1	Asgrow AG48XF2	76	1
DM46E62	95	1	DG48E49/STS	90	1
Dyna-Gro S46ES91	107	1	DG48E59	136	1
Dyna-Gro S46XS60	77	1	DG48X45	107	1
Integra 54660NS	101	1	Integra 54816N	101	1
Local LS4684E3S	103	1	Local LS4806XS	111	1
NK S46-E3S	131	1	Pioneer P48A60X	86	1
R18-14142	127	1	Progeny P4816RX	139	1
R18-14753	110	1	Progeny P4821RX	188	1
Armor 47-E03	90	1	USG 7489XT	115	1
DG47E20/STS	128	1	DG49E20	111	1
Local LS4795XS	83	1	NK S49-F5X	98	1
Progeny P4931E3S	128	1	S16-7922C	155	1
NK S47-Y9X	91	1	---	---	---

[a] Abbreviation key: DG = Delta Grow; DM = DONMARIO; NK = NK Seeds; R = University of Arkansas System Division of Agriculture; S = University of Missouri; 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 leaflet chloride (Cl) concentrations and preliminary rating of 2–5 for "Late 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 2021. A rating of 1 means strong excluder and a rating of 5 means strong includer.

Variety[a]	Mean	Rating[b]	Variety[a]	Mean	Rating[b]
	ppm			ppm	
DM46F62	342	2	R16-253	733	4
R18C-13283	345	2	R18-14272	755	4
AgriGold G4820RX	371	2	UA46i20C	653	4
DM48E62S	341	2	Asgrow AG47XF0	698	4
Integra 54891NS	394	2	Integra 74731NS	755	4
Local LS4918XFS	298	2	R15-2422	729	4
Asgrow AG45XF0	564	3	AgriGold G4813XF	774	4
Axis 4522XF	545	3	Armor 48-D03	687	4
DM45X61	506	3	Armor 48-F01	742	4
Integra 74551NS	516	3	Armor 48-F22	712	4
Local LS4506XS	571	3	Asgrow AG48XF0	698	4
NK 45-P9XF	507	3	DG48F20	744	4
NK S45-J3X	498	3	DONMARIO DM48F61	647	4
Armor 46-F13	518	3	Dyna-Gro S48XF61S	727	4
Integra 54606NS	511	3	Local LS4805XFS	621	4
R13- 14635RR:0010	541	3	Progeny P4806XFS	650	4
DG49F22/STS	563	3	AgriGold G4900XF	742	4
Dyna-Gro S48XT90	435	3	Amp 4950X	653	4
ES4890XF	517	3	DG49E90	670	4
Progeny P4921XFS	509	3	Progeny P4970RX	685	4
USG 7491XFS	476	3	R18-14502	624	4
Local LS4517XFS	722	4	Armor 45-F81	1115	5
Progeny P4501XFS	729	4	NK 45-V9E3	1132	5
Progeny P4505RXS	658	4	Axis 4641XFS	975	5
Progeny P4521XFS	715	4	Integra 74621NS	1178	5
Progeny P4541E3S	731	4	USG 7461XFS	1232	5
AgriGold G4615XF	711	4	Amp 4850XF	950	5
Amp 4690XF	642	4	Dyna-Gro S48XT40	1008	5
DG46F17/STS	758	4	NK S48-2E3S	888	5
Dyna-Gro S46XF31S	832	4	USG 7481XF	1017	5
Local LS4606XFS	790	4	Local LS4707XF	895	5
Progeny P4604XFS	798	4	---	---	---

[a] Abbreviation key: DM = DONMARIO; R = University of Arkansas System Division of Agriculture; NK = NK Seeds; DG = Delta Grow; 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 4. Mean 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 2021. A rating of 1 means strong excluder and a rating of 5 means strong includer.

Variety[a]	Mean	Rating[b]	Variety[a]	Mean	Rating[b]
	ppm			ppm	
Local LS5009XS	110	1	DG52E80	305	2
R14-1422	89	1	DG53E30	219	2
S16-14801C	82	1	Local LS5067E3	542	3
DG51E60	116	1	Local LS5119XF	451	3
NK S51-E3	61	1	Asgrow AG52XF0	574	3
Progeny P5121E3S	95	1	Dyna-Gro S52XT91	340	3
Local LS5232E3	122	1	R18-3048	414	3
R15-1587	63	1	R18-3250	367	3
R17-283F	73	1	Asgrow AG54XF0	580	3
DG54F20	60	1	Local LS5418XFS	569	3
Progeny P5411XF	62	1	UA54i19GT	682	3
Asgrow AG55XF0	57	1	Progeny P5521E3	545	3
R16-1445	96	1	Progeny P5003XF	630	4
Dyna S56XT99	81	1	Asgrow AG53XF2	651	4
R13-13997	70	1	Local LS5614XF	753	4
R17-4177	100	1	R15-5695	848	5
DG50E10	261	2	R17-3488	866	5

[a] Abbreviation key: R = University of Arkansas System Division of Agriculture; S = University of Missouri; DG = Delta Grow; NK = NK Seeds; Dyna = Dyna Gro.

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

Drivers of Yield Variability in a Variable-Rate Seeding Experiment – Preliminary Assessment

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Abstract

The Arkansas soybean [*Glycine max* (L.) Merr] seeding rate recommendation ranges from 125,000 to 140,000 seeds/ac, with higher rates needed in areas with lower production capabilities. The seeding rate is selected before planting and used across one or multiple fields, even though in-field changes in soil properties are known to affect crop establishment. Many producers use variable-rate seeding (VRS) technology to adjust seeding rates to in-field variability, but no site-specific recommendations are available to help them maximize benefits. The objectives of this study are to determine under which circumstances VRS technology is most profitable to Arkansas producers and identify the parameters which should be considered to fine-tune current seeding rate recommendations for VRS. Five seeding rate treatments were applied in a soybean production field to bracket the normal range: 75,000, 100,000, 125,000, 150,000, and 175,000 seeds/ac. Planter performance metrics, soil fertility metrics, soil texture, stand counts, and yield data were collected in 88 locations across the trial. Preliminary results showed that the planter performed well within the normal range but may have failed to apply the lowest and highest rates. The 125,000 treatment maximized average yield and minimized within-treatment variability. This data indicated that the current recommendation is Arkansas's best standard for uniform seeding rate applications. The maximum yields achieved within the 100,000 and 150,000 treatments were higher than the average yield achieved for the 125,000 treatment. These results confirmed that it might be possible to fine-tune current seeding-rate recommendations for VRS applications. Treatment selection explained most yield variability in the trial. In-field changes in soil test phosphorus (P), potassium (K), and soil texture explained most within-treatment variability. More data is needed to confirm these preliminary findings, model within-treatment variability, and determine under which conditions VRS may pay off for Arkansas soybean producers.

Introduction

Crops are established at planting, and optimum planter operation is required to maximize potential yield. Environmental conditions, planter/drill settings selection, and equipment maintenance and calibration must be optimized to create acceptable and consistent stands (Grisso et al., 2014). First, soil type, preparation, and seeding depth influence the amount of water available for the emergence and the daily soil temperature variation patterns to which the planted seeds are exposed (Poncet et al., 2018). Adequate seeding depth minimizes seed mortality and yield loss from low stand counts and uneven emergence (Knappenberger and Köller, 2012). Soybeans [*Glycine max* (L.) Merr] must be planted between 0.5 and 2.0-in depth, with shallower depths preferred in fine-textured soils and no-till systems (Ashlock et al., 2019). Next, variety selection, seed quality, planting date, seeding rate, and row spacing affect site-specific crop development. Changes in day length drive soybean productivity, and varieties from maturity groups 5 and 4 with a minimum germination rate of 80% maximize yields in Arkansas when planted between 25 April and 30 June (Ashlock et al., 2019). Seeding rate and row spacing determine how efficiently available resources such as water, sunlight, and nutrients are used by the growing crop (De Bruin and Pedersen, 2008). In Arkansas, the soybean seeding rate ranges from 125,000 to 140,000 seeds per acre, with higher rates needed in areas with lower production capabilities (Ashlock et al., 2019). Row spacing can range from 7 in. to 38-in. with 30 and 38-in being preferred by most soybean producers. Narrower row spacings minimize competition between plants and increase shading, which can help reduce drought stress during the hot summer and give the crop a competitive advantage over weeds (Cox and Cherney, 2011).

In most cropping systems, the seeding rate is selected before planting and used across one or multiple fields. The same rate is used even though spatial changes in soil texture, nutrient levels, terrain and slope, and soil water availability are known to affect the plant survival rate after emergence, canopy width, height, and yields (Matcham et al., 2020). Using the same seeding rate across entire fields may be costly to growers because of high seed costs in high-yielding areas and reduced yields from low stand counts in low-yielding areas. Fortunately, the rapid pace of technological development and the normalization of precision agriculture provides new opportunities for stakeholders interested in using variable-rate

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seeding (VRS) technology to vary soybean seeding rate with changes in field conditions (Gaspar et al., 2020). While VRS should optimize input use and increase profits, it also increases management complexity making it difficult for producers to achieve the anticipated benefits (Bullock et al., 1998). Without site-specific extension guidelines, early adopters rely solely on experience and a trial-and-error approach without proof that their choices optimize technology to maximize the return on investment. The objectives of this 3-year project are to quantify the magnitude of spatial variation in soybean yield response to seeding rate within commercial soybean fields, determine under which circumstances VRS technology could be most profitable for Arkansas soybean growers, and develop criteria on which site-specific VRS recommendations might be based. This report summarizes the preliminary findings from the data collected during project year 1.

Procedures

Site Description

The experiment was conducted on-farm in an 80-ac soybean production field near Gould, Ark. (Lincoln county). Approximate field dimensions were 1200-ft wide (north to south) and 2900-ft long (west to east). Soil development took place on loamy and clayey alluvium. A less than 1% natural slope gradient occurred from east to west in the field, creating significant changes in soil properties. The following soil series were represented in the experimental site: Rilla, Portland, and Perry (Fig. 1). Finer soil textures and poorly drained soils were found in the western half of the field (Table 1).

Experimental Design

Five seeding rate treatments were selected to bracket the typical range: 75,000 (75K), 100,000 (100K), 125,000 (125K), 150,000 (150K), 175,000 (175K) seeds per acre. The treatments were applied in strips and randomized within 4 complete blocks (Fig. 2). planting was performed using a 12-row planter equipped with auto guidance and VRS technology. Row spacing was 30-in. The treatment strips were established along the maximum direction of elongation of the field. Each strip was created with 2 consecutive planter passes (width = 60 ft). The trial was planted on 5 June 2021 with soybean variety Asgrow AG48X9. The planting speed was 3 mph. The seeding depth was 1-in. Furrow irrigation was used to minimize yield loss from drought stress. Nutrient and pest management was accomplished using the current University of Arkansas System Division of Agriculture's Cooperative Extension guidelines (Ross et al., 2020).

Data Collection

Real-time planter performance metrics, including the achieved seeding rate, were measured by the VRS technology used to establish the different seeding rate treatments. Soil samples and stand count data were collected in 88 sampling sites distributed evenly throughout the study area to capture as much within-treatment variability as possible. There were 18, 21, 13, 17, and 19 sampling sites associated with the 75K, 100K, 125K, 150K, and 175K seeding rate treatments, respectively. The sampling site distribution was uneven between treatments because of the irregular field shape. All sampling locations were located in the middle of a treatment strip (e.g., between rows 12 and 13). The soil samples were collected on 15 July 2021 using the custom-manufactured cone probe designed by Drescher et al. 2021. The soil sampling depth was 4 in., and each sample was composed of at least 15 cores collected within 15 ft from the sampling location. Because the soil test results vary within short distances in raised-bed systems, approximately 1/3, 1/3, and 1/3 of the cores were collected at the bottom, on the edge, and on top of the furrow, respectively. The collected samples were then submitted to the University of Arkansas System Division of Agriculture's Diagnostic Laboratory in Fayetteville for soil pH determination in a 1:2 (v/v) soil-to-water mixture, Mehlich 3 extraction for available nutrients, and soil texture determination using the hydrometer method.

The stand count measurements were taken on 2 of the 4 middle rows of a treatment strip over a cumulative distance of 35 ft (17.5 ft for each row, or 0.001 ac). The stand count data were also collected on 15 July 2021. The soybean growth stage was V4. Furrow irrigation was provided by a series of poly pipes laid out on the eastern side of the field. The distance between each sampling site and the field's eastern boundary (beginning of the furrow) was measured using ArcPro® GIS software (ESRI, Redlands, Calif.). The trial was harvested on 8 November 2021. The combine was equipped with a yield monitor that recorded real-time wet yield and grain moisture content. The wet yield data were cleaned by removing the combined delay times and excessive yield values (greater than the average yield plus four standard deviations) and adjusted at 13% moisture.

Data Summary and Analysis

The achieved seeding rate and adjusted yield in each sampling location were estimated as the average of all the seeding rate and yield measurements collected within a 20-ft radius from the sampling location. The achieved seeding rate and stand count data were summarized by seeding rate treatment to evaluate planter performance. The adjusted yield data were summarized by seeding rate treatment to evaluate between and within-treatment variability. The coefficient of variation (CV) values were calculated using equation 1:

$$CV_t = \frac{\sigma_t}{\mu_t} \qquad \text{Eq. 1}$$

where CV_t is the calculated coefficient of variation for seeding rate treatment t, σ_t is the standard deviation of the yield data collected within treatment t, and μ_t is the average yield data for treatment t. Higher CV values indicated stronger within-treatment yield variability. Random forest was used to identify the experiment's major drivers of yield variability. The following parameters were considered in the random forest analysis: seeding rate treatments, stand count, soil pH, available soil potassium (K), available soil phosphorus (P), soil texture quantified using the percentage of clay and sand, and distance to the irrigation poly pipe which provided a measure of the top-to-bottom effects known to occur in the experiment.

Results and Discussion

Planter Performance

The achieved seeding rate was within 95% and 100% of the seeding rate set in 84 of 91 sampling sites (95.4%). In the other 4 sites, the achieved seeding rate was within 90% and 95% of the seeding rate setting. According to the planter, the achieved seeding rate never exceeded the seeding rate setting, and the lower performance value was 93.6% of the target. The stand counts were between 73.8% to 225.0%, 75.8% to 106.4%, 52.8% to 117.3%, 63.2% to 104.5%, 41.2% to 94.2% of the achieved seeding rate for seeding rate treatments 75K, 100K, 125K, 150K, 175K, respectively (Fig. 3). Stand counts were expected to be within 72% (no less than 80% emergence and no more than 10% plant mortality after emergence) and 105% (no more than 5% measurement error) of the achieved seeding rate (Ashlock et al., 2019). Stand counts were below the minimum expected stand count threshold in 0, 0, 3 (23.1%), 2 (11.8%), 9 (47.4%) sites for seeding rate treatments 75K, 100K, 125K, 150K, 175K, respectively. Stand counts were above the maximum expected stand count threshold in 6 (33.3%), 1 (4.8%), 1 (7.7%), 0, 0 sites for seeding rate treatments 75K, 100K, 125K, 150K, 175K, respectively. Evaluation of the stand count data suggested that the planter may have failed to apply the lowest and highest seeding rate treatments, which were outside the typical range, even if this issue was not reflected by the as-applied seeding rate data from the planter. Overall, the planter tended to apply more seeds than needed to meet excessively low targets, most likely because the seed plate rotation was too slow to maintain proper vacuum and optimize seed delivery. The planter also tended to apply fewer seeds than needed to meet excessively high targets, most likely because the seed plate could not rotate fast enough to keep up with the highest seeding rate prescriptions. This issue was consistent with previous VRS research (Virk et al., 2020). The data collected in the 75K and 175K seeding rate treatments were not representative of the treatment effects and were excluded from further analysis. Any stand count value outside the 72% to 105% range for the 100K, 125K, and 150K treatments was also excluded from further analysis.

Drivers of Yield Variability

The average yield was 63, 67, and 66 bu/ac in the 100K, 125K, and 150K treatments, respectively (Table 2). The coefficient of variation (CV) was 11.3%, 6.6%, and 13.9% for the 100K, 125K, and 150K treatments, respectively. These C.V.s means that the highest average yields and smallest within-treatment variability were achieved with the 125K treatment. The second-highest average yields and strongest within-treatment variability were achieved with the 150K treatment. The lowest average yield and second highest within-treatment variability were achieved with the 100K treatment. The highest yields achieved with the 100K and 150K treatments were greater than the average yield achieved with the 125K treatment. If we can identify the drivers of within-treatment variability and predict their effect on yield, then we may be able to develop site-specific seeding rate recommendations to optimize VRS technology use. Most of the yield variability was explained by the treatment effects (Fig. 4). Then, within-treatment variability was explained by, in order: soil test P and K values, soil texture, top-to-bottom effects, and soil pH. Further analysis will need to be conducted to model the site-specific effect of soil fertility, soil texture, and top-to-bottom effects on soybean yields.

Practical Applications

The preliminary results from year 1 demonstrated that the VRS technology used to establish the different seeding rate treatments performed well within the typical range but may have failed to meet the lowest and highest seeding rate targets. The measured stand counts were inconsistent with the as-applied seeding rate information obtained from the planter. The project investigators will reach out to the VRS equipment manufacturer to determine specific operation parameters (operation speed, seed plate selection) that can be modified to improve performance outside the typical range. The preliminary results from year 1 also demonstrated that the maximum yield and uniformity were achieved at 125,000 seeds/ac. This result confirms that the current extension recommendation for seeding rates maximizes potential yield without site-specific capabilities. However, results also showed that the highest yields obtained with the 100K and 150K treatments were higher than the average yield for the 125K treatment, indicating that it may be possible to fine-tune current extension recommendations for VRS. The treatment effects explained most of the yield variability existing within the experiment. Then, within-treatment variability was mostly explained by in-field changes in soil test P and K and soil texture. Soil pH did not seem to influence yield variability significantly in this trial. Additional data collected in multiple site years are needed to confirm these preliminary findings and model within-treatment variability for developing a recommendation.

Acknowledgments

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Literature Cited

Ashlock, L., R. Klerk, G. Huitink, T. Keisling, and E. Vories. 2019. Planting Practices. Arkansas Soybean Production Handbook. MP 197. University of Arkansas System Division of Agriculture Cooperative Extension Service. 7:1-7.

Bullock, D.G., D.S. Bullock, E.D. Nafziger, T.A. Doerge, S.R. Paszkiewicz, P.R. Carter, and T.A. Peterson. 1998. Does variable rate seeding of corn pay? Agron. J. 90(6):830-836.

Cox, W.J. and J.H. Cherney. 2011. Growth and yield responses of soybean to row spacing and seeding rate. Agron. J., 103(1):123-128.

De Bruin, J.L. and P. Pedersen. 2008. Effect of row spacing and seeding rate on soybean yield. Agron. J., 100(3):704-710.

Drescher, G.L., N.A. Slaton, T.L. Roberts, and A.D. Smartt. 2021. Soil moisture condition at soil sampling time affects cores uniformity and reproducibility. In: N.A. Slaton (ed.). Wayne E. Sabbe Arkansas Soil Fertility Studies 2020. University of Arkansas Agricultural Experiment Station Research Series 675:29-35.Fayetteville. Accessed 15 Jan. 2022. Available at: https://wordpressua.uark.edu/aaes/files/2022/10/675_Sabbe_Arkansas_Soil_Fertility_Studies_2020.pdf

Gaspar, A.P., Mourtzinis, S., Kyle, D., Galdi, E., Lindsey, L.E., Hamman, W.P., Matcham, E.G., Kandel, H.J., Schmitz, P., Stanley, J.D. and Schmidt, J.P. 2020. Defining optimal soybean seeding rates and associated risk across North America. Agron. J., 112(3):2103-2114.

Grisso, R.D., D.L. Holshouser, and R.M. Pitman. 2014. Planter/drill considerations for conservation tillage systems. Publication, Virginia Cooperative Extension (VCE). Accessed 15 Jan. 2022. Available at https://vtechworks.lib.vt.edu/handle/10919/56032

Knappenberger, T. and K. Köller. 2012. Spatial assessment of the correlation of seeding depth with emergence and yield of corn. Precision Ag., 13(2):163-180.

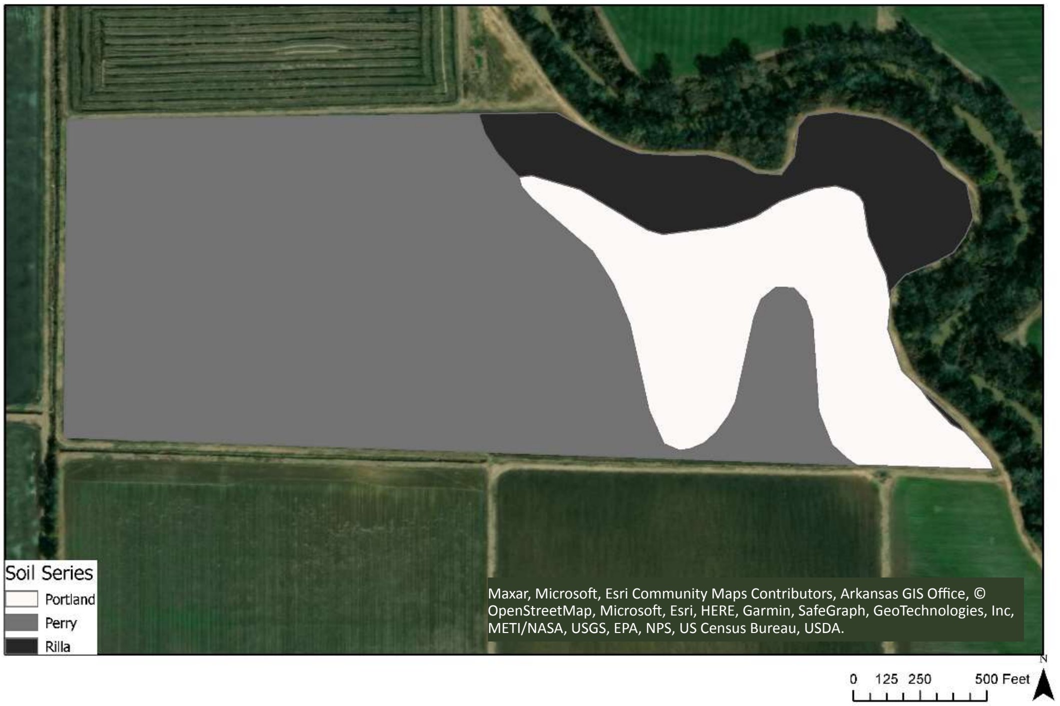
Matcham, E.G., W.P. Hamman, E.M. Hawkins, J.P. Fulton, S. Subburayalu, and L.E. Lindsey. 2020. Soil and terrain properties that predict differences in local ideal seeding rate for soybean. Agron. J., 112(3):1981-1991.

Poncet, A.M., J.P. Fulton, T.P. McDonald, T. Knappenberger, J.N. Shaw, and R.W. Bridges. 2018. Effect of heterogeneous field conditions on corn seeding depth accuracy and uniformity. Applied Eng. in Ag., 34(5):819–830.

Ross, W.J. 2000. Soybean Production Handbook. University of Arkansas System Division of Agriculture, MP 197. Accessed 15 Jan. 2022. Available at: https://www.uaex.uada.edu/publications/mp-197.aspx

USDA, 1999. United States Department of Agriculture. Soil taxonomy: a basic system of soil classification for making and interpreting soil surveys (2nd. Ed.). Washington, DC: USDA, NRCS.

Virk, S.S., J.P. Fulton, W.M. Porter, and G.L. Pate. 2020. Row-crop planter performance to support variable-rate seeding of maize. Precision Ag., 21(3):603-619.



Maxar, Microsoft, Esri Community Maps Contributors, Arkansas GIS Office, © OpenStreetMap, Microsoft, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, US Census Bureau, USDA.

Fig. 1. Spatial distribution of the Rilla, Perry, and Portland soil series in the experimental site.

Table 1. Soil series representation in the trial, corresponding soil types, and associated properties. Information was gathered from the Natural Rescources Conservation Service Web Soil Survey. Soil type and series were defined using the Soil Taxonomy (USDA, 1999).

Soil Type	Soil Series	Area	Texture Class	Drainage Class
		%		
Fine-silty, mixed, active, thermic Typic Hapludalfs	Rilla	13.0	Silt loam	Well drained
Very-fine, mixed, superactive, nonacid, thermic Vertic Epiaquepts	Portland	20.6	Clay	Somewhat poorly drained
Very-fine, smectitic, thermic Chromic Epiaquerts	Perry	66.4	Clay	Poorly drained

Maxar, Microsoft, Esri Community Maps Contributors, Arkansas GIS Office, © OpenStreetMap, Microsoft, Esri, HERE, Garmin, SafeGraph, GeoTechnologies, Inc, METI/NASA, USGS, EPA, NPS, US Census Bureau, USDA.

Fig. 2. Seeding rate treatment selection and layout in the experimental sites. Treatments were repeated four times and randomized in four complete blocks identified on the west side of the field.

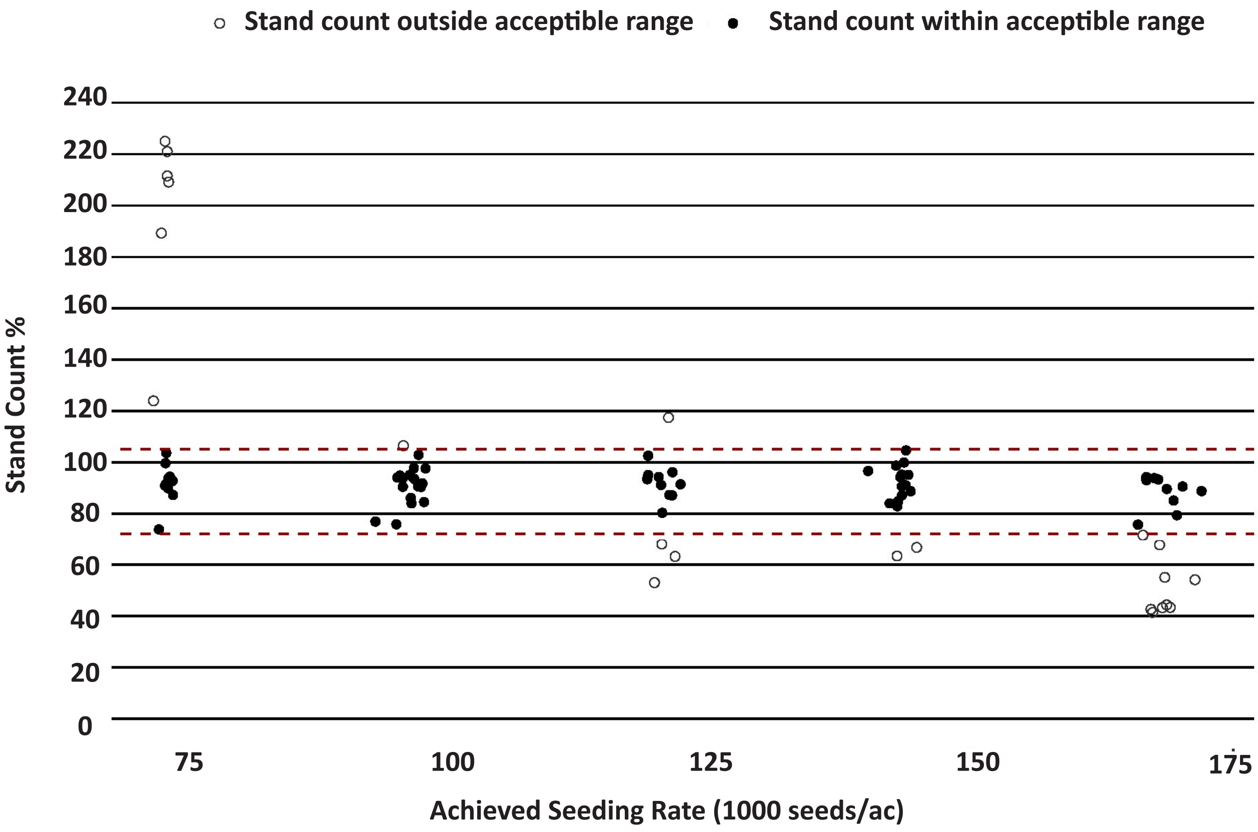


Fig. 3. Stand counts, expressed in percentage of the achieved seeding rate, per seeding rate treatment. The sampling sites for which the stand count data were outside the acceptable 72% to 100% range (represented on the plot with dashed red lines) were excluded from further analysis.

Table 2. Summary of the yield data per seeding rate treatment. From left to right in the table: number of observations (N), minimum yield value, 25% quantile, median (50% quantile), 75% quantile, maximum yield value, and coefficient of variation.

Treatment	N	Min	Q1	Median	Mean	Q3	Max	CV
		bu./ac	bu./ac	bu./ac	bu./ac	bu./ac	bu./ac	%
100,000	20	41	61	66	63	67	71	11.3
125,000	9	60	63	66	67	69	73	6.6
150,000	18	39	65	68	66	71	74	13.9

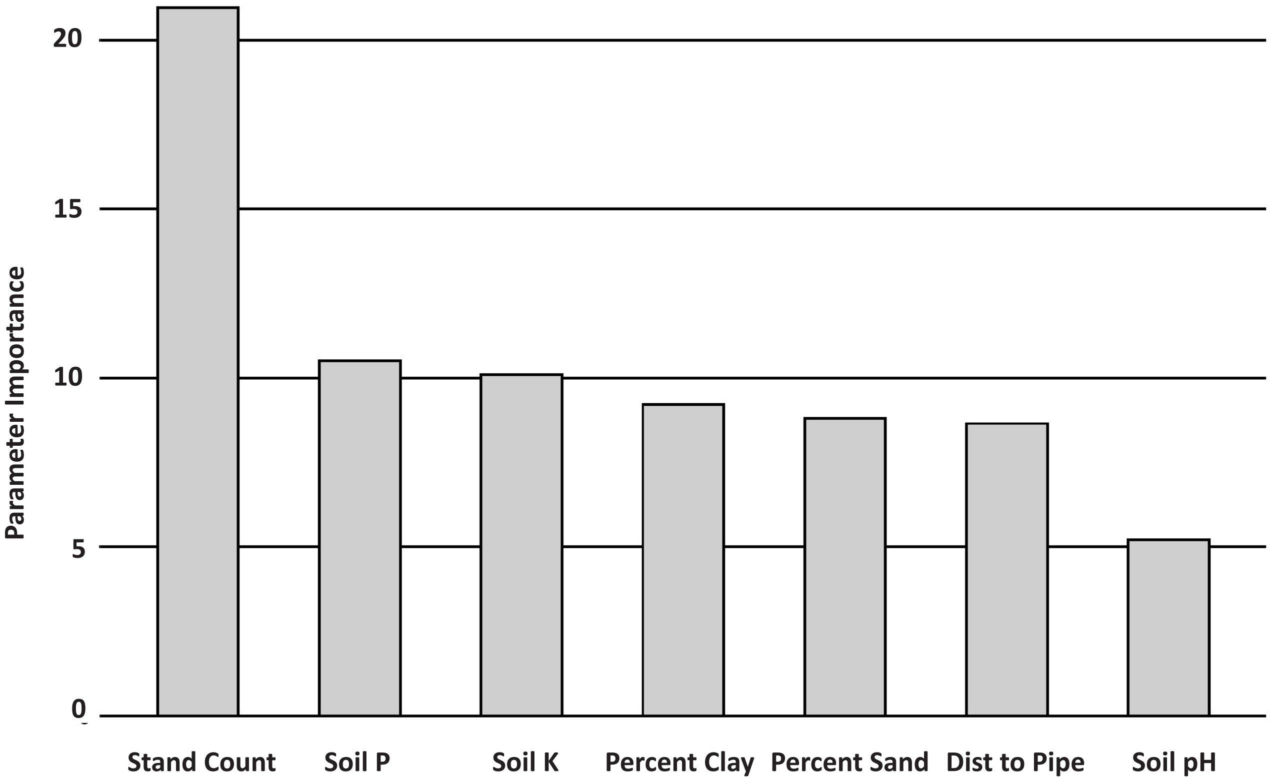


Fig. 4. Results from the random forest analysis. Importance was evaluated using the Gini impurity index. Values represented on the y-axis are the computed Gini impurity index values divided by 10^5 to improve visibility. The higher the y-value, the more important the parameter, and the more yield variability it explains in the experiment.

Soybean Variety Advancement Using a Winter Nursery

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Abstract

The University of Arkansas System Division of Agriculture's Soybean Breeding Program strives to develop and release high-yielding maturity group (MG) 4 soybean [*Glycine max* (L.) Merr.] varieties with desirable traits that are well adapted to Arkansas' growing conditions. Generation advancements are restricted to only 1 cycle per year in the United States (U.S.). Increasing to 2 cycles per year is essential to stay competitive in making genetic gains. The Soybean Breeding Program has contracted with a South American off-season nursery in Chile, offering generation advancement services during U.S. winter months to maintain the 2 cycles per year competitive advantage. In October 2020, 3141 single plants from 13 MG 3 and 4 breeding populations were selected and individually harvested in Fayetteville, Ark. Seed was processed and sent to Quillota, Chile, to grow as progeny rows. In April 2021, 590 of the best-performing lines (13% MG 3 and 87% MG 4) were selected based on a vegetative index using drone imaging data, bulk-harvested, and sent back to Ark. for preliminary yield testing in four locations with one replication. Incorporating a winter nursery into our workflow has reduced the breeding cycle by 1 year while increasing the proportion of MG 4 commodity material in testing to 59% and MG 3 to 21%.

Introduction

The University of Arkansas System Division of Agriculture's Soybean Breeding Program works to meet the needs of the Arkansas soybean [*Glycine max* (L.) Merr.] growers by developing and releasing maturity group (MG) 4 cultivars with high yield potential, a strong disease package, and improved value-added traits. The rate of genetic gain is negatively affected by the breeding cycle length (Cobb et al., 2019). Therefore, reducing the time cycle is imperative to developing competitive varieties (O'Connor et al., 2013; Cobb et al., 2019). One of the tools available to significantly shorten variety development times is utilizing winter nurseries (Mertin, 1979). In this project, progeny rows are grown in Chile during the United States off-season (November through April) in an environment that simulates Arkansas' growing conditions. Thus, phenotypic selections can be conducted. Lines are selected based on overall field appearance, harvested, and sent back to Arkansas for preliminary yield testing. This modified workflow has enabled 2 generations to be grown in 1 calendar year instead of 1 generation, increasing the rate of genetic gain.

Procedures

Twelve genetic populations were grown at the Milo J. Shult Agricultural Research and Extension Center (SAREC) in Fayetteville, Ark., in 2020. Nine of these populations (R16-253/PI573031, R16-253/K15-1800, PI556913/PI565512, R16-259/KS4117Ns, R15-2422/KS4117Ns, PI573031/PI556901, PI568254/PI556901, PI556875/PI556852, and PI556912/PI556784) were derived from crossing high-yielding conventional MG 4 parents. The other 3 populations (PI550731/PI550739, PI556875/PI556857, and DS43-91/SA13-1385) were derived from crossing a MG 4 conventional parent and a MG 3 conventional parent. That fall, 3141 single plants (SPS) were individually harvested, the seed was cleaned for purity, treated with Seed Shield MAX Beans (3.54% Mefenoxam, 21.7% Thiamethoxam, 1.08% Fludioxonil, 1.08% Sedaxane, 0.87% Azoxystrobin), and sent to Quillota, Chile, to be grown as progeny rows during winter 2020–2021. In April 2021, 590 lines (75 MG 3 and 515 MG 4) were selected based on drone imaging data using an experimental procedure involving image-predicted maturity, a vegetation index calculated using RGB (red, green, blue) composite bands, and the actual visual evaluation of the plot pictures. Selected lines were bulk harvested and sent back to Arkansas for evaluation in preliminary yield trials in 4 locations with 1 replication.

Results and Discussion

The Soybean Breeding Program evaluated 590 (13% MG 3 and 87% MG 4) preliminary lines a year earlier than under the standard workflow, all while maintaining a consistent inbreeding stage. Using our modified workflow helped to increase the proportion of commodity MG 3 entries from 3% to 13% and MG 4 entries in yield testing from 52% to 59%.

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Practical Applications

Implementing a winter nursery into our breeding pipeline has allowed us to conduct 2 cycles of selections in a given calendar year, decreasing the time it takes to develop and release new varieties to the Arkansas farmers. This modified breeding workflow has also rapidly increased the proportion of MG 4 commodity lines tested in yield trials in our program.

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Literature Cited

Cobb, J.N., R.U. Juma, P.S. Biswas, J.D. Arbelaez, J. Rutkoski, G. Atlin, T. Hagen, M. Quinn, and E. Hwa Ng. 2019. Enhancing the rate of genetic gain in public-sector plant breeding programs: lessons from the breeder's equation. TAG 132:627-645.

Mertin, J.V. 1979. Offseason Nurseries: Speeding the Breeding. CIMMYT TODAY No. 11. Accessed: 31 March 2022. Available at: https://repository.cimmyt.org/bitstream/handle/10883/3897/22593.pdf?sequence=1&isAllowed=y

O'Connor D. J., G. C. Wright, M. J. Dieters, D. L. George, M. N. Hunter, J. R. Tatnell, and D.B. Fleischfresser. 2013. Development and Application of Speed Breeding Technologies in a Commercial Peanut Breeding Program. Peanut Sci. 40(2):107-114.

Breeding New and Improved Soybean Cultivars with High Yield and Local Adaptation

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Abstract

The University of Arkansas System Division of Agriculture's Soybean Breeding Program has been working towards developing conventional and non-conventional high-yielding maturity group (MG) 4 and 5 soybean cultivars. These cultivars have a complete disease package and are widely adapted to Arkansas' environment. The Soybean Breeding Program has previously released several conventional and glyphosate-tolerant cultivars. Our breeding pipeline begins with the combination of elite lines crossed to exotic materials that are new, previously developed in our program, or identified in external breeding programs. Additionally, crosses may include materials developed by other breeding programs in the southern states, often including essential disease and pest tolerance traits. After completing the initial crosses, 4-generation advancements are conducted until reaching plant homozygosity. Single plant selections are performed based on plant architecture and physiological traits. Afterward, entries resulting from individual plant selections with the best performance are advanced and evaluated for 3 consecutive years in multi-location yield trials. Only lines with excellent adaptation, high yield performance, and an adequate disease package are selected and advanced to the next cycle each year. Finally, promising lines are further evaluated in the Arkansas State Variety Testing, the United States Department of Agriculture Uniform Soybean Tests, and other southern states' official variety testing programs.

Introduction

The University of Arkansas System Division of Agriculture's Soybean Breeding Program works toward the development and release of new conventional and non-conventional soybean elite cultivars for Arkansas farmers. Developed cultivars are widely adapted to Arkansas' environments and possess disease and pest-resistant traits and high seed quality. Released cultivars commercialized and used as germplasm sources in other breeding programs include 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), UA5715GT (Orazaly et al., 2019), UA5414RR, UA5615C, UA5115C (Florez-Palacios et al., 2019), UA54i19GT, R13-13997 (Florez-Palacios et al., 2021), and UA46i20C. Osage and UA5612 have been extensively used as yield checks in the United States Department of Agriculture (USDA) Uniform Soybean Trials. Here we summarize the work towards the development and commercialization of new high-yielding MG 4 and 5 soybean varieties.

Procedures

A traditional breeding pipeline and molecular tools, such as genomic selection and marker-assisted selection (MAS), are used. The first step of our breeding pipeline is to identify and cross materials with key traits, such as yield, disease, pest, and stress tolerance, from elite cultivars developed in our program, exotic germplasm from gene banks, and high-yielding varieties from different southern breeding programs. After initial crossing, 3 to 4 generations of advancements are allowed to promote genetic segregation and recombination. After an initial selection based on performance and identification of materials with the traits of interest, selected lines are tested during 5 consecutive years of multi-location yield trials.

In 2021, 240 new crosses were made, a total of 362 populations from early generation (EG) 1 to 5 were evaluated, and 10,860 progeny rows were planted (of which a total of 669 were selected for preliminary yield trials). The Chile winter nursery was used during the off-season to expedite the breeding process. Arkansas yield testing was performed at the following University of Arkansas System Division of Agriculture's research centers: Northeast Research and Extension Center, Keiser; Lon Mann Cotton Research Station, Marianna; Rohwer Research Station, Watson; Rice Research and Extension Center (RREC), Stuttgart, as well as outsourcing field testing near Weiner, and Newport, Ark. Preliminary (first-year) yield trials were grown in 3 Arkansas locations in non-replicated tests. Intermediate (second-year) yield trails were grown in 5 Arkansas locations with 3 replications. Advanced (third-year) yield trials were grown in all Arkansas locations with 2 replications. Seed increase purity rows were grown at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark. Best adapted, high-yielding

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lines from advanced yield trials were evaluated in our pre-commercial test, the USDA Southern Uniform Tests, the Arkansas Official Variety Test (OVT), and other variety tests in southern states. Simultaneously, breeder seed was produced at the RREC, Stuttgart, Ark., and foundation seed was provided for seed production. Additionally, all pre-commercial lines were screened for disease resistance to soybean cyst nematode (SCN), root-knot nematode (RKN), stem canker (SC), frogeye leaf spot (FLS), and drought and flood-tolerance under either greenhouse or field conditions.

Results and Discussion

Three conventional lines, R15-2422, R16-253, and R16-259, were evaluated in the 2021 USDA Uniform Test IV and yielded 57.0, 63.9, and 64.1 bu./ac, respectively, (77.7%, 87.17%, and 87.44% of check mean; 73.3 bu./ac). Lines R15-5695 and R17-283F were evaluated in the 2021 USDA Uniform Test V and yielded 65.5 and 61.1 bu./ac (100.9% and 94.1% of the check mean), respectively.

Three promising lines (R18-14229, R18-14793, and R18-3048) were also evaluated for yield in the 2021 Uniform Preliminary MG 4 early Soybean Tests. Lines R18-14229 and R18-3048 had higher yields, with 66.6 and 68.8 bu./ac (104.2% and 107.6% of the check mean, respectively), ranking 2nd and 6th out of 25 entries in the test. Lines R13-14635RR:0010, R18-14572, and R18-14753 were also evaluated in the 2021 USDA Preliminary Uniform Test IV late and yielded 68.5, 65.3, and 62.3 bu./ac, respectively (98.4%, 93.8%, and 89.51% of the check mean; 69.6 bu./ac).

Lines R18-14272, R18-14502, R18-3332, and R18-67F were also evaluated in the 2021 USDA Preliminary Uniform Test V early and yielded 65.6, 69.6, 69.2 and 71.3 bu./ac (95.7%, 100.8%, 100.2% and 103.3% of the check mean; 69.0 bu./ac). Lines R15-7063, R17-1079, R17-3393, R17-3488, R18-14286 and R18-3250 were also evaluated in the 2021 USDA Preliminary Uniform Test V late and yielded 75.4, 66.4, 63.5, 75.5, 64.8, and 74.3 bu./ac (96.41%, 84.91%, 81.20%, 95.64%, and 82.86% of the check mean; 78.2 bu./ac) respectively.

A total of 1776 conventional breeding lines were evaluated for yield in multi-location advanced, intermediate, and preliminary Arkansas yield tests in 2021 (Table 1), with approximately 76% of entries being MG 4 and 23% MG 5. In the pre-commercial trials, 70 conventional lines were evaluated. A total of 9027 progeny rows were grown at the Vegetable Research Station in Alma, Ark., and 668 lines (7.4%) were selected based on field appearance for yield trial evaluation in 2021. Finally, 19,110 single plants were pulled from F_3-F_5 breeding populations and have been evaluated as progeny rows at a winter nursery (Table 1).

Practical Applications

The Soybean Breeding Program aims to supply Arkansas soybean growers with high-yielding, locally adapted, and beneficial cultivars at low cost. The continued release of public cultivars, including Ozark, Osage, UA5612, UA5213C, UA5014C, UA5414RR, UA5715GT, UA54i19GT, and UA-46i20C offers a low-cost seed for Arkansas farmers and provides sources of germplasm for public and private breeding programs in the U.S.

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Literature Cited

Chen, P., C.H. Sneller, J.C. Rupe, and R.D. Riggs. 2004. Registration of 'Ozark' soybean. Crop Sci. 44(5):1872-1873.

Chen, P., C.H. Sneller, L.A. Mozzoni, and J.C. Rupe. 2007. Registration of 'Osage' Soybean. J. Plant Reg. 1(2):89-92.

Chen, P., C.P. Gray, T.L. Hart, M. Orazaly, J.C. Rupe, D.G. Dombek, R.D. Bond, T. Kirkpatrick, R.T. Robbins, and L.O. Ashlock. 2014a. Registration of 'UA 5612' soybean. J. Plant Regist. 8(2):145-149.

Chen, P., M. Orazaly, J.C. Rupe, D.G. Dombek, T. Kirkpatrick, R.T. Robbins, C. Wu, and P. Manjarrez. 2014b. Registration of 'U.A. 5213C' soybean. J. Plant Regist. 8(2):150-154.

Chen, P., M. Orazaly, C. Wu, P. Manjarrez-Sandoval. L. Florez-Palacios, J.C. Rupe, and D.G. Dombek. 2016. Registration of ‘UA 5014C’ Soybean. J. Plant Regist. 10(2):119-123.

Florez-Palacios, L., M. Orazaly, P. Manjarrez-Sandoval, C. Wu, L. Mozzoni, D. Dombek, and P. Chen. 2019. Registration of ‘UA 5115C’ Soybean Cultivar. J. Plant Regist. 13:1-4.

Florez-Palacios, L., M.P. Da Silva, A. Acuña, C. Wu, D. Rogers, L. Mozzoni, J.F. Carlin, and P. Chen. 2021. Registration of ‘R13-13997’ soybean cultivar. J. Plant Regist.15:313-317.

Orazaly, M., L. Florez-Palacios, P. Manjarrez-Sandoval, L. Mozzoni, D. Dombek, C. Wu, and P. Chen. 2019. Registration of ‘UA 5715GT’ Soybean Cultivar. J. Plant Regist. 13:1-7.

Sneller, C.H., P. Chen, J.C. Rupe, and R.D. Riggs. 2004. Registration of 'Lonoke' soybean. Crop Sci. 44(2):689.

Table 1. Overview of University of Arkansas System Division of Agriculture's Soybean Breeding and Genetics Program tests in 2021.

Testing stage	Number of entries
USDA Uniform/Preliminary Tests	21
Arkansas Variety Testing Program	15
Arkansas Advanced Lines	435
Arkansas Intermediate Lines	170
Arkansas Preliminary Lines	1161
Progeny Rows	9027
Single plants	19,110
Breeding Populations (F_1 – F_4 generation)	362
New Crosses	240

Fast-Tracking Maturity Group 4 and 5 Cultivars with Southern Root-Knot Nematode Resistance

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Abstract

The University of Arkansas System Division of Agriculture's Soybean Breeding Program is currently developing locally adapted maturity group (MG) 4 and 5 soybean [*Glycine max* (L.) Merritt} cultivars with resistance to southern root-knot nematode (*Meloidogyne incognita*, SRKN). Southern root-knot nematode is economically significant in Arkansas, causing an estimated 8.6 million bushel yield reduction on average annually. There is currently a gap in resistance packages offered in high-yielding commercial lines available in Arkansas and the mid-South states. In 2021, a total of 15 MG 4 and 13 MG 5 advanced stage pre-commercial (PCM) lines were evaluated in a 3 replication trial for resistance response to SRKN in a field setting in Kerr, Ark. Recorded responses to characterize resistance or susceptibility included: average galling, average height, SRKN juveniles (J2/100 cm^3), dry root weight (g), dry plant top weight (g), SRKN eggs/root (g) and reproductive factor. Additionally, 12 MG 4 and 10 MG 5 entries from the Arkansas Official Variety Trial were screened in a field in Kerr, Ark., and the University of Arkansas System Division of Agriculture's Nematode Diagnostic Lab (ANDL) in Hope, Ark., for galling versus reproduction responses. Data were subsequently analyzed to identify lines with possible resistance. Four lines (R14-1422, R18-14142, R13-13997, and R13-11034) were found to have possible resistance mechanisms. R14-1422, the only line to be categorized as very resistant in field settings, is to be used in the University of Arkansas System Division of Agriculture's Soybean Breeding Program's crossing block to develop multiple breeding populations with the potential for SRKN resistance. All entries that were screened in field and greenhouse settings, as well as 2 F_2 breeding populations, were tissue sampled to be tested for the presence of a molecular marker associated with tolerance to SRKN in late maturity groups in 2022.

Introduction

Southern root-knot nematode (*Meloidogyne incognita*, SRKN) can limit soybean yields by 10%, even with low population densities (Fourie et al., 2010). It has surpassed soybean cyst nematode as the primary pest nematode pressure in Arkansas (Kirkpatrick and Sullivan, 2015). Developing resistant cultivars is the most cost-effective and lowest input practice to control SRKN (Khanal et al., 2018). Despite the need for genetically resistant cultivars to minimize damages and losses resulting from SRKN, there are mechanisms of resistance and susceptibility that are not known (Mazzetti et al., 2019).

Procedures

A total of 12 MG 4, as well as 10 MG 5 entries from the University of Arkansas System Division of Agriculture's Official Variety Test (OVT), were screened for SRKN resistance in a field in Kerr, Ark., in 2021, as well as in a greenhouse at the University of Arkansas System Division of Agriculture's Nematode Diagnostics Lab (ANDL) in Hope, Ark. The nematode population density in the field setting spanned from moderate to severe, whereas eggs of *M. incognita* were used as an inoculum in the greenhouse test. Separate from the OVT, 15 MG 4 and 13 MG 5 advanced stage pre-commercial (PCM) lines were evaluated for resistance response to SRKN in a field setting in Kerr, Ark. All cultivars were grown in 3 replication trials. Evaluations in the field and greenhouse settings used the same parameters and procedures as the OVT screening.

Results and Discussion

In 2021, R14-1422 was categorized as very resistant (avg. gall rating = 1.0) in the field setting in Kerr, Ark. R13-13997 was categorized as resistant (avg. gall rating = 1.3) in the field setting in Kerr, Ark. Both of these lines do offer some promise in soybean breeding application based on their resistance to SRKN in the field tests. Field trials were conducted in a grower's field near Kerr, Ark. Field root gall ratings were a visual assessment of the percentage root system galled using an 0–100 scale (0–1.0 = VR, 1.1–4.0 = R, 4.1–9.0 = MR, 9.1–20.0 = MS, 20.1–40.0 = S, 40.1–100 = VS) at the R5 growth stage

In 2021, 44 PCM entries, as well as F_2 breeding populations 20CBPR-013 and 20CBPR-15, were tissue sampled.

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DNA was extracted in the fall of 2021 and will be tested for the presence of a marker previously associated with SRKN resistance in late MG 5 cultivars. Final marker analyses will be conducted in 2022 to further confirm phenotypic evaluations in the field and greenhouse.

An updated list of entries for the 2022 OVT and 2022 PCM tests that were advanced in 2021 will be screened under the greenhouse and field conditions as in the previous growing season. The identification of new lines and the confirmation of previous findings will aid in the development of elite cultivars that are adapted to Arkansas to provide SRKN-resistant lines to soybean producers in the state. Due to the strong field-resistant response to R14-1422, new breeding populations are set to be developed in the Soybean Breeding Program's 2022 crossing block. Products of the crosses will be sent to the winter nursery, where breeding populations will be advanced to the F_2 generation to fast-track the process of cultivar development.

There were 24, and 244 single plants pulled from F_4 breeding populations to be evaluated in 2022 progeny rows with R14-1422 and R13-13997 lines in their parentages, respectively. These progeny rows will be evaluated under normal field conditions (no nematodes) at the Vegetable Research Station in Alma, Ark. in the 2022 growing season; plants will be selected solely on visual appearance and screened for nematode tolerance if selected following subsequent yield evaluations. In the 2021 progeny rows test, there were 12 entries evaluated that had R14-1422 in the pedigree, of which 6 lines were selected based on physical appearance and agronomic criteria such as lodging resistance, plant architecture, and plant health. These entries were advanced to the 2022 preliminary multi-location yield trials. Additionally, there were 122 entries in the 2021 progeny rows test with R13-13997 in the pedigree, of which all 122 entries were advanced to the 2022 preliminary multi-location yield trials.

Practical Applications

Genetic resistance in soybean is the best form of protecting yield loss from parasitic nematodes. Lines with existing resistance remove the need for a chemical application, which increases production costs and has the potential to threaten human health and the environment (Xiang et al., 2018). Furthermore, there is limited availability of existing MG 4 and early MG 5 cultivars in the market that allow for the innate protection against yield reductions associated with SRKN pressures.

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Literature Cited

Fourie, H., A.H. Mc Donald, and D. De Waele. 2010. Relationships between initial population densities of *Meloidogyne incognita* race 2 and nematode population development in terms of variable soybean resistance. J. Nematol. 42(1):55.

Khanal, C., E.C. McGawley, C. Overstreet, and S.R. Stetina. 2018. The elusive search for reniform nematode resistance in cotton. Phytopath. 108(5):532-541.

Kirkpatrick, T., and K. Sullivan. 2015. Incidence, population density, and distribution of soybean nematodes in Arkansas. N: J. Ross (ed.). Arkansas Soybean Research Studies 2016. Arkansas Agricultural Experiment Station Research Series 648:47-49. Fayetteville.

Mazzetti, V. C. G., G.L. Visintin, I.P. Valério, J.N. Camera, C.C. Deuner, and P.L.M. Soares. 2019. Reaction of soybean cultivars to *Meloidogyne javanica* and *Meloidogyne incognita*. Revista Ceres. 66:220-225.

Xiang, N., K.S. Lawrence, and P.A. Donald. 2018. Biological control potential of plant growth□promoting rhizobacteria suppression of *Meloidogyne incognita* on cotton and *Heterodera glycines* on soybean: A review. J. Phytopath. 166(7-8):449-458.

BREEDING

Soybean Germplasm Enhancement Using Genetic Diversity

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Abstract

The University of Arkansas System Division of Agriculture's Soybean Breeding Program continuously collects exotic germplasm to build a diverse pool with excellent genes and traits for soybean breeding and genetic research. These diverse genetic traits are being introduced into Arkansas cultivars and breeding lines using classic and molecular breeding selection schemes to enhance the genetic diversity of Arkansas germplasm. Important traits such as yield, maturity group (MG) 4, and disease resistance from diverse genetic sources are used to improve Arkansas breeding lines and develop and release elite varieties and germplasm. In 2021, 8 pre-commercial lines, R18-13333, R18C-1450, R18-14142, R18-14147, R18-5783, R15-7063, R18-4614, and R13-11034, developed utilizing diverse, exotic germplasm, were evaluated for yield in multiple regional trials. Two lines, R18-13333 and R18-14147, were selected for further yield evaluation and other agronomic traits in a 2022 regional trial and advanced Arkansas yield trials for potential cultivar and germplasm releases. Additionally, 32 advanced, and 258 preliminary lines with exotic high-yielding, early maturity (MG 4), and disease resistance pedigrees were evaluated for yield in multiple Arkansas locations. Furthermore, 25 MG 5 lines derived from exotic pedigrees were visually selected and hand-harvested from 393 progeny lines. Multiple breeding populations were developed from new crosses between Arkansas elite varieties/lines and diverse exotic germplasm in the summer of 2021. All these breeding efforts effectively enhance the genetic diversity of Arkansas germplasm and support varietal development.

Introduction

During the long-term domestication and breeding activities, several diverse traits in the soybean germplasm were lost, resulting in a very narrow genetic pool. Gizlice et al. (1994) reported that only 26 ancestors accounted for 90% of the total ancestry of commercial soybean cultivars in the United States. The widely grown cultivars have lower nutritional values with less protein and oil content and are sensitive to multiple diseases and abiotic stresses with lower growth adaptation in diverse environments. Therefore, it is imperative to use diverse exotic germplasm to improve and develop soybean cultivars and germplasm with elite traits and genes (Carter et al., 1993; Gizlice et al., 1994). A germplasm exchange system was created among public United States (U.S.) soybean breeding programs to facilitate exotic germplasm exchange. Additionally, the U.S. National Plant Germplasm System has collected and provided exotic soybean accessions to breeders. These active systems efficiently facilitate access to diverse germplasm for cultivar development and improvement.

The soybean breeding program at the University of Arkansas System Division of Agriculture focuses on using exotic germplasm to enhance the genetic diversity of Arkansas soybean, especially for key traits such as high yield, early maturity (MG 4), disease resistance, and wide environmental adaptation. Historically, several lines with exotic germplasm and traits of interest are used as donors in the crossing block of the soybean breeding program. As a result of these efforts, nine elite germplasms (R01-416F, R01-581F, R99-1613F, R01-2731F, R01-3474F, R10-5086, R11-6870, R10-2436, and R10-2710) have been developed and released to public breeders for line enhancement (Chen et al., 2007 and 2011; Manjarrez-Sandoval et al., 2018 and 2020).

The soybean germplasm enhancement project using genetic diversity effectively supports our soybean breeding activities. It enhances Arkansas soybean germplasm genetic diversity by continuously introducing novel exotic genetic materials. Herein, we report the efforts and accomplishments made in 2021.

Procedures

Arkansas varieties and elite lines were crossed to diverse germplasm and breeding lines with exotic genes in 2021. Over 40 crossing combinations were made, and F_1 seeds were harvested and sent to a winter nursery for F_1 generation advancement. Additional breeding populations from F_2 to F_4 generations were advanced at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark, using the modified single-pod descent method (Fehr, 1987). Furthermore, individual plants from F_2 to F_4 breeding populations

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were selected, harvested, and threshed to grow single-short progeny rows. The best-performing lines were visually selected based on yield, early maturity, plant height, growth habit, plant uniformity, and overall plant and seed quality. Selected progeny rows were hand-harvested and will be evaluated in the 2022 preliminary yield trials. Lines in preliminary, intermediate, and advanced testing were grown in multiple Arkansas locations and other southern states in 2021.

Results and Discussion

Yield Improvement Using Genetic Diversity

In 2021, 4 MG 4 (R18-13333, R18C-1450, R18-14142, and R18-14147) and 4 MG 5 (R18-5783, R15-7063, R18-4614, and R13-11034) advanced lines with exotic pedigrees were evaluated in the 2021 USDA Southern Uniform Tests and the United Soybean Board Diversity Test (USB-DIV), as well as in the 2021 Arkansas Official Variety Test (OVT) and the 2021 pre-commercial (PCM) yield trials. As a result, R18-13333 and R18-14147 were selected for further yield testing in the 2022 regional and Arkansas yield trials. In addition, 14 MG 4 and 6 MG 5 advanced lines derived from diverse exotic pedigrees were evaluated for yield performance in multiple Arkansas locations. Of those, 4 high-yielding MG 4 lines, R18C-144, R18-5798, R19-35367, R19-39444, and 1 MG 5 line, R18-13309, were selected for advancement in 2022. Twelve lines (9 MG 4 and 3 MG 5) with exotic pedigrees were tested for yield and agronomic traits in intermediate tests, and 5 (3 MG 4 and 2 MG 5) were selected for evaluation in our advanced test in 2022. Moreover, 258 preliminary lines with diverse exotic pedigrees were tested in multiple yield trials (Table 1). Sixty-three lines (50 MG 3, four MG 4, and nine MG 5) with good yield performance were selected for 2022 intermediate yield trials. Twenty-five of the 393 MG 5 progeny lines grown in 2021 were visually selected and hand-harvested and will be tested for yield in 2022 preliminary trials. A total of 143 single plants were selected and harvested from multiple breeding populations with exotic genes for the 2022 single-row progeny row. In addition, a total of 32 breeding populations with exotic pedigrees were selected and harvested for further advancement purposes in the winter nursery in Chile and in Arkansas. We also made 17 new cross combinations between high-yielding and exotic parents for this project in the summer of 2021.

Disease Resistance

In 2021, 14 MG 4 and 3 MG 5 advanced lines derived from exotic high-yielding and disease-resistant parents such as soybean cyst nematode (SCN), sudden death syndrome (SDS), and soybean rust (SBR) were evaluated for yield in 5 Arkansas locations. Five high-yielding lines (R18C-11737, R18C-11151, R18C-13665, R18C-11127, and R18C-11272) were selected for further yield evaluation in multiple 2022 regional trials (USDA Southern Uniform and the United Soybean Board Diversity Test)) and Arkansas local yield tests (OVT and PCM). Five MG 4 lines with exotic SDS and SCN resistance genes were tested in 2 intermediate yield trials in 5 Arkansas locations. Unfortunately, no line showed high-yielding performance; therefore, no advancements were made for 2022. Twenty-one (16 MG 4 and 5 MG 5) lines with SDS-resistant pedigrees were selected from progeny rows and will be evaluated for yield in 2022 preliminary tests in 3 Arkansas locations. Eight F_1 and 5 F_2 breeding populations derived from exotic parents with disease resistance were grown for advancement purposes in Fayetteville. These populations were harvested as bulk or modified-pod pick. In addition, 19 new crosses were made between high-yielding parents and soybean root-knot nematode-resistant parents in the summer of 2021.

Practical Applications

The University of Arkansas System Division of Agriculture's Soybean Breeding Program makes continuous progress in developing value-added germplasm with diverse genetic traits through exchanging exotic germplasm among the U.S. public breeding community. The program also provides available germplasm and lines with diverse traits to other public soybean breeding programs for variety development purposes. All efforts supported by this project integrate and stack diverse, necessary genes and traits into elite Arkansas breeding lines and germplasm for parental stock and potential release.

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Literature Cited

Carter, T.E., Jr, Z. Gizlice, and J.W. Burton. 1993. Coefficient-of-parentage and genetic similarity estimates for 258 North American public cultivars released by public agencies during 1945-1988. U.S. Dep. of Agric. Tech. Bull. Num. 1814, U.S. Gov. Print. Office, Washington, DC.

Chen P., C.H. Sneller, L.C. Purcell, T.R. Sinclair, C.A. King, and T. Ishibashi. 2007. Registration of soybean germplasm lines R01-416F and R01-581F for improved yield and nitrogen fixation under drought stress. J. Plant Regist. 1:166-167.

Chen P., T. Ishibashi, J.C. Rupe, D.G. Dombek, and R.T. Robbins. 2011. Registration of R99-1613F, R01-2731F, and R01-3474F soybean germplasm lines with diverse pedigrees. J. Plant Regist. 5:220-226.

Fehr, W.R. 1987. Principles of cultivar development. Vol 1. Theory and technique. Iowa State Univ. Press, Ames, Iowa.

Gizlice Z., T.E. Carter Jr., and J.W. Burton. 1994. Genetic base for North American public soybean cultivars released between 1947 and 1988. Crop Sci. 34:1143-1151.

Manjarrez-Sandoval P., P. Chen, L. Florez-Palacios, M. Orazaly, C. Wu, R. Nelson, and T. Carter Jr. 2018. Registration of R10-5086 and R11-6870 soybean germplasm lines with exotic pedigree. J. Plant Regist. 12:118-123.

Manjarrez-Sandoval P., L. Mozzoni, P. Chen, L. Florez-Palacios, M. Orazaly, C. Wu, T.R. Sinclair, T.E. Carter, L.C. Purcell, and C. Andy King. 2020. Registration of the soybean germplasm lines R10-2436 and R10-2710 with drought tolerance traits and high yield under moderate water stress. J. Plant Regist. 14:1-8.

Table 1. Germplasm enhancement project overview in 2021.

Test	"Multi-state" stage	"Advanced" stage	"Preliminary" stage
	-------------------------number of entries------------------------------		
High Yielding	8	32	258
Early Maturity (MG4)	4	23	215
Disease Resistance	0	18	17

PEST MANAGEMENT: DISEASE CONTROL

Reproduction of the Southern Root-Knot Nematode on Fall-Volunteer Corn in Central Arkansas

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Abstract

Fall-volunteer corn (*Zea mays* L.) results from grain passing through the combine, germinating, and maturing to at least a vegetative growth stage until killed by freezing temperatures or tillage. Although corn is susceptible to the southern root-knot nematode, *Meloidogyne incognita*, the impact of fall-volunteer corn on nematode density is lacking. Nematode density and reproduction were assessed in 2021 on fall-volunteer corn in a field with a history of the southern root-knot nematode. Second-stage juveniles extracted from soil samples decreased by 43.8% at 45 days after harvest, which was expected as the survival of second-stage juveniles in the absence of a host is short, or they infect a suitable host. Nematode reproduction (87 eggs/plant) was observed at the V5 growth stage or 45 days after harvest. These data indicate the reproduction potential of at least one life cycle of the southern root-knot nematode on fall-volunteer corn in central Arkansas.

Introduction

The southern root-knot nematode (SRKN) [*Meloidogyne incognita* (Kofoid and White) Chitwood] is among the most important plant-pathogenic nematodes that affect soybean [*Glycine max* (L). Merr.] 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). The average yield loss estimates due to the southern root-knot nematode in 2021 were 4.0% or 6.7 million bushels of grain in Arkansas and 1.1% or 17.1 million bushels across the southern U.S. (Allen et al., 2022).

Management of the SRKN 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. These crops can sustain and potentially increase the population of SRKN, which can have a greater impact on grain yield losses for the subsequent soybean crop. During harvest, some corn grain passes through the combine and spreads across the field. These seeds germinate, and fall-volunteer corn is established and can grow for several weeks until they are killed by freezing temperatures or tillage. During the 2021 cropping season, fall-volunteer corn was observed and ranged in growth stages from V1 to V10 across the mid-South. However, the potential impact of fall-volunteer corn on extending the potential reproduction of the SRKN is lacking. Therefore, the objective of this study was to assess the reproduction of the southern root-knot nematode on fall-volunteer corn in Arkansas.

Procedures

The population density and reproduction of the SRKN were monitored on fall-volunteer corn in a field with a history of SRKN near Kerr, Ark. The soil texture analysis resulted in sandy loam (58% sand, 40% silt, 2% clay, and <1% OM). Corn was harvested on 29 Aug. with a commercial harvester, and the field was disked within 7 days after harvest (DAH), except for one strip. Hereafter referred to as no-tillage vs. tilled strips in the field. Soil samples were collected at 4 points across the field in the tilled and no-tillage strips. More volunteer corn was observed in the tilled than in the no-tillage strips. At each sample point, soil samples were collected in the furrow or adjacent bed; the majority of the volunteer corn was in the furrow. Soil samples were collected at 15, 45, and 60 DAH. Soil samples were a composite of a minimum of 8 soil cores taken 6- to 8-in. deep with a 0.75-in. diameter soil probe. Nematodes were collected with a modified Baermann funnel system and enumerated using a stereoscope. Ten roots were arbitrarily sampled from each of the 8 sites at 30 and 45 DAH to determine nematode reproduction. Eggs were extracted from each root system with 1% NaOCl and enumerated with a stereoscope. Freezing temperatures killed the fall-volunteer corn 45 days after harvest (the first week in Nov.), which terminated the experiment.

Data were analyzed using a general linear mixed model analysis of variance with sample time, tillage, and sample location as fixed variables and sample sites as a random variables using IBM SPSS 27.0 (International Business Machines Corp., Armonk, N.Y.). Means, when appropriate, were separated according to Tukey's honestly significant difference (HSD) test at $\alpha = 0.05$.

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Results and Discussion

There was no ($P > 0.05$) interaction for any combination of the fixed variables: sample time, tillage, or sample location (furrow or bed). Fewer ($P \leq 0.05$) SRKN were recovered from soil samples at each sample time (15, 45, and 60 DAH) compared to the previous sample time (Table 1). This was expected because the SRKN second-stage juveniles are relatively short-lived in soil, and those that infect a host (i.e., fall-volunteer corn) would not be detected. Typically, 80% to 90% of the SRKN population dies each year during the winter months, and the lowest population density is detected in the early spring.

Tillage had no ($P > 0.05$) impact on nematode densities, with an average of 381 and 149 J2/100 cm^3 soil across sample times in the no-tilled and tilled strips, respectively. There was, however, a difference in nematode densities based on sample location as more ($P \leq 0.05$) SRKN were recovered from soil sampled in the bed (387 J2/100 cm^3 soil) than the furrow (221 J2/100 cm^3 soil) across sample times. Greater densities of SRKN in the bed may be due to greater root density than that in the furrow, but root density was not sampled in this study.

Eggs from the SRKN were not recovered from the volunteer corn roots until the V5 growth stage (45 DAH). On average, 87 eggs/plant were recovered, which was greater ($P > 0.05$) than that detected at V3 (30 DAH, Table 1). Although the volunteer corn crop in this study died from freezing temperatures, 1 generation of the SRKN life cycle was observed. Volunteer corn that continues to grow longer than 30 DAH or V3 has the potential to increase SRKN densities when conditions favor infection (soil temperature > 65 °F) and reproduction (soil temperature > 50 °F). Soil temperatures remained above 50 °F in the field until the first week in November, when freezing temperatures killed the fall-volunteer corn. These data indicate SRKN can complete 1 life cycle on a suitable host, volunteer corn, or susceptible cover crop in the fall in central Arkansas. Management of fall-volunteer corn prior to V5 may be beneficial in reducing nematode densities for the subsequent susceptible soybean crop.

Practical Applications

Volunteer corn in the fall is a suitable host for SRKN. The longer fall-volunteer corn grows, the greater the potential for nematode reproduction and impact on the subsequent soybean crop.

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Literature Cited

Allen, T.W., K. Bissonnette, C.A. Bradley, N.S. Dufault, T.R. Faske, T. Isakeit, R.C. Kemerait, A. Koehler, D. Langston, J. Lofton, J.D. Mueller, G.B. Padgett, P.P. Price, E.J. Sikora, I.M. Small, R. Vann, and H. Kelly. 2022. Southern United States disease loss estimates for 2021. in: Proceedings of the Southern Soybean Disease Workers; 49th Annual Meeting, Pensacola Beach, Fla. Pp. 1-11.

Emerson, M., K. Brown, T.R. Faske, and T.L. Kirkpatrick. 2018. Field performance of several glyphosate-resistant maturity group 4 and 5 soybean cultivars in a root-knot nematode infested field. in: J. Ross (ed.) Soybean Research Studies 2016. University of Arkansas System Division of Agriculture Agricultural Experiment Station Research Series 648: 40-42. Fayetteville.

Kirkpatrick, T.L., and K. Sullivan. 2018. Incidence, population density, and distribution of soybean nematodes in Arkansas. in: J. Ross (ed.) Soybean Research Studies 2016. University of Arkansas System Division of Agriculture Agricultural Experiment Station Research Series 648:47-49. Fayetteville.

Table 1. Population densities of southern root-knot nematode in soil and on roots of fall-volunteer corn.

Days after harvest	Growth stage[†]	Southern root-knot nematode[‡]	
		J2/100 cm^3 soil	Eggs/plant
15	V1	556 c[§]	---
30	V3	---	0 a
45	V5	312 b	87 b
60	---	44 a	---

[†] Vegetative growth stages correspond to the number of leaf collars visible.

[‡] J2 = Second-stage juveniles. "---" indicates no sample collected.

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

On-Farm Soybean Fungicide Trial Summary, 2021

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Abstract

Ten large block foliar fungicide trials were established in soybean (*Glycine max* L. Merr.) fields in 8 Arkansas counties in 2021. The objectives of this work were to determine the efficacy of fungicides applied and yield impacts associated with different foliar diseases. 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*), and aerial blight (*Rhizoctonia solani*) were determined at each location. Fields maturing later in the season tended to have more severe disease. All fungicides applied provided good control of foliar diseases and protected yield where these diseases were most severe. Where disease levels were low, fungicides did not add value to the crop above the application cost. This tended to occur in fields maturing earlier in the season.

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 for a large portion of these varieties 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

Ten large block foliar fungicide trials, ranging in size from 15–55 acres, were established in soybean fields in 8 Arkansas counties in 2021. Treatments present in each trial were Miravis Top® (serving as the fungicide standard), which contains the active ingredients pydiflumetofen (a succinate dehydrogenase inhibitor, SDHI) and difenoconazole (a demethylation inhibitor, DMI or triazole) (The Syngenta Group, Basel, Switzerland), applied at 13.7 fluid ounces per acre and a nontreated control. Other fungicide treatments applied at each location are listed in Table 1. 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, and in a total water volume of 10 gal/ac at 40 psi using TeeJet XR11002VS tips (Spraying Systems Co, Glendale Heights, Ill.) at 5.0 mph. Five points were marked by GPS approximately equidistant throughout each block, and disease levels were determined in a 1.5-meter radius around each point at fungicide application and again at R6 on a 0–9 scale. 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 (Micasense, Seattle, Wash.) 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 either yield monitor data were recorded, or a weigh wagon was used to determine yields within each plot. Yields from the monitors were adjusted to 13% moisture by volume, buffered by application blocks and the field boundaries, and outliers removed using the interquartile range method prior to analysis. Data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Tukey's honestly significant difference test at $P = 0.05$. All analyses and reports for each trial location were completed in an automated model in ArcGIS Pro 2.4 (ESRI, Redlands, Calif.) using standard tools and custom script tools (developed using Python 3.6.8 or R 4.0.2). Weather and soil data and high-resolution field images were included in the reports distributed to each cooperating farmer and county agent.

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Results and Discussion

In all, 5 different fungal diseases were rated across the trial locations. Septoria brown spot, caused by *Septoria glycines*, was rated at 2 locations; aerial blight, caused by *Rhizoctonia solani* AG 1-IA, was rated at 2 locations; frogeye leaf spot, caused by *Cercospora sojina*, was rated at 5 locations; target spot, caused by *Corynespora cassiicola*, was rated at 6 locations; and Cercospora leaf blight, likely caused by *Cercospora flagellaris*, was rated at 3 locations. Yields were available for 9 of the 10 trials. Average yields for the trials ranged from 44.5 bushels per acre (bu./ac) to 98.9 bu./ac (Table 2). Of the 4 trials where soybeans were R3 in late June/early July, one had a significant yield response by fungicide treatment where brown spot was severe (Fig. 2).

Of the 6 trials where soybeans were R3 in late July through August, 4 had a significant yield response by fungicide treatment where foliar diseases were moderate to severe. Yield data were not available for one trial in this group. These results point to the value of on-farm trials at various production areas to determine product efficacy and yield impact of several different foliar diseases. Additionally, these results suggest foliar disease pressure is likely to increase in soybean fields, progressing through the reproductive stages later in the normal growing season.

Practical Applications

Since 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 (assuming an application cost of $21/acre) more often than in those moving through reproductive stages earlier in the year. Therefore, 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 soybean may have a higher likelihood of increased foliar disease pressure because it will mature more slowly. Therefore, as a rule, one should consider using 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.

Acknowledgments

The authors appreciate the cooperating farmers for granting space for these studies on their farms and the support provided by Arkansas soybean producers through checkoff 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, Amy Carroll–Prairie County, Jan Yingling–White County, Kevin Norton–Ashley County, and Courtney Sisk–Lawrence County.

Literature Cited

Faske, T., T. Kirkpatrick, J. Zhou, and I. Tzanetakis. 2014. Chapter 11: Soybean Diseases in Arkansas Soybean Production Handbook. Accessed 18 April 2022. Available at: https://www.uaex.uada.edu/publications/pdf/mp197/chapter11.pdf

Ross, J. 2017. Soybean production in Arkansas. Accessed: 18 April 2022. Available at: https://www.uaex.uada.edu/farm-ranch/crops-commercial-horticulture/soybean/

Ross, J., C. Elkins, and C. Norton. 2021. Arkansas Soybean Quick Facts. Accessed: 18 April 2022. Available at: https://www.uaex.uada.edu/farm-ranch/crops-commercial-horticulture/soybean/2021%20Arkansas%20Soybean%20Quick%20Facts_%20Final.pdf

Table 1. Fungicide trial location and products applied, 2021.

Trial	Approximate location[a]	Products applied	Rate applied (fl oz/ac)
Lincoln	-91.888, 34.078	Miravis Top® 1.62 SC	13.7
		Revytek® 3.33 SC	7
Arkansas A	-91.403, 34.389	Miravis Top 1.62 SC	13.7
		Revytek 3.33 SC	7
Jefferson	-91.724, 34.233	Miravis Top 1.62 SC	13.7
		Revytek 3.33 SC	7
		Aproach Prima® 2.34 SC	6.8
Chicot	-91.365, 33.139	Miravis Top 1.62 SC	13.7
		Revytek 3.33 SC	7
		Priaxor® 4.17 SC + Tilt 41.8 EC	4+4
Lawrence	-91.018, 36.042	Miravis Top 1.62 SC	13.7
		Revytek 3.33 SC	7
White	-91.646, 35.153	Miravis Top 1.62 SC	13.7
		Revytek 3.33 SC	7
Arkansas B	-91.498, 34.542	Miravis Top 1.62 SC	13.7
		Revytek 3.33 SC	7
		Aproach Prima 2.34 SC	6.8
Prairie	-91.541, 34.977	Miravis Top 1.62 SC	13.7
		Revytek 3.33 SC	7
Ashley	-91.686, 33.281	Miravis Top 1.62 SC	13.7
		Trivapro® 2.21 SE	13.7
Arkansas C	-91.520, 34.373	Miravis Top 1.62 SC	13.7
		Trivapro 2.21 SE	13.7

[a] **Longitude, latitude in geographic coordinate system 'WGS 1984**.'

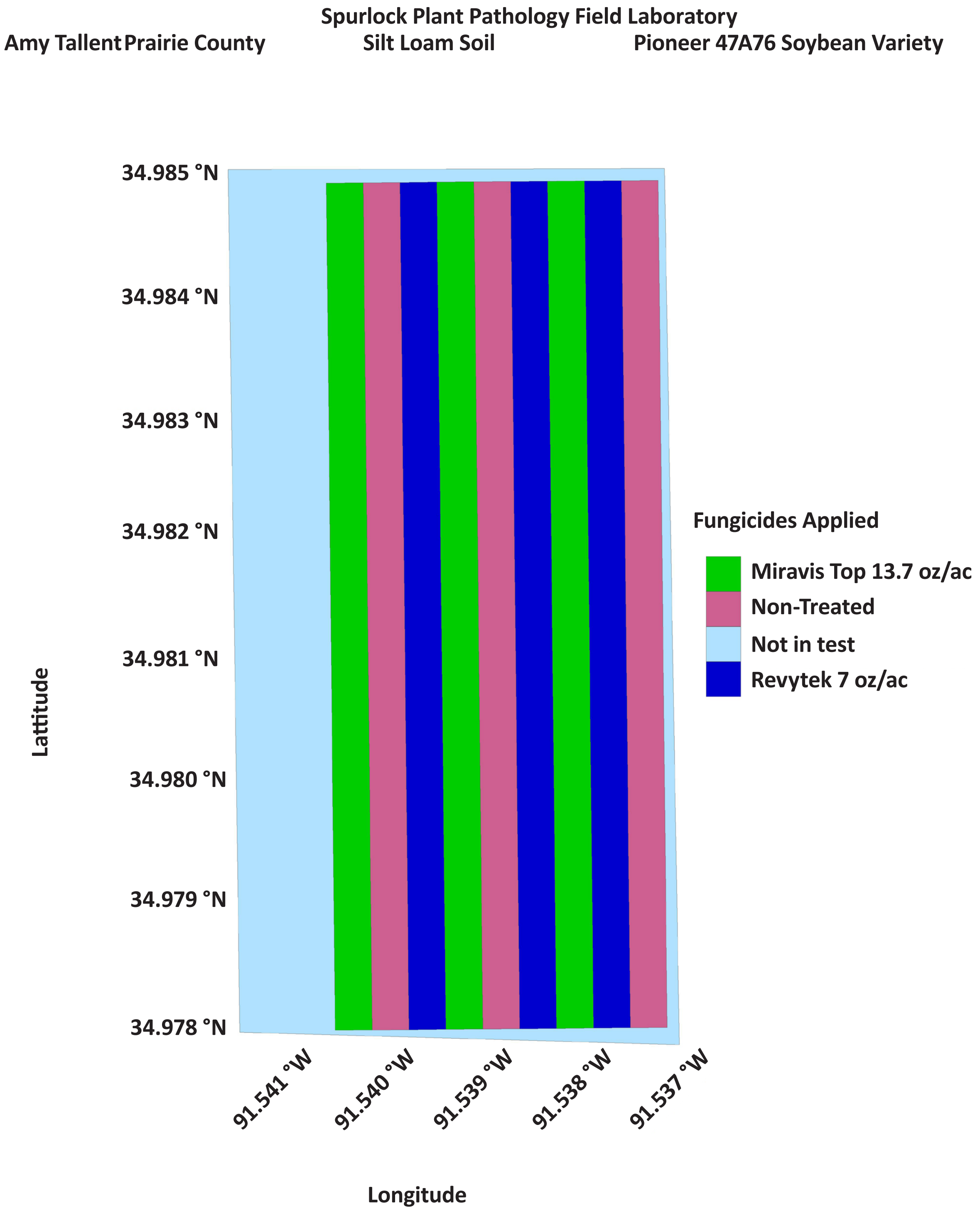

Fig. 1. An example of a randomized complete block field plot design from the trial at Prairie County, 2021.

Table 2. Summary of fungicide trial results, 2021.

Trial	Application date (Growth stage)	Diseases rated	Disease levels	Treatment response	Average yield
					(bu./ac)
Lincoln	June 29 (R3)	No foliar diseases rated	low	*NS*[a]	51.0[b]
Arkansas A	June 30 (R3)	Septoria brown spot/Aerial blight[c]	high/ moderate	***/***	75.7***
Jefferson	July 8 (R3)	Frogeye leaf spot/ Cercospora leaf blight/ Target spot	low/low/ low	*NS*/***/ **	98.9
Chicot	July 9 (R3)	Frogeye leaf spot/ Cercospora leaf blight	low/low	*NS*/*NS*	64.1
Lawrence	July 26 (R3)	Target spot	low	*NS*	79.3
White	July 27 (R3)	Frogeye leaf spot/ Target spot	moderate/ low	***/*NS*	56.6***
Arkansas B	July 29 (R3)	Target spot/ Cercospora leaf blight	moderate/ low	***/*NS*	72.2***
Prairie	August 5 (R3)	Septoria brown spot/ Target spot	moderate/ moderate	***/***	44.5***
Ashley	August 12 (R3)	Frogeye leaf spot/ Target spot	high/ moderate	*/*NS*	Yield data not recorded
Arkansas C	August 16 (R3)	Frogeye leaf spot/ Aerial blight	high/high	***/***	44.7***

[a] 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.

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

[c] Septoria brown spot (*Septoria glycines*); Aerial blight (*Rhizoctonia solani*); Frogeye leaf spot (*Cercospora sojina*); Cercospora leaf blight (*Cercospora flagellaris*); Target spot (*Corynespora cassiicola*).

Fig. 2. Severe Septoria brown spot from the nontreated control in trial Arkansas County A, 2021.

Determining the Impact of Disease and Stinkbug Feeding on Selected Soybean Varieties, 2020–2021

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

Abstract

Trials were established in 2020–2021 to determine the impact of variety on grain disease. When analyzed across maturity groups, trends emerged in the occurrence of purple seed stain (*Cercospora spp*.) and Phomopsis seed decay (*Phomopsis longicolla*) that indicated the environment after maturity and until harvest influenced overall seed quality. Additionally, stink bug (*Pentatomidae spp*.) feeding did not appear to result in a greater occurrence of either of these diseases in either year.

Introduction

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 et al., 2017). Multiple stink bug species (*Pentatomidae*) are commonly observed in Arkansas soybean [*Glycine max* (L.) Merr.] production, where both adults and nymphs feed on soybean pods and grain. These insects feeding on pre-mature grain can cause yield loss by initiating pod and 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 et al., 2000) The wounds created by actively feeding stink bugs can also create opportunities for pathogens to colonize and reproduce. Common soybean fungal diseases impacting seed 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 (Fig. 1). This disease has not been associated with yield loss but can cause significant reductions 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 (Fig. 2), altering seed viability and oil composition (Li et al., 2010). The objectives of this work were to determine seed quality by variety and maturity group and determine if stink bug feeding influenced seed quality reduction by common fungal pathogens already known to impact it (i.e., *Cercospora* and *Phomopsis*).

Procedures

Variety trials were established at the University of Arkansas System Division of Agriculture's Rohwer Research Station near Rohwer, Ark., on 2 June 2020 and 23 June 2021. Plots for both trials were 2-rows wide and 10-ft long on 38-in. row spacings. Trials were planted at 150,000 seed/ac and 125,000 seed/ac for 2020 and 2021, respectively. Grain samples from 2020 plots were collected from the combine weigh system. Plots were harvested on 3 Nov 2020 with a plot combine using an onboard weighing system. In 2021, 2 plants per plot were hand-harvested at maturity. Samples were transported to the laboratory and stored under ambient conditions until assessments could be made. In both years, grain samples were placed into a standard 100 × 15 mm Petri dish filling the dish with as many grains as possible, one layer deep. Grain was observed for PSD, PSS, and stink bug damage (SBD) by percentage estimate in 2020 or by counting the seed exhibiting damage from these pests, dividing that number by the total number of seeds observed and expressed as a percentage in 2021. Overall seed quality (SDQ) was likewise calculated as the percentage of grain per sample without noticeable defects. All data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Tukey's honestly significant difference at $P = 0.05$. Grain quality was determined on 516 plots (172 varieties replicated 3 times) in 2020, with 66 in maturity group (MG) 3.9–4.4, 24 in MG 4.5, 96 in MG 4.6, 48 in MG 4.7, 96 in MG 4.8, 81 in MG 4.9, 81 in MG 5.0–5.3, and 24 in MG 5.4–6.0. In 2021, grain quality was determined for 453 plots (151 varieties replicated 3 times) with 54 in MG 3.9–4.4, 54 in MG 4.5, 81 in MG 4.6, 33 in MG 4.7, 102 in MG 4.8, 48 in MG 4.9, 57 in MG 5.0–5.3, and 24 in MG 5.4–6.0.

Results and Discussion

Comparing the results of PSD, PSS, SBD, and SDQ across all varieties of each MG for 2020 and 2021, different trends emerge when analyzed by MG over the 2 years. In 2020, PSD was higher in all MGs and greater in the earlier-maturing varieties (Fig. 3). A similar trend occurred for PSS.

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However, in 2021, there was greater PSS in the later-maturing groups (Fig. 4). In 2020, SBD was low and only slightly different across maturity groups. Stink bug damage was much higher in 2021, and tended to be higher in the later maturing varieties (Fig. 5). Seed quality across all MGs was poor when compared to 2021, with no real trends emerging in the dataset (Fig. 6). It is unclear why the SDQ did not match the PSD and PSS trends in either year, especially 2020, but may be indicative of other microorganisms impacting seed quality outside of those mentioned in this work.

Rainfall was greater than the 30-year average in both years, with 9.8 in. above in 2020 and 5.8 in. above in 2021 for the crop season. In 2020, rainfall received was 7.5 in. greater than the year after. From the last rating through harvest, 2020 had 6.8 inches greater rainfall, lower temperatures, and greater relative humidity percentages than 2021.

Practical Applications

The data collected from the 2020–2021 seed quality trials show that stink bug damage did not correlate with grain disease, nor does the data indicate that one MG consistently has greater SDQ over another. Differences in weather relative to maturity likely contributed to the variance in the data between the 2 years and explained why in 2020, the early maturing varieties had a lesser percent SDQ than the later maturing varieties and overall lesser than in 2021. In 2020, there was significantly more rainfall and cooler temperatures than in 2021 from R6 to harvest time. Additionally, all MG were harvested at the same time in both years, allowing the early maturing varieties to sit in the field after reaching maturity (R8) longer than the later maturing varieties.

Acknowledgments

The authors appreciate the support provided by Arkansas soybean producers through checkoff funds administered by the Arkansas Soybean Promotion Board. Support was also provided by the University of Arkansas System Division of Agriculture.

Literature Cited

Alloatti, J., S. Li, P. Chen, L. Jaureguy, S.F. Smith, L. Florez-Palacios, M. Orazaly, and J. Rupe. 2015. Screening a diverse soybean germplasm collection for reaction to purple seed stain caused by *Cercospora kikuchii*. Plant Dis. 99:1140-1146.

Li, S., G.L.Hartman, and D.L. Boykin. 2010. Aggressiveness of *Phomopsis longicolla* and other *Phomopsis spp*. on soybean. Plant Dis. 94:1035-1040.

Lorenz, G., D. Johnson, G. Studebaker, C. Allen, and S. Young III. 2000. Chapter 12: Insect Pest Management in Soybeans. In: Arkansas Soybean Handbook. University of Arkansas System Division of Agriculture Cooperative Extension Service. p.6.

Ross, J. 2017. Soybean production in Arkansas. Accessed: 15 April 2021. Available at: https://www.uaex.uada.edu/farm-ranch/crops-commercial-horticulture/soybean/

Rupe, J.C. and R.L. Luttrell. 2008. "Effect of Pests and Diseases on Soybean Quality." In SOYBEANS: Chemistry, Production, Processing, and Utilization Edited by L.A. Johnson, P.J. White, and R. Galloway, American Oil Chemists Society.

Fig. 1. Soybean seed exhibiting purple seed stain.

Fig. 2. Soybean seed exhibiting Phomopsis seed decay.

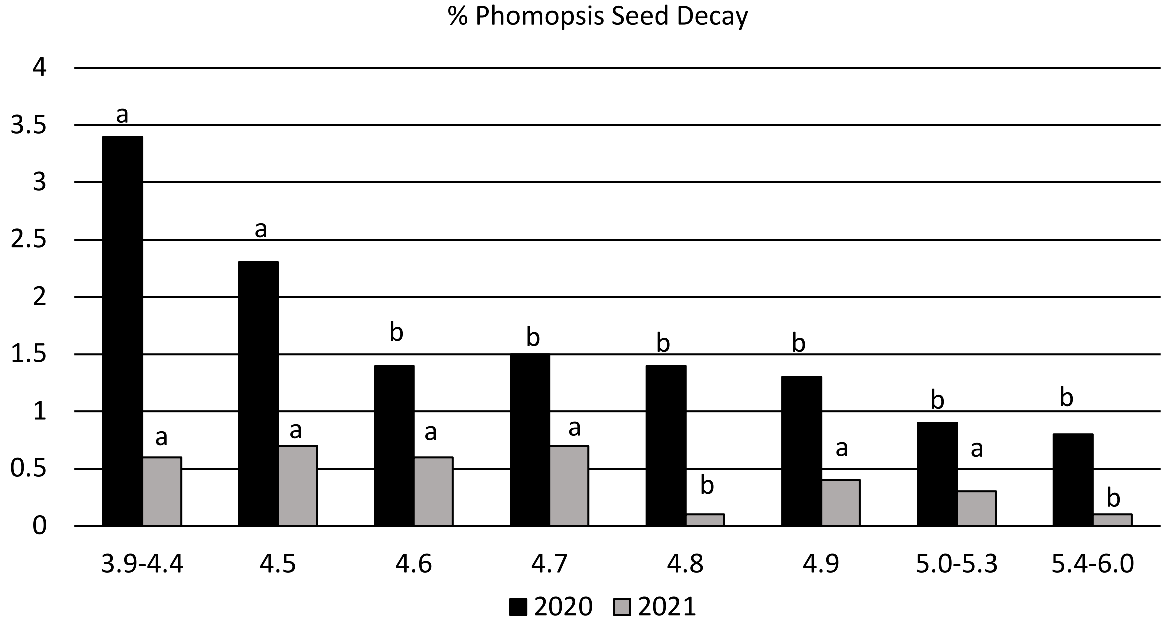

Fig. 3. Percent Phomopsis seed decay by maturity group from a variety trial at Rohwer, Ark., 2020–2021. Years were analyzed separately. Means that have the same letter are not different using Tukey's honestly significant difference at *P* = 0.05.

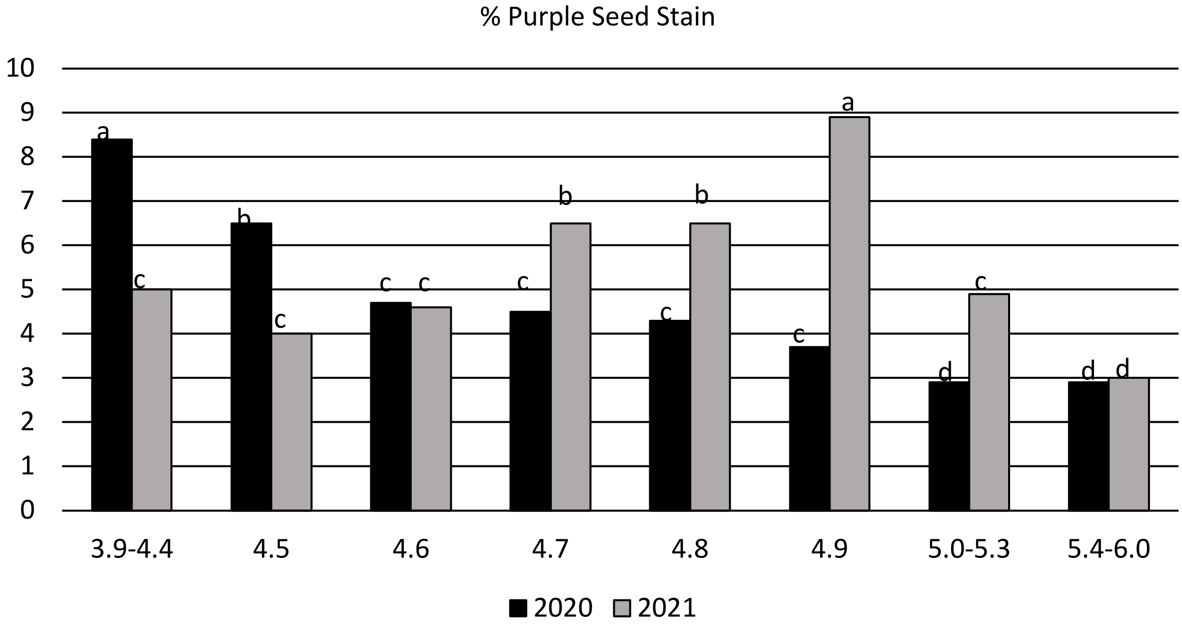

Fig. 4. Percent purple seed stain by maturity group from a variety trial at Rohwer, Ark., 2020–2021. Years were analyzed separately. Means that have the same letter are not different using Tukey's honestly significant difference at *P* = 0.05.

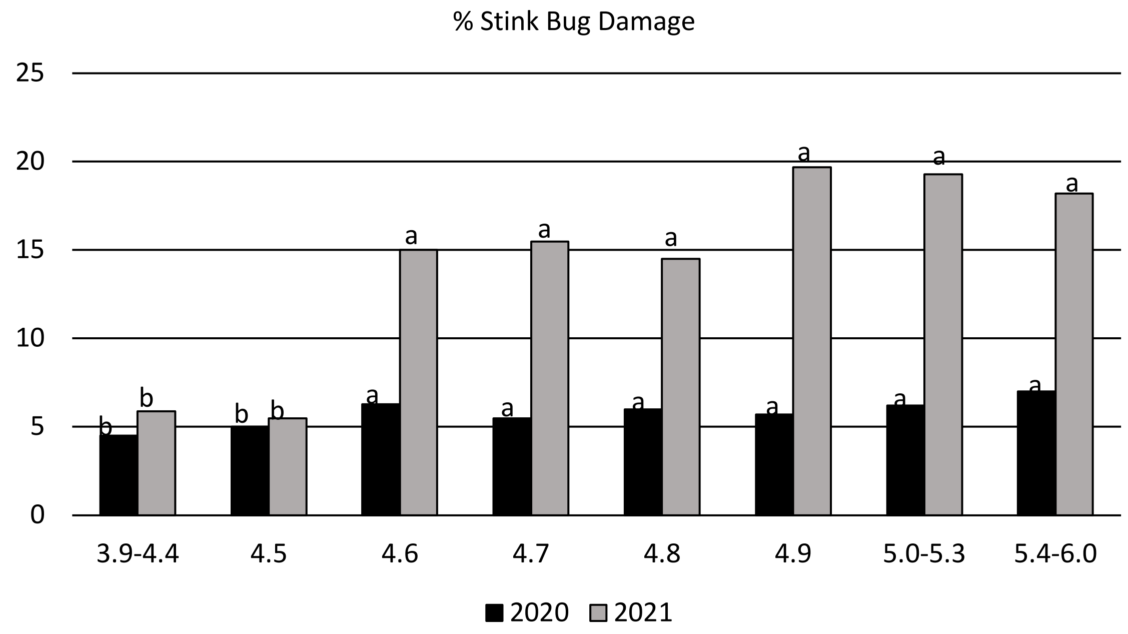

Fig. 5. Percent stink bug damage by maturity group from a variety trial at Rohwer, Ark., 2020–2021. Years were analyzed separately. Means that have the same letter are not different using Tukey's honestly significant difference at *P* = 0.05.

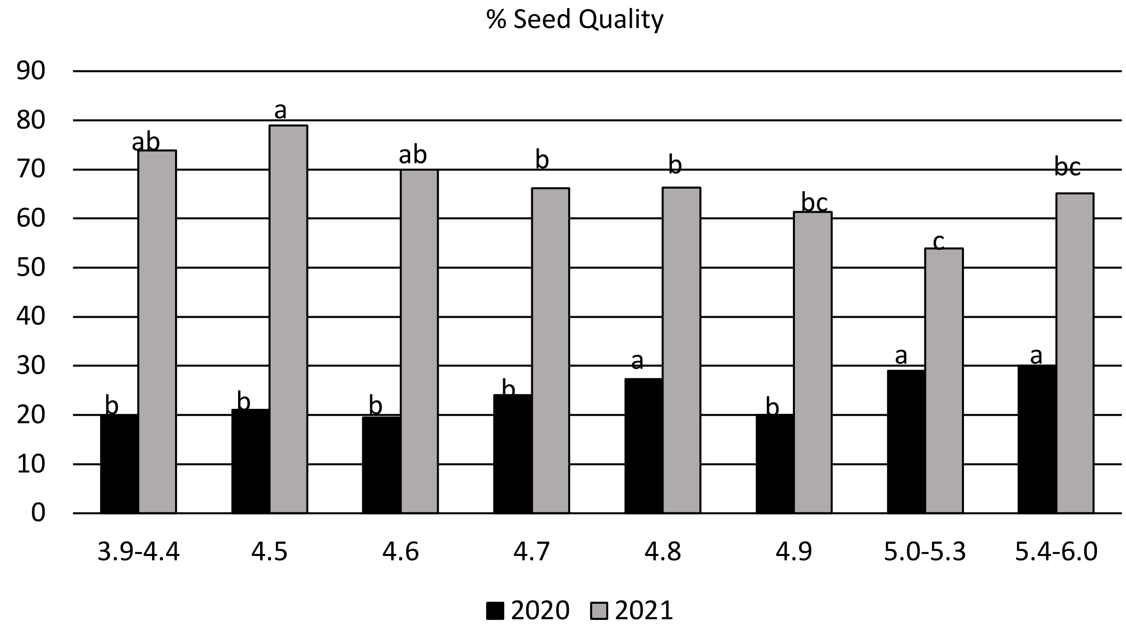

Fig. 6. Percent seed quality (no visible abnormalities) by maturity group from a variety trial at Rohwer, Ark., 2020–2021. Years were analyzed separately. Means that have the same letter are not different using Tukey's honestly significant difference at *P* = 0.05.

PEST MANAGEMENT: DISEASE CONTROL

Understanding Taproot Decline: A Soybean Disease of Increasing Importance in Arkansas, 2021

T.N. Spurlock,[1] *A.C. Tolbert,*[2] *and R. Hoyle*[2]

Abstract

Taproot decline (TRD), recently classified as *Xylaria necrophora*, is a disease of increasing importance in Arkansas soybean [*Glycine max* (L.) Merr.] production. In 2021, the incidence and severity of TRD were examined in commercial fields, and it was determined that in the southeastern portion of Arkansas, it is yield limiting while also reducing plant stand early-season. To date, TRD has been found in 15 counties in Arkansas. In addition, artificially inoculated trials done in the laboratory indicated that TRD severely limited the germination of most varieties tested, indicating that in certain conditions, it can be a severe seedling disease.

Introduction

A group of scientists from the University of Arkansas System Division of Agriculture, Mississippi State University, and Louisiana State University has characterized a soybean disease [*Glycine max* (L.) Merr.] prevalent in their respective states and named it taproot decline (TRD) (Allen et al., 2017). It was determined that an undescribed fungus causes the disease 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 (Fig. 1). 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 leaflets have a "leopard spot" or "sanded" appearance. As the disease progresses, aboveground 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. Mild vascular staining is observed if the root or lower stem is split longitudinally, 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 after rain or irrigation.

Taproot decline has been found as far north as Lawrence County and in a total of 15 counties in Arkansas (Fig. 2). In the southeastern Arkansas counties of Desha, Chicot, and Ashley, yield losses in some fields have been estimated to be as great as 20 bu./ac. Currently, we do not have seed treatment fungicides or varietal recommendations for growers to combat TRD in areas where it is yield-limiting. The objectives of this paper are to update the distribution of TRD across the state and introduce evidence of its potential impact on soybean seedlings.

Procedures

A laboratory trial was established at the University of Arkansas System Division of Agriculture's Rohwer Research Station. On 8 Oct. 2021, 20 soybean varieties were planted in trays with wells 3-in. deep by 2.5-in. wide (5 seed/plot) filled with a mixture of 50% sand and 50% *X. necrophora* infested sterile Japanese millet (*Echinochloa esculenta*) for the inoculated plots and un-infested sterile Japanese millet for the uninoculated plots. Two replications were placed in the growth chamber, and 2 replications were set on the laboratory bench for observation. Growth chamber conditions were set to 20 □ with a 12.5-hour photoperiod. Bench conditions were approximately 21 □ with 9 hours of fluorescent lighting. Emergence data were taken daily to record when each plant emerged. The trial was terminated on 25 Oct. 2021, and all data were subjected to analysis of variance followed by means separation using Fisher's least significant differences at $P = 0.10$.

Results and Discussion

In both trials, Pioneer 43A42X, a suspected susceptible variety, performed better than all other varieties tested except for Dyna-Gro S45ES10, which performed the same. Differences in emergence were seen in both inoculated tests, where the few varieties that had a plant emerge performed better than those that did not. Overall, varieties that were inoculated did not emerge (Table 1). No differences in emergence were observed in non-inoculated trials.

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Practical Applications

The data collected from these trials show the importance of finding resistant/tolerant varieties that allow the plants to emerge and yield well. We will continue to screen available varieties in search of a possible solution to this disease. Further, our initial thought was that Pioneer 43A42 was susceptible because we had seen foliar symptoms of TRD in fields. However, this variety emerged with a greater percentage than other varieties in the inoculated treatments. This suggests that susceptibility to foliar symptoms and seedling disease may not be related.

Acknowledgments

The authors appreciate the support provided by Arkansas soybean producers through checkoff funds administered by the Arkansas Soybean Promotion Board. Support was also provided by the University of Arkansas System Division of Agriculture.

Literature Cited

Allen, T., B. Bluhm, K. Conner, V. Doyle, T. Price, E. Sikora, R. Singh, T. Spurlock, M. Tomaso-Peterson, and T. Wilkerson. 2017. First Description of the Causal Agent of Taproot Decline of Soybean, an Emerging Disease in the Southern United States. Plant Health Prog. 18:1 p. 35. Accessed 29 April 2021. Available at: https://apsjournals.apsnet.org/doi/full/10.1094/PHP-01-17-0004-RS

Garcia-Aroca, T., P.P. Price, M. Tomaso-Peterson, T.W. Allen, T.H. Wilkerson, T.N. Spurlock, T.R. Faske, B. Bluhm, K. Conner, E. Sikora, R. Guyer, H. Kelly, B.M. Squiers, and V.P. Doyle. 2021. *Xylaria necrophora*, sp. nov., is an emerging root-associated pathogen responsible for taproot decline of soybean in the southern United States. Mycologia. Vol 113. 2:1–22. Accessed 29 April 2021. Available at: https://www.tandfonline.com/doi/abs/10.1080/00275514.2020.1846965

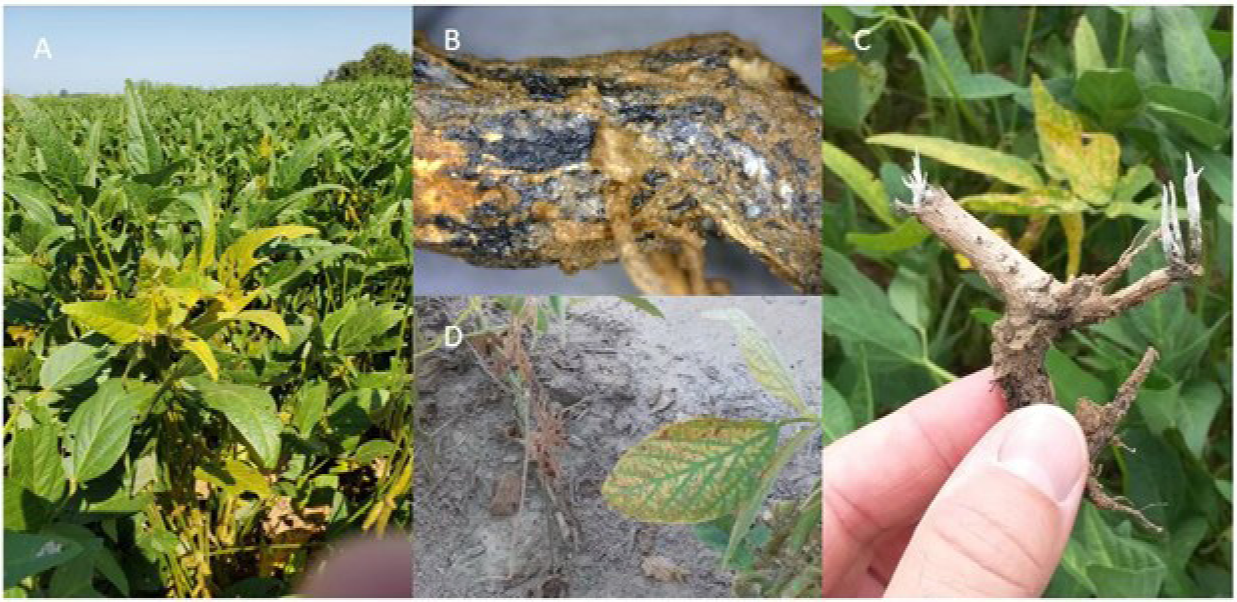

Fig. 1. Common signs and symptoms of taproot decline on soybean: A. chlorotic leaflets B. black stoma (specialized hyphae) growing along the outside of the soybean root C. 'dead man's fingers' emerging from crop residue D. chlorotic leaflets and smaller plant that died during the vegetative stages of development.

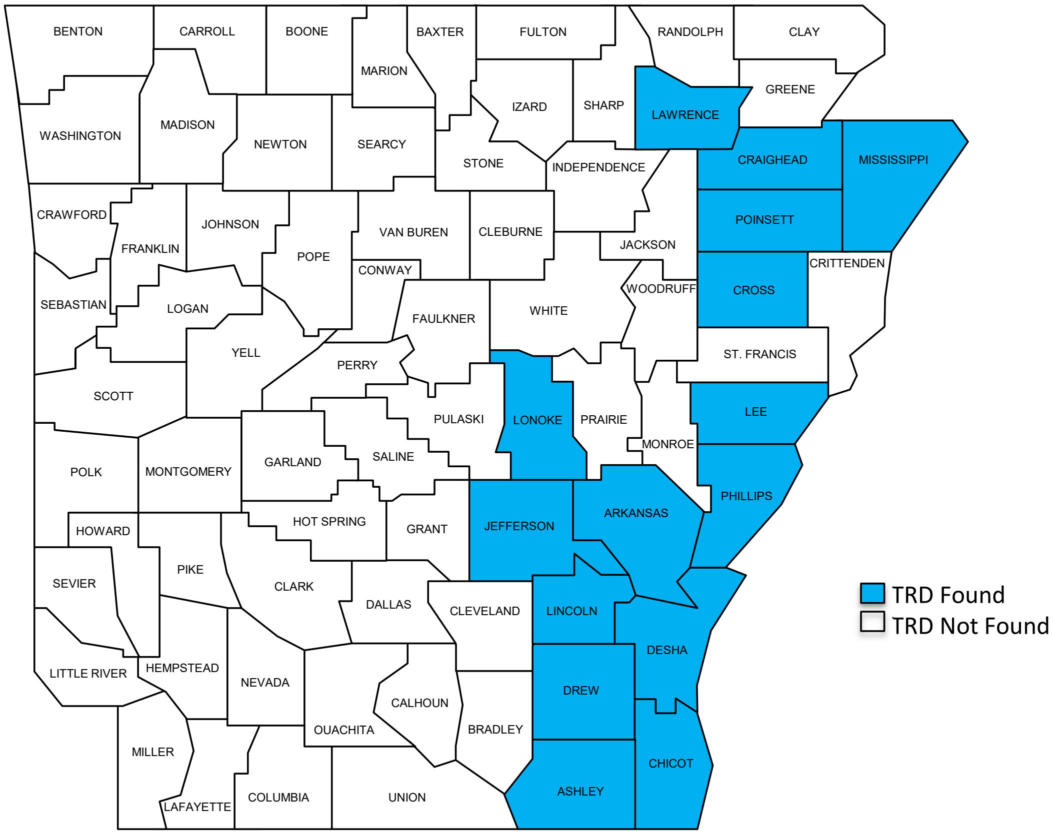

Fig. 2. Current map (after the 2021 crop season) of counties where taproot decline was found in soybean fields.

Table 1. The average number of emergent plants out of 5 by variety, inoculation, and location from a laboratory trial at the University of Arkansas System Division of Agriculture's Rohwer Research Station, Rohwer, Ark., 2021.

Variety	Growth Chamber Inoculated	Growth Chamber Un-inoculated	Bench Inoculated	Bench Un-inoculated
Amp 4448X	0.3 b[†]	0.5	0.3 b	1.0
Armor 44-D49	0.3 b	1.8	0.0 b	1.5
Asgrow AG42XF0	0.0 b	1.5	0.3 b	0.8
Asgrow SG45XF0	0.0 b	1.0	0.0 b	1.8
Credenz CZ4202XF	0.0 b	2.8	0.0 b	2.3
Credenz CZ4562XF	0.3 b	0.5	0.0 b	1.5
Delta Grow DG45ES10	0.0 b	1.0	0.0 b	1.5
Dyna-Gro S45ES10	1.5 a	1.5	0.0 b	1.3
Local LS 4517 XFS	0.0 b	1.5	0.0 b	0.5
Local LS4415XF	0.0 b	1.0	0.0 b	1.5
NK 42-T5XF	0.0 b	1.0	0.0 b	0.5
NK 43-V8XF	0.0 b	1.3	0.0 b	1.3
NK 44-J4XFS	0.0 b	0.3	0.0 b	0.3
NK 45-P9XF	0.0 b	0.3	0.0 b	0.5
PIONEER 43A42X	1.0 a	1.3	1.0 a	0.8
Progeny P4501XFS	0.0 b	1.3	0.0 b	2.0
Progeny P4505RXS	0.0 b	1.8	0.0 b	2.5
R18-14229	0.0 b	1.8	0.0 b	1.8
R18-14287	0.0 b	1.8	0.0 b	2.0
R18C-1450	0.0 b	0.0	0.0 b	2.0
LSD *P* = 0.10	0.64	1.34	0.42	1.58
MSE	0.29	1.29	0.13	1.78
Prob (F)	0.02	0.19	0.07	0.53

[†] Columns with means followed by the same letter are not significant according to Fisher's least significant difference (LSD) at *P* = 0.10.

Evaluation of Plant Elicitor Peptides to Control Soilborne Pathogens in Soybean

M. Da Silva,[1] J. Rupe,[1] F. Goggin,[1] and A. Rojas[1]

Abstract

Seedling and seed rot diseases of soybean are important issues that growers must address early in the season. Often, chemical treatments are applied to the seed to control diseases, but disease resistance is a risk. Therefore, novel strategies to control diseases are necessary to increase productivity and plant health. Plant elicitor peptides (PEPs) are natural peptides that occur in different plant species that enhance the immune response of plants and potentially trigger defense mechanisms for different pests. Soybean PEPs have shown activity against nematodes in controlling disease, but there is no evidence of control for other microorganisms associated with the rhizosphere. The present study evaluated the use of PEPs to control soilborne fungal pathogens of soybean.

Introduction

Chemical seed treatments often control soybean seed and seedling diseases, minimizing the impact of early-season diseases caused by soilborne pathogens. Early planting in wet and cold soils leads to infection by pathogens like *Pythium* and *Rhizoctonia*. Growers must decide on seed treatments ahead of the season to manage diseases. At planting, nearly 50% of the cost is associated with seed and seed treatment selection, making decisions on cost and profitability critical (Lamichhane et al. 2019). Using broad-range molecules that control multiple pathogens could reduce the use of chemicals and facilitate the decision-making process for seedling disease treatments. Plant elicitor peptides (PEPs) naturally occur on different plant species since these conserved molecules modulate defense when pests or pathogens attack plants.

Plants like soybean, corn, and rice have PEPs that are widely present in other angiosperms (Lee et al., 2018; Bartels and Boller, 2015; Poretsky et al., 2020; Shen et al., 2022). The PEPs play a role in the development and defense against different pests, including nematodes, bacteria, fungi, and oomycetes (water molds). The delivery of PEPs by different mechanisms enhances the defense response of plants and could increase the plant response against soilborne pathogens. Hence, PEPs treatments are relevant for managing nematodes and other root pathogens. Lee et al. (2018) documented that PEP seed treatments confer tolerance against root-knot nematode and soybean cysts nematode on soybean 'Williams82.'

However, there is no information on other effects that PEPs, especially soybean peptides, could have on beneficial microbes, like *Rhizobium* (nitrogen fixers) or plant pathogens, such as *Pythium*, *Rhizoctonia*, and *Macrophomina*. Peptides could affect soybean plant health and productivity when challenged with nematodes and other soilborne pathogens. Ruiz et al. (2018) showed in peach orchards that PEPs did have a protective role against disease, enhancing resistance. Currently, soybean peptide PEP3 showed a stronger response against nematodes, and it was evaluated against different soilborne pathogens to determine its effectivity on modulating the plant immune response. The current study will characterize the role of PEPs in managing soilborne fungi and oomycetes.

Procedures

A seed plate assay was used with the soilborne pathogens *Macrophomina phaseolina*, *Rhizoctonia solani* anastomosis group 4 (AG4), and *Pythium ultimum* to assess the protective potential of plant elicitor (PEPs) as a seed treatment on soybean ('Magellan' and 'Williams82'). The assay was conducted as described by Da Silva et al. (2019). Briefly, pathogens were grown on potato dextrose agar (PDA) for 5 days, and a plug from the edge of the actively growing colony was transferred to a new PDA plate and grown for 5 days. The colonized agar was covered with 2g of sterile vermiculite before seeds were placed around the plate. Then, soybean seeds were imbibed for 24 h in distilled sterile water with Tween 20, a surfactant, to increase coverage at 0.05% and 1 µM of PEP3, which is the plant elicitor peptide.

For controls, seeds were imbibed only with Tween 20. Each treatment combination received 10 seeds per plate after imbibition. Seeds were arranged circularly, and plates with seeds were covered with aluminum foil and incubated at room temperature. Treatments are listed in Table 1. The fungicide treatment corresponded to commercial seed treatments available for each pathogen (*M. phaseolina* – fludioxonil, *Rhizoctonia* spp – sedaxane, and *Pythium ultimum* – mefenoxam). Three plates were done for each pathogen (*M. phaseolina, R. solani* AG4, and *Pythium*) and seed treatment combination, including controls, and the experiment was repeated three times. All treatments were randomized for the experimental design.

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After 7 days of incubation, seeds were rated for germination. A seed was considered germinated if the radicle was >1 cm long and was not visibly colonized by the pathogen (Broders et al. 2007).

Results and Discussion

Overall, PEP treatment with the surfactant (Tween 20) increases soybean seed germination in both cultivars. The control with Tween 20 and the pathogen resulted in a maximum of 30% germination. When the plant elicitor peptide (PEP) was present and challenged with the pathogen, germination was slightly increased. However, these results varied between pathogens. Results indicated that *M. phaseolina* had the highest number of germinated seeds, with an average of 80% germination per plate. *Pythium ultimum* presented an average of 16% of germination, and *Rhizoctonia solani* (AG4), had the lower germination between treatments, with all seeds colonized by the pathogen.

The seed plate assay was used to evaluate the response of cultivars 'Magellan' and 'Williams82' in response to *Rhizoctonia solani* AG 4 when treated with PEPs. The results indicated a significant difference between treatments ($P < 0.0001$), varieties ($P < 0.0001$) and interaction for Treatment*Varieties ($P = 0.0213$). Control treatment with fungicide presented a slightly higher number of seeds germinating when compared with treatments PEP + Pathogen and PEPs alone (Table 2). Soybean 'Magellan' presented higher germination than 'Williams82.' The interaction profile showed that besides PEPs alone, 'Magellan' presented a higher number of germinated seeds in all treatments. Overall, germination with 'Magellan' was higher when compared with 'Williams82.' Treatment with PEPs in the presence of the pathogen increases germination compared to control Tween20.

Practical Applications

The impact of soilborne diseases on growers at planting and continuing into the seedling stage is an issue resulting in greater costs for growers (Lamichhane et al., 2019; Rossman et al., 2018). The incorporation of novel disease management strategies, used in conjunction with existing control methods, has the potential to provide consistent and reliable disease management results. These tools can improve plant health and increase yields in the long term. Plant elicitor peptides provide a broad range of protection against nematodes, soilborne fungi, and oomycetes. It could aid in the management of resistance against traditional fungicide seed treatments.

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Literature Cited

Bartels, S., and Boller, T. 2015. Quo Vadis, Pep? Plant elicitor peptides at the crossroads of immunity, stress, and development. Journal of Experimental Botany. 66:5183–5193.

Da Silva, M. P., Pereira, A., Rupe, J.C., Bluhm, B., Gbur, E., Wood, L., Mozzoni, L.A., and Chen. P. 2019. Effectiveness of a seed plate assay for evaluating charcoal rot resistance in soybean and the relationship to field performance. PDIS-10-18-1908-RE.

Lamichhane, J. R., M.P. You, V. Laudinot, M.J. Barbetti, and J.N. Aubertot. 2019. Revisiting Sustainability of Fungicide Seed Treatments for Field Crops. PDIS-06-19-1157-FE.

Lee, M. W., A. Huffaker, D. Crippen, R.T. Robbins, and F.L. Goggin. 2018. Plant elicitor peptides promote plant defenses against nematodes in soybean. Mol. Plant Path. 19:858–869.

Poretsky, E., K. Dressano, P. Weckwerth, M. Ruiz, S.N. Char, D. Shi, R. Abagyan, B. Yang, and A. Huffaker. 2020. Differential activities of maize plant elicitor peptides as mediators of immune signaling and herbivore resistance. Plant J., 104(6), pp.1582-1602.

Rossman, D. R., A.M. Byrne, and M.I. Chilvers. 2018. Profitability and efficacy of soybean seed treatment in Michigan. Crop Protection. 114:44–52.

Ruiz, C., A. Nadal, L. Foix, L. Montesinos, E. Montesinos, and M. Pla. 2018. Diversity of plant defense elicitor peptides within the Rosaceae. BMC Genetics. 19:11.

Shen, W., X. Zhang, J. Liu, K. Tao, C. Li, S. Xiao, W. Zhang, and J.F. Li. 2022. Plant elicitor peptide signaling confers rice resistance to piercing□sucking insect herbivores and pathogens. Plant Biotech. J., 20(5):991.

Table 1. Treatment descriptions for plant elicitor peptides used in the present study.

Treatments	Description
T1	Solution of H_2O + Tween + PEPs + Pathogen
T2	Solution of H_2O + Tween + PEPs
T3	Solution of H_2O + Tween + Pathogen
T4	Solution of H_2O + Tween
T5	Solution of H_2O + Tween + Fungicide + Pathogen

Table 2. The average number of seed germinated under treatment with plant elicitor peptides (PEP) or control treatments in laboratory trials in 2021.

Pathogen	Treatment	Average Germination†	
		number of seed	
Macrophomina phaseolina	Solution of H_2O + Tween + PEPs + Pathogen	2.6	bcde
	Solution of H_2O + Tween + PEPs	7.8	ab
	Solution of H_2O + Tween + Pathogen	1.4	de
	Solution of H_2O + Tween	6.8	abc
	Solution of H_2O + Tween + Fungicide + Pathogen	6.4	abcd
Pythium ultimum	Solution of H_2O + Tween + PEPs + Pathogen	5.2	abcde
	Solution of H_2O + Tween + PEPs	8.8	a
	Solution of H_2O + Tween + Pathogen	3.0	bcde
	Solution of H_2O + Tween	2.0	cde
	Solution of H_2O + Tween + Fungicide + Pathogen	0.0	e
Rhizoctonia solani	Solution of H_2O + Tween + PEPs + Pathogen	2.6	bcde
	Solution of H_2O + Tween + PEPs	7.8	ab
	Solution of H_2O + Tween + Pathogen	1.4	de
	Solution of H_2O + Tween	6.8	abc
	Solution of H_2O + Tween + Fungicide + Pathogen	6.4	abcd

† Columns with means followed by the same letter are not significant according to Fisher's least significant difference (LSD) at *P* = 0.05.

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

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Abstract

The susceptibility of 40 soybean cultivars to the southern root-knot nematode (*Meloidogyne incognita*) was evaluated in 4 field trials. In all trials, the damage threshold was severe, with an average population density of 234 second-stage juveniles(J2)/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 root system galled percentage was between 0.0% to 1.0%, resistant from 1.1% to 4.0%, and moderately resistant from 4.1% to 9.0%. Of the maturity group (MG) 4 Roundup Ready/Xtend® and Enlist® E3 cultivars, Delta Gro DG4940, Progeny P4431E3, Armor EN21E42, Pioneer 46A35, Delta Gro DG46E10, Pioneer P43A42X, Armor EN21E49, and Petrus Seed 49G16GT were moderately resistant. At the same time, Pioneer 45A29L-SA2P was resistant in the Liberty Link® trial. In the maturity group 5 Roundup Ready/Xtend and Enlist E3 trial, Pioneer P52A05X and Syngenta S55-Q3 were resistant, Pioneer P53A74BX, Pioneer P54A54X, Pioneer P55A49X, Progeny P5424XF, Syngenta NKS61-M2X, and Progeny P5554RX were moderately resistant. In contrast, Pioneer P52A43L-SA2P was very resistant in the Liberty Link® trial. The 3 resistant cultivars would be a preferred choice in fields with a high density of southern root-knot nematode; however, the other fourteen 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 2019 cropping season, yield losses by RKN were estimated at 5.56 million bushels (Allen et al., 2020). 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. Using resistant soybean cultivars is the most economical and effective strategy for managing RKN (Kirkpatrick et al., 2014). Unfortunately, resistance is limited in the most common maturity groups (MG 4) grown in the state (Emerson et al. 2020) 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 Cooperative Extension Service (CES) and only provides information on those cultivars that are entered into the 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

Forty soybean cultivars were evaluated in a field naturally infested with Meloidogyne incognita near Kerr, Ark. The cultivars were among what each company considered to be resistant in the most common MG 4 and 5s grown in the state (Tables 1–4). The 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 CES. Plots consisted of 4 rows, 30 ft long, spaced 30 in. apart, separated by a 5-ft fallow alley. Plots were furrow irrigated. Seeds were planted using a Kincaid Precision Voltra Vacuum plot planter (Kincaid Equipment Manufacturing, Haven, Kan.) on 27 May 2021 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 66 second-stage juveniles (J2)/100 cm^3 of soil, with a final population

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density of 234 J2/100 cm^3 of soil. Nematode infection was based on root galling using a 0-100 percent 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 19 Oct 2021 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 2021.7 (Gylling Data Management, Inc., Brookings, S.D.). When appropriate, mean separations were performed using Tukey's honestly significant difference 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 2.3% to 72.5% of the root system being galled. One cultivar was resistant to the southern root-knot nematode, Pioneer 43A42X, and had a lower ($P = 0.05$) gall rating than Delta Grow DG4880, the susceptible control (Table 1); however, this cultivar had a slightly higher gall rating and was moderately resistant in the other maturity group 4 trial (Table 2). These gall ratings show there is variability in nematode populations across field trials. In addition, this resistant cultivar had an average grain yield of 61 bu./ac, which was 26 bu./ac greater than the average yield (35 bu./ac) of the susceptible cultivars. In both trials, there was a negative correlation between root system galling and yield.

Of the maturity group 5, Roundup Ready/Xtend and Enlist E3 cultivars, 2 were resistant. Susceptibility ranged from 2.6% to 59.9% of the root system being galled. Pioneer P52A05X and Syngenta S55-Q3 were resistant, and all had a lower ($P = 0.05$) gall rating than Delta Grow DG5170, the susceptible control cultivar (Table 3). These resistant cultivars' grain yield average was 69 bu./ac, which was 32 bu./ac greater than the average yield (37 bu./ac) of the susceptible cultivars. There was a significant negative correlation ($r = -0.81$, $P = 0.0001$) between galling and yield.

In the maturity group 4 and 5, Liberty Link cultivars, one was very resistant, and one was resistant. Susceptibility ranged from 0.1% to 34.7% of the root system being galled. Pioneer P52A43L was very resistant, and Pioneer P45A29L was resistant, and both had a lower ($P = 0.05$) gall rating than Delta Grow DG47E80, the susceptible control (Table 5).

The resistant cultivar grain yield average was 70 bu./ac, which was 24 bu./ac greater than the average yield (35 bu./ac) of the susceptible cultivars. There was a significant negative correlation ($r = -0.91$, $P = 0.0001$) between galling and yield. With the decrease in the availability of cultivars, this will be the last year we will have a sole Liberty Link cultivar screen.

Practical Applications

The southern root-knot nematode is an important yield-limiting pathogen affecting soybean production worldwide. These data provide information on cultivars' 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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Literature Cited

Allen T. W., K. Bissonnette, C.A. Bradley, J.P. Damicone, N.S. Dufault, T.R. Faske, T. Isakeit, R.C. Kemerait, A. Koehler, D. Langston, J.D. Mueller, G.B. Padgett, P.P. Price, E.J. Sikora, L.M. Small, L. Thiessen, and H. Young. 2020. Southern United States soybean disease loss estimate for 2020. Proceedings of the Southern Soybean Disease Workers, Pensacola, Fla., March 6–7, 2020.

Emerson, M. and T.R. Faske. 2020. Field performance of thirty-seven group 4 and 5 soybean cultivars in a root-knot nematode infested field. In J. Ross, ed. Arkansas Soybean Research Studies 2020. University of Arkansas System Division of Agriculture Agricultural Experiment Station, Research Series 680:54–58. Fayetteville.

Kirkpatrick, T. 2017. Incidence, population density, and distribution of soybean nematodes in Arkansas. in J. Ross ed. Arkansas Soybean Research Studies 2015. University of Arkansas System Division of Agriculture Agricultural Experiment Station, Research Series 637:72-73 Fayetteville.

Kirkpatrick, T., T. Faske, and B. Robbins. 2014. Nematode management in Arkansas Soybean Production Handbook, MP197. University of Arkansas System Division of Agriculture Cooperative Extension Service, Little Rock.

Robbins, R.T., R.D. Riggs, and D. Von Steen. 1987. Results of annual phytoparasitic nematode surveys of Arkansas soybean fields, 1978-1986. J. Nematol. 9:50-55.

Table 1. 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 (*Meloidogyne incognita*) infested field near Kerr, Ark.

Cultivar	Root system galled[†]	Susceptibility[‡]	Yield[§]
	%		bu./ac
Pioneer P43A42X	2.3 d[¶]	R	59.2 a
Agri Gold G4881E3	12.9 a-d	MS	57.2 a
Armor EN21E49	8.7 bcd	MR	54.4 a
Petrus Seed 4916GT	6.3 cd	MR	52.8 a
Progeny P4444RKS	14.6 a-d	MS	50.8 ab
Dyna Gro S48X40	18.3 abc	MS	50.2 ab
Syngenta NKS44-2E3	20.3 abc	S	49.1 ab
Delta Grow DG48E28	21.0 abc	S	48.2 ab
Syngenta NKS45-J3X	42.2 a	VS	47.2 ab
Syngenta S46-E3S	20.1 abc	S	45.1 ab
Delta Grow DG47E80	41.7 a	VS	36.5 bc
Armor EX4121X	35.8 ab	S	28.6 c
Delta Grow DG4880 (Susceptible Check)	44.7 a	VS	28.2 c

[†] Root gall rating severity was based on a percent scale where 0 = no galling and 100 = 100% of 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 10 Roundup Ready/Xtend® and Enlist® E3 maturity group 4 soybean cultivars grown in a southern root-knot nematode (*Meloidogyne incognita*) infested field near Kerr, Ark.

Cultivar	Root system galled[†]	Susceptibility[‡]	Yield[§]
	%		bu./ac
Pioneer P43A42X	5.9 d	MR	53.7 a
Delta Grow DG4940	4.6 d[¶]	MR	63.2 a
Progeny P4431E3	5.0 d	MR	63.2 a
Armor EN21E42	6.1 d	MR	60.1 ab
Pioneer P46A35X	5.4 d	MR	60.0 ab
Delta Grow DG46E10	5.4 d	MR	59.9 ab
Delta Grow DG49E90	13.5 cd	MS	59.0 ab
Local Seed LS 4506XS	28.1 bc	S	50.3 b
Northup King NKS48-2E3S	43.3 ab	VS	27.2 c
Delta Grow DG4880 (Susceptible Check)	56.8 ab	VS	21.8 c
Armor EX4821X	72.5 a	VS	21.7 c
Armor EN4221X	63.8 a	VS	19.1 c

[†] Root gall rating severity was based on a percent scale where 0 = no galling and 100 = 100% of 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 (*Meloidogyne incognita*) infested field near Kerr, Ark.

Cultivar	Root system galled[†]	Susceptibility[‡]	Yield[§]
	%		bu./ac
Pioneer P53A74BX	5.7 cd[¶]	MR	74.8 a
Pioneer P52A05X	2.6 d	R	72.1 ab
Pioneer P54A54X	6.7 cd	MR	69.3 abc
Pioneer P55A49X	8.6 cd	MR	65.8 a-d
Progeny P5424XF	7.0 cd	MR	65.4 a-d
Syngenta S55-Q3	3.4 d	R	65.0 a-d
Syngenta NKS61-M2X	8.0 cd	MR	63.7 a-d
Progeny P5604XF	9.8 cd	MS	62.7 a-d
Progeny P5554RX	5.8 d	MR	61.6 a-d
Local Seed LS 5418XFS	13.8 bcd	MS	59.4 bcd
Delta Grow DG50E10	10.3 cd	MS	56.6 cd
Stine 50EA22	10.8 cd	MS	56.6 cd
Syngenta S51-E3	21.6 abc	S	54.6 d
Delta Grow 5170 (Susceptible Check)	59.9 a	VS	29.7 e
Delta Grow 5170 (Susceptible Check)	52.7 ab	VS	27.3 e

[†] Root gall rating severity was based on a percent scale where 0 = no galling and 100 = 100% of 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 and 5 Liberty Link® and Enlist® E3 soybean cultivars grown in a southern root-knot nematode (*Meloidogyne incognita*) infested field near Kerr, Ark.

Cultivar	Root system galled[†]	Susceptibility[‡]	Yield[§]
	%		bu./ac
Pioneer P52A43L	0.1 b[¶]	VR	74.1 a
Pioneer P45A29L	2.8 ab	R	65.9 a
Delta Grow DG47E80 (Susceptible Check)	34.7 a	S	46.4 b

[†] Root gall rating severity was based on a percent scale where 0 = no galling and 100 = 100% of 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.

Accelerated Development of Bioherbicides to Control Palmer Amaranth (Pigweed)

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Abstract

Palmer amaranth (*Amaranthus palmeri* S. Watson), commonly known as Palmer pigweed, is a highly invasive weed that affects row crop production throughout Arkansas. Palmer pigweed has evolved resistance to most herbicide chemistries, and thus new technologies are urgently needed to control existing populations and curb the further spread. Bioherbicides–weed control agents derived from living organisms–have the potential advantages of being highly effective, specific, and environmentally friendly. However, to date, bioherbicides targeting Palmer pigweed have not been developed. This project's overarching goal is to utilize Palmer pigweed's fungal pathogens to create novel bioherbicides. In previous work, fungal pathogens of Palmer pigweed were isolated and cataloged from symptomatic plants collected throughout Arkansas. In this report, we utilized a greenhouse screening assay to identify highly virulent pathogens of Palmer pigweed. In addition, in a complementary approach, the most virulent pathogens identified in the greenhouse assay were evaluated for the production of phytotoxins (secondary metabolites produced by fungi that are toxic to Palmer pigweed). This approach identified 2 previously undescribed fungal isolates (AF22 and AF24) that are virulent on Palmer pigweed plants and produce 1 or more phytotoxins that induce wilting, charring, necrosis, and plant death. These 2 isolates have the potential to be utilized as biological control products, and the phytotoxin(s) produced by these strains could be developed into chemical bioherbicide products.

Introduction

Herbicide-resistant weeds are currently the most problematic and expensive management issue in row-crop agriculture (Beckie et al., 2019). The most egregious herbicide-resistant weeds belong to the Amaranthus complex, which includes pigweeds (Ward et al., 2013). The most damaging of these is Palmer pigweed (*Amaranthus palmeri* S. Watson), now considered one of the most economically destructive weeds in U.S. row crop agriculture (Roberts and Florentine, 2022). Palmer pigweed is a highly competitive, fast-growing summer annual present in most row-crop systems and can cause significant yield losses even with moderate populations (Roberts and Florentine, 2022). As a result, this weed has become a flashpoint for herbicide resistance, extending to agricultural communities' political and social environments (Clayton, 2016).

Chemical control of Palmer pigweed is extremely challenging, and options are limited. Few new herbicide modes of action have been developed in recent years for row crop production, the most recent being the Group 27 herbicides in the late 1990s/early 2000s. Many recent herbicide products are repackaged or tweaked formulations of older chemistries. These older chemistries primarily target trait-specific, genetically modified crops such as Round-Up Ready® or Liberty Link™ soybeans and corn. The most recent product targeted at controlling Palmer pigweed in soybean is the Xtend® soybean (Round Up Ready 2 Xtend®) system developed for resistance to over-sprays of the older herbicide dicamba. However, dicamba is not particularly effective against pigweed complexes. In addition, resistance has already emerged in Palmer pigweed populations in some U.S. states after only a few seasons of Xtend soybean production (Unglesbee, 2020). Thus, alternative chemistries and herbicide products are urgently needed to control Palmer pigweed in soybean production.

Biotechnology is "the application of science and engineering in the direct or indirect use of living organisms, or parts or products of living organisms, in their natural or modified forms" (Pattison et al., 2001). Biorational products within the agricultural biotechnology sector have emerged as an integral part of the sustainability movement in agriculture. These products include biopesticides, biofertilizers, crop inoculants, and probiotics. Biocontrol technologies have inherent economic and practical values, such as counteracting drawbacks associated with chemical pesticides (including safety, environmental concerns, and resistance development). Bioherbicides have the potential to provide more effective weed management, reduce the emergence of resistant weed populations, lessen environmental impacts, and improve producer economics. Thus, bioherbicides are ideally suited for controlling Palmer pigweed and other weed pests affecting soybean production.

This project aims to develop novel bioherbicides from native fungal pathogens of Palmer pigweed to create new management products for sustainable weed control. In previous work, we isolated >300 pathogens of Palmer pigweed from symptomatic plants collected throughout Arkansas. These pathogens have been evaluated through various approaches

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for their potential future development as a bioherbicide. This report will present information about 2 novel fungal isolates from Palmer pigweed that putatively produce a host-specific phytotoxin that is highly lethal to young Palmer pigweed plants. These 2 fungal isolates, and the phytotoxin(s) they produce, are ideal candidates for bioherbicide development.

Procedures

Cut-Stem Assay

Fungal isolates collected from diseased Palmer pigweed plants were evaluated with a cut-stem assay to assess pathogenicity. A cut-stem assay, initially developed to evaluate soybean resistance to *Macrophomina phaseolina* (Twizeyimana et al., 2012), was adapted to evaluate the virulence of fungal isolates on Palmer pigweed. The fungal inoculum was prepared by culturing fungi individually on V8 juice agar plates (V8 agar) in darkness at room temperature for 7–14 days. Palmer amaranth plants were grown from seed in a greenhouse under high-pressure sodium lights with a 14-hr photoperiod in commercial potting soil (BM6 All-Purpose Mix; Berger Corp., Quebec, Canada). Seeds were initially broadcast in trays, and healthy seedlings were transplanted 10 days later to individual 2.5-in. pots.

Greenhouse inoculations were performed with a randomized complete block design, in which each greenhouse bench represented a block (6 blocks per experiment). Within each block, each fungal isolate was represented once. Palmer pigweed plants (2–3 weeks old) were arranged randomly within each block, cut at the third to fifth node, and inoculated with agar plugs excised from actively growing cultures. A sterile pipette tip was placed over each inoculation to stabilize the agar plug and maintain humidity. Negative controls consisting of sterile, uninoculated V8 agar were included within each block. In a separate block, soybean cultivar Traff was inoculated with each isolate described above to evaluate host specificity. Each fungal isolate was evaluated in at least 2 separate experiments, and more virulent isolates were evaluated in at least 3 experiments.

Disease severity was determined by quantifying the length of stem lesions at 12 and 16 days after inoculation. Lesions, assessed as visually necrotic tissue, were measured with a ruler in greenhouse conditions. Data for each experiment were analyzed as the average lesion length +/- the standard error of the mean for each isolate. After data collection, plants were incubated in the greenhouse for 14 days to evaluate whether additional symptoms were expressed.

Toxin Translocation Assay

To further explore the potential production of phytotoxins, including host-selective toxins, by fungal pathogens of pigweed, a subset of highly virulent isolates (strains PWA43, PWA78, PWA87, PWA98) along with isolates that induced charring necrosis (strains AF22 and AF24) were evaluated in a toxin translocation assay. Liquid cultures of each fungal isolate were prepared to induce the production of phytotoxin(s). Fungal inoculum for liquid cultures was prepared by culturing fungal isolates on V8 agar plates, collecting fungal mycelia from cultures after 7 days of growth, and pulverizing fungal tissue by vigorous shaking in tubes containing sterile water (1 ml) and glass beads (2 mm diameter) in a bead mill (Tissuelyser II by Qiagen, Germantown, Md.). Pulverized fungal tissue from each isolate was transferred to individual Erlenmeyer flasks containing 50 mL of yeast extract peptone dextrose (YEPD) growth medium. Flasks (6 per isolate) were incubated on a bench top at room temperature, agitated daily by hand (30 sec) for aeration, and harvested after 2 or 4 weeks of growth. Cultures were filtered through sterile cheesecloth to remove fungal tissue, and filtrates were frozen and stored in 50 mL conical tubes.

To perform the toxin translocation assay, stems of Palmer pigweed plants were cut, roots were discarded, and the above-ground portions of plants were placed in culture filtrates so that phytotoxins could be translocated into foliar tissue. The 50 ml of culture filtrate described above for each fungal isolate was thawed and divided into 5 aliquots (10 ml each). Aliquots were transferred to 15 mL conical tubes and sealed with parafilm. Palmer pigweed plants, grown as described above, were collected 4–5 weeks after transplantation, cut 5–10 mm above the root/shoot interface, and inserted into the culture filtrates by piercing the parafilm seals on tubes. Plants were incubated in a growth chamber with a 12/12 light/dark cycle at 28–30 °C for 96 h.

Inoculated plants were incubated in a growth chamber with a randomized complete block design, in which each shelf in the chamber represented a block (3 blocks per experiment). Within each block, each fungal isolate was represented 1 to 3 times with randomized placement. Two controls (sterile water and uninoculated YEPD growth medium) were included (3 plants per control per block). Plants were visually assessed for symptoms (wilting, leaf curling, interveinal discoloration, foliar chlorosis) at 24, 48, 72, and 96 hours. Results were documented by photographing each plant at each time point of data collection.

Results and Discussion

The overarching goal of this work is to create viable bioherbicide products that selectively target Palmer pigweed. To this end, a collection of Palmer pigweed pathogens was obtained from locations throughout Arkansas and evaluated for virulence. The most promising isolates can be modified via non-transgenic genome editing to optimize commercially important traits (such as lethality, dormancy during storage and transport, etc.). In this report, we describe the discovery process underlying the selection of promising isolates and the somewhat unexpected discovery of a potential host-selective phytotoxin targeting Palmer pigweed.

Cut Stem Assay

A range of stem necrosis induced by isolates, varying from highly to moderately virulent, was consistently observed (Fig. 1A). We designated 3 groups of isolates: highly virulent (average lesion length >20 mm), moderately virulent (average lesion length between 5–20 mm), and weakly virulent (average lesion length <5 mm). Highly virulent isolates rapidly induced necrosis in Palmer pigweed, which spread down plant stems throughout the experiment. Many isolates with the lowest virulence (average stem lesion length <5 mm) appeared to induce a defense response in Palmer pigweed, which resembled heightened callose deposition to 'wall off' fungal isolates before they could fully colonize stems and induce necrosis. No fungal pathogens isolated from pigweed were virulent on soybean (data not shown). Highly virulent isolates from Palmer pigweed are being further investigated via genetic approaches, including non-transgenic genome editing, for further improvement as bioherbicide candidates.

Intriguingly, 2 of the isolates that were moderately virulent 14 days after inoculation, AF22 and AF24, induced expansive, necrotizing cell death in Palmer pigweed 14–30 days after inoculation (Fig. 1B). Cell death resembling charred tissue is consistent with many host-selective toxins, such as HC-toxin produced by *Cochliobolus carbonum* (Walton, 2006). Host-selective toxins have recently shown promise as bioherbicides targeting various weed species (Masi et al., 2019; Hasan et al., 2021). However, a host-selective toxin targeting Palmer pigweed has not yet been reported and would be an ideal candidate for development as a bio-based chemical herbicide for pigweed control.

Toxin Translocation Assay

Culture filtrates from strains AF22 and AF24 induced severe wilting in Palmer pigweed 24 hours after exposure (Fig. 2A), whereas culture filtrates from strains PWA43, PWA78, PWA87, and PWA98 did not begin to induce wilting until 72–96 hours after incubation. No wilting was observed in the negative controls (water or sterile YEPD medium) throughout the experiment. By 48 hours after inoculation, leaves of plants exposed to culture filtrates from AF22 and AF24 began to show foliar necrosis in a manner consistent with the translocation of one or more phytotoxins (Figs. 2B and 2C).

The discovery of highly virulent pathogens of Palmer pigweed (in particular, isolates that potentially produce a host-selective toxin) represents a significant advancement on the path to bioherbicide development. Future work will focus on confirming the identity of the putative toxin(s), the fungal genes underlying their biosynthesis, and ways to optimize toxin production via conventional genetic approaches and/or genome editing.

Practical Applications

Palmer pigweed is one of the most problematic and difficult weeds to control in Arkansas soybean production. Bioherbicides are potentially the ideal solution to noxious weeds affecting crop production in Arkansas, including Palmer pigweed. In particular, a host-selective toxin exclusively targeting Palmer pigweed could be used individually or in combination with other herbicide chemistries for weed control without harming soybean or other crop species. Additional benefits of host-selective bioherbicides include reduced environmental impacts compared to conventional herbicides, lower cost to growers, greater public acceptance, and increased sustainability.

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Literature Cited

Beckie, H.J., M.B. Ashworth, and K.C. Flower. 2019. Herbicide resistance management: Recent developments and trends. Plants. Basel, Switzerland. 8:161.

Clayton, C. 2016. Farmer allegedly killed over dicamba. Progressive Farmer. Accessed 1 May 2022. Available at: https://www.dtnpf.com/agriculture/web/ag/news/article/2016/10/28/confrontation-herbicide-drift-leads

Hasan, M., M.S. Ahmad-Hamdani, A.M. Rosli, and H. Hamdan. 2021. Bioherbicides: An Eco-Friendly Tool for Sustainable Weed Management. Plants. Basel, Switzerland. 10:1212.

Masi, M., S. Meyer, S. Clement, A. Cimmino, and A. Evidente. 2021. Effect of cultural conditions on the production of radicinin, a specific fungal phytotoxin for buffelgrass (*Cenchrus ciliaris*) biocontrol, by different *Cochlioboulus australiensis* strains. Natural Products Research 35:99-107.

Pattison, W., B. Van Beuzekam, and A. Wyckoff. 2001. Internationally comparable industries on biotechnology: A stock-taking, a proposal for work and supporting materials. Statistics Canada 88F0017MIE No. 9.

Roberts, J., and S. Florentine. 2022. A review of the biology, distribution patterns and management of the invasive species *Amaranthus palmeri* S. Watson (*Palmer amaranth*): Current and future management challenges. Weed Res. 62:113-122.

Twizeyimana, M., C.B. Hill, M. Pawlowski, C. Paul, and G.L. Hartman. 2012. A cut-stem inoculation technique to evaluate soybean for resistance to *Macrophomina phaseolina*. Plant Dis. 96:1210-1215.

Unglesbee, E. 2020. Dicamba-resistant pigweed confirmed. Now what? AgFax Weed Solutions. Accessed: 1 May 2022. Available at: https://agfaxweedsolutions.com/2020/07/30/dicamba-resistant-pigweed-confirmed-now-what-dtn/

Walton, J.D. 2006. HC-toxin. Phytochemistry 67:1406-13.

Ward, S.M., T.M. Webster, and L.E. Steckel. 2013. Palmer Amaranth (*Amaranthus palmeri*): A review. Weed Tech. 27:12–27.

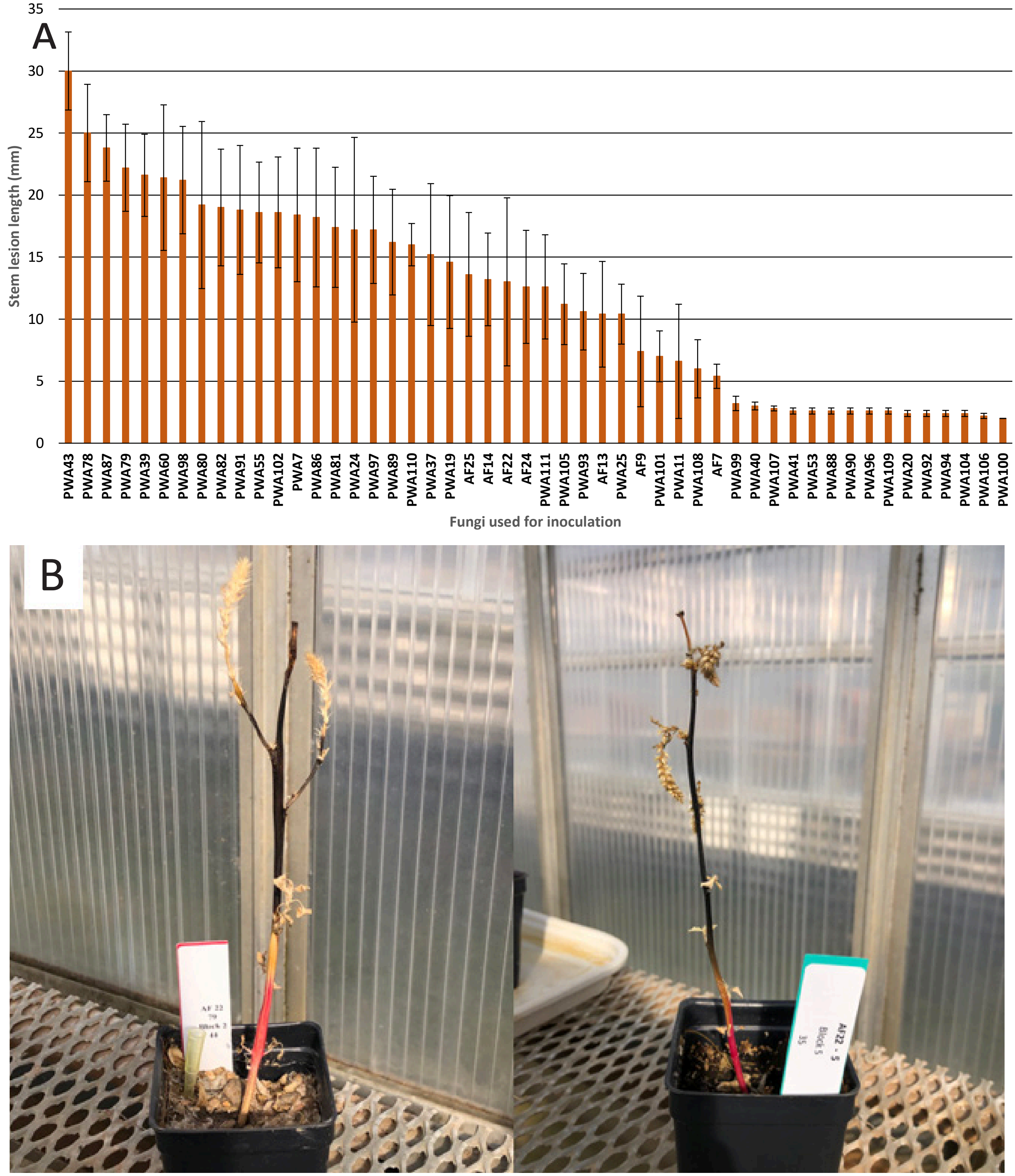

Fig. 1. Results of the cut-stem assay to assess fungal virulence on Palmer pigweed (*Amaranthus palmeri*). (A) Average length of stem lesions caused by *Colletotricum spp.* and other filimentous fungi in pigweed cut-stem assay. 50 fungal isolates from diseased pigweed plants were assayed for virulence 14 days after inoculation. (B) Fungal strains AF22 and AF24 (not shown) induced charring necrosis on Palmer pigweed plants, which is consistent with damage induced by phytotoxins.

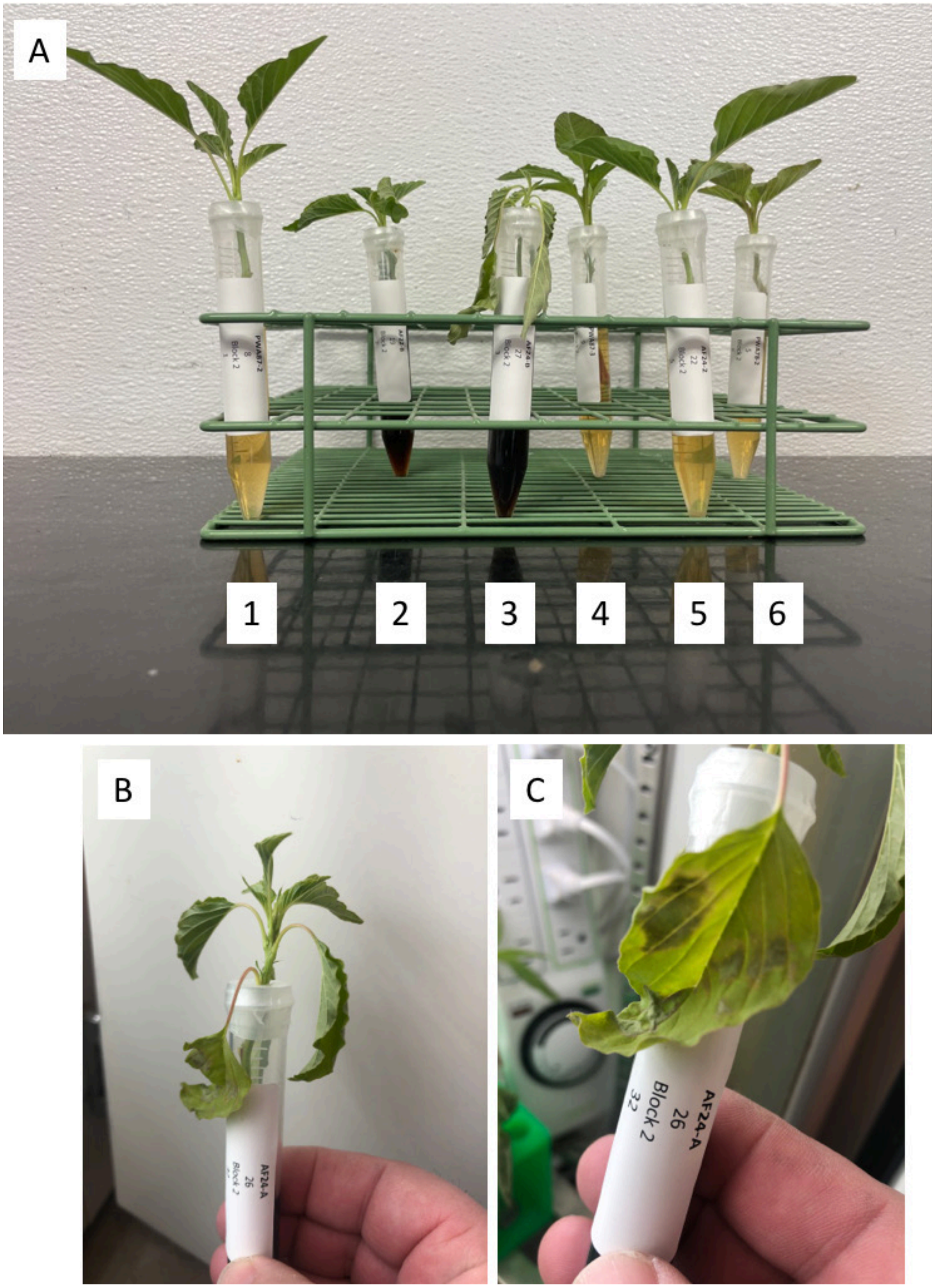

Fig. 2. Results of the toxin translocation assay to assess the potential production of host-selective toxins targeting Palmer pigweed. (A) Representative symptoms induced 24 h after exposure to culture filtrates from strains 1. PWA87 (4-week-old culture), 2. AF22 (4-week-old culture), 3. AF24 (4-week-old culture), 4. PWA87 (2-week-old culture), 5. AF24 (2-week-old culture), and 6. PWA78 (4-week-old culture). (B) Example of wilting induced by strain AF24 (4-week-old culture) after 48 h exposure to culture filtrate. (C) Close-up of discolored foliar tissue, consistent with phytotoxin-induced damage, induced by culture filtrate from strain AF24, 48 h after exposure.

PEST MANAGEMENT: INSECT CONTROL

Impact of Purified *ChinNPV* on Soybean Looper Control

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Abstract

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 2021 to evaluate selected formulations of *Chrysodeixis includens* nucleopolyhedro-virus (*ChinNPV*), for control of soybean looper in soybean. Purified formulation 2 provided the quickest control, although all formulations provided equivalent control 14 days after treatment (DAT). When using purified formulation 2 in a field setting, soybean looper control occurred between 10–14 DAT.

Introduction

Soybean looper, *Chrysodeixis includens*, (SBL) is a major soybean pest in the mid-southern United States. In Arkansas, growers experienced approximately $15 million in losses due to this pest in 2020 (Musser et al., 2021). In 2020, soybean looper infested approximately 65% of Arkansas soybean [*Glycine max* (L.) Merr.] acres resulting in 510,220 bushels in losses. Approximately 20% of the infested acreage was treated with an insecticide application averaging $15.92 per acre. (Musser et al., 2021). The annual migration of soybean looper coincides with late-season soybean production. After entering a field, this pest can quickly cause severe defoliation resulting in yield reductions if left untreated (Carner et al., 1974). Synthetic insecticides (pyrethroids) have become less effective due to resistance by soybean looper (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 the control of soybean looper.

ChinNPV is a naturally occurring virus capable of producing epizootic events in soybean looper (Fuxa and Ritcher 2001). Ingestion of occlusion-derived virus of *ChinNPV* by the soybean looper provides control by addition production of budded virus causing infection spread within the host allowing for the spread of more virus upon mortality. Trials were conducted to evaluate purified *ChinNPV* as a potential alternative for synthetic insecticides in Arkansas soybean production.

Procedures

Soybean Looper ChinNPV Formulation Comparison Trial

A study was conducted at the University of Arkansas System Division of Agriculture's Lonoke County Extension Center, Lonoke, Ark., to evaluate the efficacy of multiple formulations of *ChinNPV* for the control of soybean looper in soybean. Treatments included commercial Chrysogen® and 2 formulations of purified *ChinNPV* at 2 oz/ac. Commercial Chrysogen® consists of *ChinNPV* isolate 460 with 7.5 x 109 occlusion bodies per milliliter and 65.8% diet substrate. Purified *ChinNPV* #1 and #2 consist of *ChinNPV* isolate 460 with 7.5 x 109 occlusion bodies per milliliter with the diet substrate removed. Each treatment was replicated 30 times and arranged in a randomized complete block design. Leaf disks (1.5 in.) were punched from vegetative soybeans (Asgrow 46X6) and dipped into Chrysogen® treatments. Treatments were maintained in an insect incubator at a 14:10 light: dark ratio and 85 °F:78 °F, respectively. All treatments were evaluated daily up to 14 DAT for percent defoliation and mortality. Defoliation percentages were obtained from the LeafByte app (Adam Campbell) installed on an iPhone X (Apple, Cupertino, Calif.). All data were analyzed using JMP Pro v16 (JMP, Version 16, SAS Institute Inc., Cary, N.C.). Differences were determined by utilizing Tukey's honestly significant difference (HSD) at $\alpha = 0.05$. Formulation of *ChinNPV* was considered a fixed effect. Random effects consisted of cumulative leaf area consumed, percent mortality, and day of mortality.

Soybean Looper Purified Field Trial

A field study was conducted in Tillar, Ark. Consisting of 4 treatments (UTC; Intrepid Edge® 6 oz/ac; Purified Formulation 2, 2oz/ac; Purified Formulation 2, 4 oz/ac) with 4 replications per treatment to evaluate soybean looper efficacy. A randomized complete block design was implemented with a plot size of 4 rows (38-in. row spacings) by 40-ft long. Treatment applications were made to soybean (Asgrow 46XF2) on 12 August with a Mudmaster using 10 gal/ac at 40 psi. Soybean looper density was collected twice per plot using a

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standard black shake sheet. ACCUPAR LP-80 (Meter Group, Inc., Pullman, Wash.), a handheld device, was used to determine light penetration of the soybean canopy and leaf area index (LAI) to correlate defoliation. All treatments were evaluated at 7, 10, and 14 DAT for SBL density and LAI readings. All data were analyzed using JMP Pro v16 (JMP, Version 16, SAS Institute Inc., Cary, N.C.). Differences in SBL density and LAI were determined using Tukey's honestly significant difference at $\alpha = 0.05$. Treatment and dates of observations were considered fixed effects. Random effects consisted of replication and location.

Results and Discussion

Soybean Looper ChinNPV Formulation Comparison Trial

At 1–4 days after application (DAA), no purified *ChinNPV* treatments differed from the untreated check (UTC) (Table 1). 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 2). At 7–14, DAA purified *ChinNPV* treatments had less defoliation than the UTC 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.

Soybean Looper Purified Field Trial

Intrepid Edge® reduced SBL densities compared to UTC and Chrysogen treatments at 7 and 10 DAT (Table 3). A reduction in SBL density was observed for all rates of Chrysogen formulation 2 when compared to the UTC and Intrepid Edge at 14 DAT (Table 3). No difference was observed in LAI readings for all days of observation (Table 4).

Practical Applications

With the increased insecticide resistance in soybean looper populations and the increasing cost of soybean production, Arkansas growers need a cost-effective product for soybean looper control. In the formulation comparison, all treatments provided equivalent control, with purified ChinNPV formulation 2 providing quicker control when compared to other treatments. Soybean looper control occurred between 10–14 DAT when applied in the field trial. Purified ChinNPV is not available for large-scale use; therefore, applications are not recommended at this time until increased efficacy is observed.

Acknowledgments

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Literature Cited

Boethel, D.J., J.S. Mink, A.T. Wier, J.D. Thomas, B.R. Leonard, and F. Gallardo. 1992. Management of insecticide-resistant soybean loopers (*Pseudoplusia includens*) in the southern United States L.G. Copping, M.B. Green, R.T. Rees (Eds.), Pest Management in Soybean. Springer. Dordrecht. Pp. 66-87.

Carner, G.R., M. Shepard and S.G. Turnipseed. 1974. Seasonal Abundance of Insect Pests of Soybeans. J. Econ. Entomol. 67: 487-493.

Felland, C.M., H.N. Pitre, R.G. Luttrell, and J.L. Hamer. 1990. Resistance to pyrethroid insecticides in soybean looper (Lepidoptera: Noctuidae) in Mississippi. J. Econ. Entomol. 83, No.1, 35–40.

Fuxa, J. R. and A. R. Richter. 2001. Quantification of Soil-to-Plant Transport of Recombinant Nucleopolyhedrovirus: Effects of Soil Type and Moist, Air Currents, and Precipitation. Appl. Environ. Microbiol. 67. 5166-5170.

Musser, F.R., A.L. Catchot, Jr., S.P. Conley, J.A. Davis, C. DiFonzo, J.K. Greene, G.M. Lorenz, D. Owens, D.D. Reisig, P. Roberts, T. Royer, N.J. Seiter, R. Smith, S.D. Stewart, S. Taylor, K. Tilmon, R.T. Villanueva, and M.O. Way. 2020. 2019 soybean insect losses in Southern US. Midsouth Entomol. 11: 1-23.

Table 1. Total Area Consumed (cm^2) up to 7 days after treatment (DAT) for 2021 Soybean Looper Formulation Comparison Trial.

Treatment	1 DAT	2 DAT	3 DAT	4 DAT	5 DAT	6 DAT	7 DAT
Untreated Check	5.34 a†	10.26	15.56	25.19	35.94	47.12 a	57.52 a
Commercial Chrysogen®	3.24 b	8.17	13.56	21.24	29.06	33.13 b	35.48 b
Purified Formulation #1	4.11 ab	9.63	15.97	25.17	33.62	38.07 b	39.43 b
Purified Formulation #2	4.42 ab	9.87	15.89	24.72	29.38	30.26 b	30.87 b
P value	0.028	0.12	0.25	0.22	0.11	0.0007	<0.0001

† Means followed by the same letter are not significantly different at *P* = 0.10.

Table 2. Soybean looper formulation comparison trial mortality up to 7 days after treatment (DAT) in 2021.

Treatment	4 DAT	5 DAT	6 DAT	7 DAT
Untreated Check	13.33 a†	16.67 a	16.67 a	16.67 a
Commercial Chrysogen®	16.67 ab	33.33 b	73.33 b	76.67 b
Purified Formulation #1	10 a	53.33 c	73.33 b	83.33 b
Purified Formulation #2	26.67 b	76.67 d	90 c	93.33 b
P value	0.0125	<0.0001	<0.0001	<0.0001

† Means followed by the same letter are not significantly different at *P* = 0.10.

Table 3. Soybean Looper (SBL) density at 7, 10, and 14 days after treatment (DAT) for 2021 Soybean Looper Purified Field Trial in Tillar, Ark.

Treatment	7 DAT	10 DAT	14 DAT
Untreated check	29 a†	31.25 a	19.25 a
Intrepid Edge (6 oz)	3.25 b	8 b	12.25 b
Chrysogen (2 oz)	28 a	21.5 a	6.0 d
Chrysogen (4 oz)	34 a	19.5 ab	9.5 c
P value	<0.0001	0.0169	<0.0001

† Means followed by the same letter are not significantly different at *P* = 0.10.

Table 4. Leaf Area Index (LAI) readings at 7, 10, and 14 days after treatment (DAT) for 2021 Soybean Looper Purified Field Trial conducted in Tillar, Ark.

Treatment	7 DAT	10 DAT	14 DAT
Untreated check	5.7	6.1	4.77
Intrepid Edge (6 oz)	5.56	6.56	4.98
Purified formulation #2 (2 oz)	5.31	6.22	4.75
Purified formulation #2 (4 oz)	5.76	5.85	4.73
P value	0.28	0.78	0.94

† Means followed by the same letter are not significantly different at *P* = 0.10.

Preliminary Tests on the Impact of Water Hardness on Chlorantraniliprole Efficacy

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Abstract

Insecticide efficacy often varies by location and year. Many factors can influence an insecticide's efficacy, but an often-overlooked factor is the quality of water in a carrier solution. Multiple experiments were conducted to evaluate the impact of water on insecticide efficacy. In the first experiment, leaf dip assays were conducted with chlorantraniliprole on corn earworm (*Helicoverpa zea*) using soybean [*Glycine max* (L.) Merr.] leaves. Serial dilutions were used to achieve a concentration of 6 ng/ml of chlorantraniliprole in 4 different water samples with a hardness of 10.9, 20, 178, and 430 ppm, respectively. Larvae were placed on leaves after drying, and larval mortality was rated at 24 and 48 hours. In the second experiment, chlorantraniliprole at a rate of 14 oz/ac was mixed with 3 different water samples with a hardness of 10.9, 178, and 430 ppm, respectively, then applied to soybean plants. Leaves were pulled from each plant at 1, 7, 21, 28, and 35 days, and larvae were placed on the leaves and checked for mortality at 24 and 48 hours. In the first experiment, very hard water reduced the control of chlorantraniliprole at 24 and 48 hours when compared to soft and very soft water. In the second experiment, there was reduced mortality as hardness increased.

Introduction

Most insecticides used in agriculture must be dissolved or suspended in water. A spray solution is often 95% or more water. Water is seen as a clean input, and its quality is often overlooked. Measures of water quality consist of hardness and pH. Water hardness is the amount of dissolved calcium and magnesium in water. Spray solutions containing hard water have the potential to cause antagonism. Antagonism may reduce the degree or speed of pesticides' activity or active ingredient uptake. Water hardness in the mid-South ranges from very soft to very hard (H2O Distributors, 2022). The pH of water is how acidic or alkaline the solution is. Water at various pH ranges in a spray solution may affect how long the molecule in the pesticide stays intact. Most pesticides perform best in slightly acidic water (Whitford et al., 2009). The objective of this study is to evaluate the impact of water hardness on corn earworm (*Helicoverpa zea*) insecticides in soybean [*Glycine max* (L.) Merr.].

Procedures

The University of Arkansas System Division of Agriculture's Lonoke County Extension Center conducted a soybean leaf dip assay on chlorantraniliprole to control the corn earworm. The assays consisted of 5 treatments, including the untreated check. Water samples at a hardness of 10.9 ppm, 20 ppm, 178 ppm, and 430 ppm were mixed with chlorantraniliprole. The hardness of the water samples was determined with a multifunction water quality tester and a Waypoint Analytical water test. These samples were 1000ml of water at the designated hardness with 6 ng/ml of chlorantraniliprole. Leaf discs with a diameter of 3/4-in. were dipped in each treatment. The leaves were dried and placed in 100 mm Petri dishes with a damp cotton pad and a third instar corn earworm larvae. The leaf dip was in unrandomized order, with each treatment containing 30 dishes. The larva was observed at 24 and 48 hours for mortality. Data were analyzed using PROC GLIMMIX with SAS v 9.4 at an alpha level of 0.05.

A greenhouse trial was conducted at the University of Arkansas System Division of Agriculture's Lonoke County Extension Center. In this experiment, chlorantraniliprole at a rate of 14 oz/ac was mixed with 3 water samples with a hardness of 10.9, 178, and 430 ppm, then sprayed using a spray chamber on soybean plants at the V3 growth stage. This consisted of 4 treatments, including an untreated check. Leaves were pulled from the soybean plants at 1, 7, 21, 28, and 35 days and cut into leaf discs with a diameter of 1.5 inches. Leaf discs were placed into a 100 mm Petri dish with a damp cotton pad and a third instar corn earworm larva. The larvae were observed 24 and 48 hours after each of the pull dates. Only 48-hour data is reported. This test was arranged in unrandomized order, with each treatment containing 30 dishes.

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Results and Discussion

The results from the leaf dip assays show that very soft water, 10.9 ppm, and soft water, 20 ppm, mixed with chlorantraniliprole have a higher mortality percentage than the very hard water, 430 ppm, mixed with chlorantraniliprole at 24 and 48 hours after treatment (Fig. 1). At 2 DAA, hard water, 178 ppm, with chlorantraniliprole had the lowest mortality. At 8 DAA, soft water, 20 ppm, with chlorantraniliprole had the lowest mortality. For the remainder of the test, the very hard water, 430 ppm, with chlorantraniliprole had the lowest percent mortality of all treatments, with percent mortality being 27%, 14%, and 17% lower than the soft water, 20 ppm, with chlorantraniliprole at 22, 29, and 36 DAA, respectively (Fig. 2). These are preliminary results and must be further replicated. However, these data indicate that hard water may have a negative impact on the residual control of chlorantraniliprole.

Practical Applications

Insecticide efficacy often varies from field to field. One thing that many growers commonly overlook is water quality. These results show a trend indicating a decrease in chlorantraniliprole's residual control as water hardness increases. This research and future studies will be used to help make recommendations to growers for water conditioners in a spray solution to improve insect control in soybean.

Acknowledgments

We want to think Arkansas Soybean Promotion Board for funding and Helena Agri-Enterprises. Support was also provided by the University of Arkansas System Division of Agriculture.

Literature Cited

H2O Distributors, Inc., 2022. Water hardness map of the United States. Accessed 10 Aug. 2022, Available at: https://www.h2odistributors.com/pages/info/hard-water-map.asp

Whitford, F., Penner, D., Johnson, B., Bledsoe, L., Wagoner, N., Garr, J., Wise, K., Obermeyer, J., and A. Blessing. 2009. The impact of water quality on pesticide performance. Accessed 5 Aug. 2022. Available at: https://www.extension.purdue.edu/extmedia/ppp/ppp-86.pdf

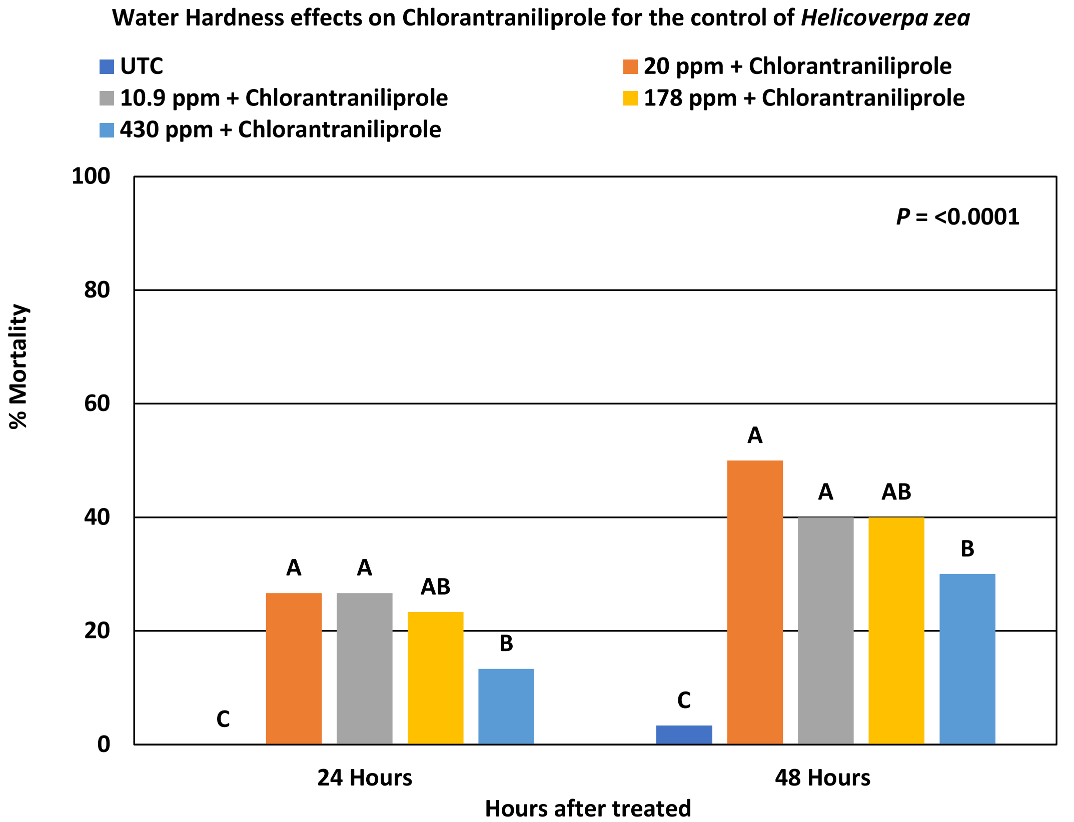

Fig. 1. Percent mortality observations of chlorantraniliprole treatments for control of corn earworm (*Helicoverpa zea*). Means followed by the same letter are not statistically significant at α = 0.05.

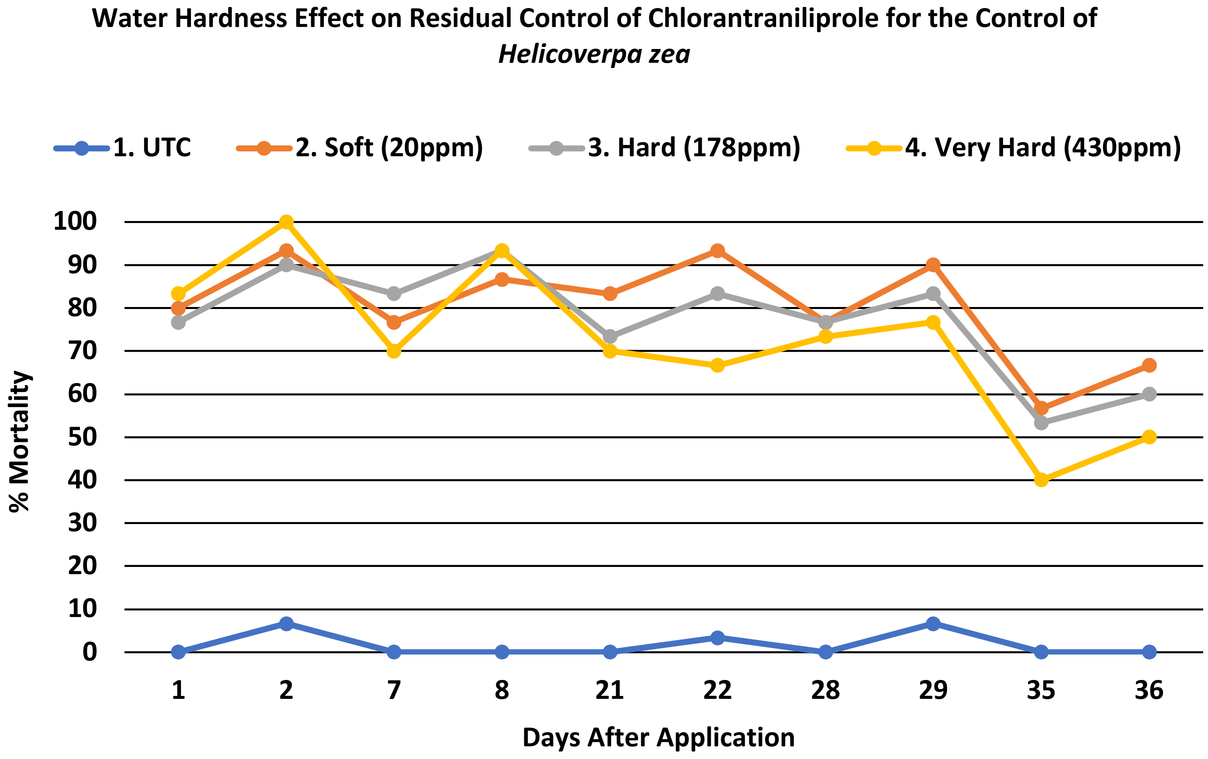

Fig. 2. Percent mortality observations on chlorantraniliprole residual.

PEST MANAGEMENT: INSECT CONTROL

Management of Slugs in Soybean

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Abstract

Slugs are becoming a more frequent soybean pest in Arkansas as farms shift to more no-till or cover crop cropping systems. Slugs feed on the leaf material of small soybean plants and can cause stand loss if feeding is severe. Currently, there are very few chemical control options for slugs. Metaldehyde (Deadline® MP) is the main control option; however, it is costly to growers. Therefore, a study was conducted in 2021 to determine if there are more economical ways to apply Deadline to achieve adequate slug control while being more cost-efficient. For stand counts and yield, the standard 10 lb broadcast rate of Deadline performed the best; however, some trends suggest that either going with a reduced rate or banded rate could still provide adequate control of slugs while reducing the price significantly.

Introduction

No-till and cover crops are gaining popularity in many areas of Arkansas. With these changes in production practices come new challenges with insect pest management. In many of these situations, especially in a cool, wet spring, slugs can become a major problem in soybean (Hammond, 1985). Slugs feed on and defoliate seedling soybean and can cause plant death. Metaldehyde (Deadline® MP) is the only product labeled for the control of slugs in row crops. Unfortunately, this product is expensive, and many growers do not want to pay for it. The objective of this study was to determine if the rate could be reduced or if banding this product could provide adequate control of slugs and reduce the overall cost for the grower.

Procedures

A study was conducted in Jackson County, Arkansas, in 2021 to compare multiple rates and application methods with Metaldehyde (Deadline MP) for slug control in soybean. Application methods included broadcast at 10 lb/ac and 5 lb/ac, banded applications at the same rates, and a non-treated control. Treatments were arranged as a randomized complete block design with four replications. All applications were made using a Wintersteiger cone-fertilizer, with 10 "Y" drop tubes on 7.5-in. spacing. For the banded application, drop tubes not directly over the drill row were blocked off to ensure that the Metaldehyde was only applied to the drill row. All applications were made on the day of planting. Stand counts were taken 7 and 30 d after emergence, and yield was obtained with a plot combine with moisture corrected to 13%. All data were analyzed using PROC GLIMMIX in SAS v 9.4 (SAS Institute, Cary, N.C.) with an alpha level of 0.05.

Results and Discussion

Only the 10 lb/ac broadcast rate of Deadline increased soybean stands compared to the untreated control at 7 d after emergence. At 30 d after emergence, all Deadline rates and application methods increased soybean stand compared to the untreated control. Both broadcast rates of Deadline increased soybean yields compared to the untreated control; however, only the 10 lb/ac rate yielded higher than the banded applications (Table 1).

Practical Applications

In general, broadcast applications of Deadline, whether it was 10 lb/ac or 5 lb/ac, performed better than banded rates. However, general trends were observed throughout the data to suggest some potential for banded applications. For now, our recommendation will be to broadcast Deadline for control of slugs in cover crop and no-till situations. A final stand of 4.4 plants per row foot is needed to achieve a maximum yield potential of 30 bu./ac in dryland soybean. All treatments, except the 10 lb/ac broadcast rate, had stand reductions that lowered the final stand count below the recommended population. Only the broadcast treatments yielded high enough to pay for using Deadline in this situation.

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Promotion Board for funding this work and the University of Arkansas System Division of Agriculture.

Literature Cited

Hammond, R.B, 1985. Slugs as a new pest of soybeans. J. Kan. Entomol. Soc. 364-366.

Table 1. Deadline®MP rate and application method for slug control in soybean.

Treatment	7 DAE†	30 DAE	Yield
	---------plants/10 row ft-------		bu./ac
Untreated Control	27.8 b‡	26.3 b	42.5 c
Broadcast 10 lb/ac	44.0 a	45.0 a	49.8 a
Broadcast 5 lb/ac	34.5 ab	36.8 a	47.3 ab
Banded 10 lb/ac	38.0 ab	40.5 a	44.8 bc
Banded 5 lb/ac	34.0 ab	39.5 a	44.0 bc
P-value	<0.01	<0.01	<0.01

†DAE = Days after emergence.

‡ Means followed by same letter are not significantly different at an alpha level of 0.05.

PEST MANAGEMENT: INSECT CONTROL

Analysis of Five Years of Soybean Looper and Corn Earworm Insecticide Efficacy and Residual Control

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Abstract

The 2 most damaging lepidopterous soybean pests in Arkansas are corn earworm (*Helicoverpa zea*) and soybean looper (*Chrysodeixis includens*). On average, corn earworm is soybean's most damaging insect pest [*Glycine max* (L.) Merr.] in Arkansas, soybean looper is the third most damaging. The objective of this study was to combine data from the past 5 years of corn earworm and soybean looper insecticide efficacy trials and examine commonly recommended products for efficacy and residual control of these pests. Data indicate chlorantraniliprole and chlorantraniliprole + pyrethroid provided the greatest control of corn earworm while Denim® 8 oz/ac, Intrepid Edge® 5 oz/ac, and chlorantraniliprole provided the greatest control of soybean looper.

Introduction

The 2 most damaging lepidopterous pests of soybean [*Glycine max* (l.) Merr.] in Arkansas are corn earworm (*Helicoverpa zea*) and soybean looper (*Chrysodeixis includens*). On average, corn earworm is the most damaging insect pest of soybean in Arkansas, while soybean looper is the third most damaging (Musser et al. 2017, 2018, 2019, 2020, 2021). Corn earworm is typically a problem in Arkansas soybean when fields reach the early reproductive stage, preferring to feed on soybean flowers and pods. On the other hand, loopers usually become an issue later in the growing season on later planted soybean and prefer to feed on foliage (Carner et al., 1974). Loopers that infest Arkansas soybean are made up of a complex of 2 insects, cabbage looper and soybean looper. Cabbage looper (*Trichoplusia ni*) is susceptible to pyrethroid insecticides, whereas soybean looper is not (Leonard et al., 1990). Because the two species are difficult to distinguish, all loopers should be considered soybean loopers, and pyrethroids should be avoided when treatment is required. Corn earworm and soybean looper do not typically infest soybean fields at treatment level at the same time, although this does occasionally happen in late-planted soybean. Some newer products provide extended residual control that may be able to control both pests with a single insecticide application. Each year, multiple insecticide efficacy trials are conducted to evaluate new products' efficacy and residual control and ensure that those currently recommended continue to provide acceptable levels of control. The objective of this study was to combine data from the past 5 years of corn earworm and soybean looper insecticide efficacy trials and examine commonly recommended products for efficacy and residual control of these pests.

Procedures

Data from 44 soybean looper and corn earworm efficacy trials conducted from 2017 to 2021 were combined for analysis. Treatments included in the analysis were chlorantraniliprole (Prevathon® 14 oz/ac, Vantacor® 1.2 oz/ac), chlorantraniliprole + pyrethroid (Besiege® 7 oz/ac, Besiege 8 oz/ac, Elevest® 6.75 oz/ac), Denim® 8 oz/ac, Intrepid Edge® 5 oz/ac, and pyrethroid (Warrior® 1.92 oz/a, Silencer® 3.65 oz/a, Bifenture® 6.4 oz/a). The plot size for all trials was 12.5 ft. by 40 ft., and the treatments were arranged in a randomized complete block with 4 replications. Applications were made using a Mudmaster high clearance sprayer fitted with Teejet XR 8002 dual flat fan nozzles at 19.5 in. spacing with a spray volume of 10 gal/ac at 40 psi. Plots were evaluated by making 25 sweeps per plot with a standard 15-in. diameter sweep net. Insect densities from each trial were standardized by converting means to percent control relative to the untreated check. The data were analyzed using JMP 15.2 (SAS Institute Inc., Cary, NC, 1989–2021). Means were separated using Tukey's honestly significant difference ($P \leq 0.10$).

Results and Discussion

Both chlorantraniliprole and chlorantraniliprole + pyrethroid provided the best control of corn earworm, and they had greater residual control than all other products (Table 1, Fig. 1). Intrepid edge provided greater control of corn earworm than a pyrethroid alone, but not as good as any of the chlorantraniliprole-containing products. In addition, all products provided better control for soybean looper than the tested pyrethroids, which only provided 35% control, due to widespread pyrethroid resistance in soybean looper (Fig. 2).

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These data indicate that Intrepid Edge, Denim, and chlorantraniliprole provided the greatest control of soybean looper.

The residual control in this analysis is likely more accurately reflected in the corn earworm data than in the soybean looper data due to reinfestations of corn earworm occurring more frequently than reinfestations of soybean looper. Once a soybean looper infestation is controlled, the likelihood of reinfestation is low, thus giving the appearance of extended residual control.

Practical Applications

These data show products providing the greatest initial and residual control of corn earworm and soybean looper across years and locations. These results will allow growers to make a more informed decision when selecting an insecticide to control either of these pests.

Acknowledgments

We want to thank the Arkansas Soybean Promotion Board, ADAMA Agricultural Solutions, Corteva Agriscience, Syngenta AG, FMC Corporation, and UPL Ltd. for helping to fund this research. The University of Arkansas System Division of Agriculture also provided funding and resources.

Literature Cited

Carner, G.R., M. Shepard, S.G. Turnipseed. 1974. Seasonal Abundance of Insect Pests of Soybeans. J. Econ. Entomol. Volume 67. Issue 4. Pp. 487–493. Accessed: 13 April 2022. Available at https://doi.org/10.1093/jee/67.4.487

Musser, F.R., G.M. Lorenz, S.D. Stewart, and A.L. Catchot. 2017. 2016 soybean insect losses for Mississippi, Tennessee, and Arkansas. Mid-south Entomol. 10: 1–13.

Musser, F.R., A.L. Catchot, Jr., J.A. Davis, D.A. Herbert, Jr. B.R. Leonard, G.M. Lorenz, T. Reed, D.D. Reisig, and S.D. Stewart. 2018. 2017 soybean insect losses in the Southern US. Midsouth Entomol. 11: 1–23.

Musser, F.R., A.L. Catchot, Jr., S.P. Conley, J.A. Davis, C. DiFonzo, J. Greene, G.M. Lorenz, D. Owens, T. Reed, D.D. Reisig, P. Roberts, T. Royer, N.J. Seiter, S.D. Stewart, S. Taylor, K. Tilmon, R.T. Villanueva, and M.O. Way. 2019. 2018 soybean insect losses in the Southern US. Mid-south Entomol. 12:1-24.

Musser, F.R., A.L. Catchot, Jr., S.P. Conley, J.A. Davis, C. DiFonzo, J.K. Greene, G.M. Lorenz, D. Owens, D. D. Reisig, P. Roberts, T. Royer, N.J. Seiter, R. Smith, S.D. Stewart, S. Taylor, K. Tilmon, R.T. Villanueva, and M.O. Way. 2020. 2019 soybean insect losses in the United States. Mid-south Entomol. 13:1-23.

Musser, F.R., A.L. Catchot, Jr., S.P. Conley, J.A. Davis, C. DiFonzo, S.H. Graham, J.K. Greene, R.L. Koch, D. Owens, D.D. Reisig, P. Roberts, T. Royer, N.J. Seiter, S.D. Stewart, S. Taylor, B. Thrash, K. Tilmon, R.T. Villanueva, and M.O. Way. 2021. 2020 soybean insect losses in the United States. Mid-south Entomol. 14:1-25.

Leonard, R.B., D.J. Boethel, A.N. Sparks, Jr., B.M. Layton, J.S. Mink, A.M. Pavloff, E. Burris, J.B. Graves. 1990. Variations in Response of Soybean Looper (Lepidoptera: Noctuidae) to Selected Insecticides in Louisiana. J. Econ. Entomol. Volume 83. Issue 1. Pp. 27–34, Accessed 13 April 2022. Available at https://doi.org/10.1093/jee/83.1.27

Table 1. Season-long mean percent control for corn earworm (*Helicoverpa zea*)and soybean looper (*Chrysodeixis includens*) with selected insecticides. Means followed by the same letter are not significantly different ($P < 0.10$).

Treatment	Corn Earworm	Soybean Looper
	-------------------------% control----------------------	
Chlorantraniliprole	94.3 a	84.8 ab
Chlorantraniliprole + Pyrethroid	93.1 a	79.2 b
Denim® 8 oz/a	76.1 bc	86.4 ab
Intrepid Edge® 5 oz/a	84.1 b	89.2 a
Pyrethroid	76.3 c	37.4 c
Untreated Check	0 d	0 d
	$P < 0.0001$	$P < 0.0001$

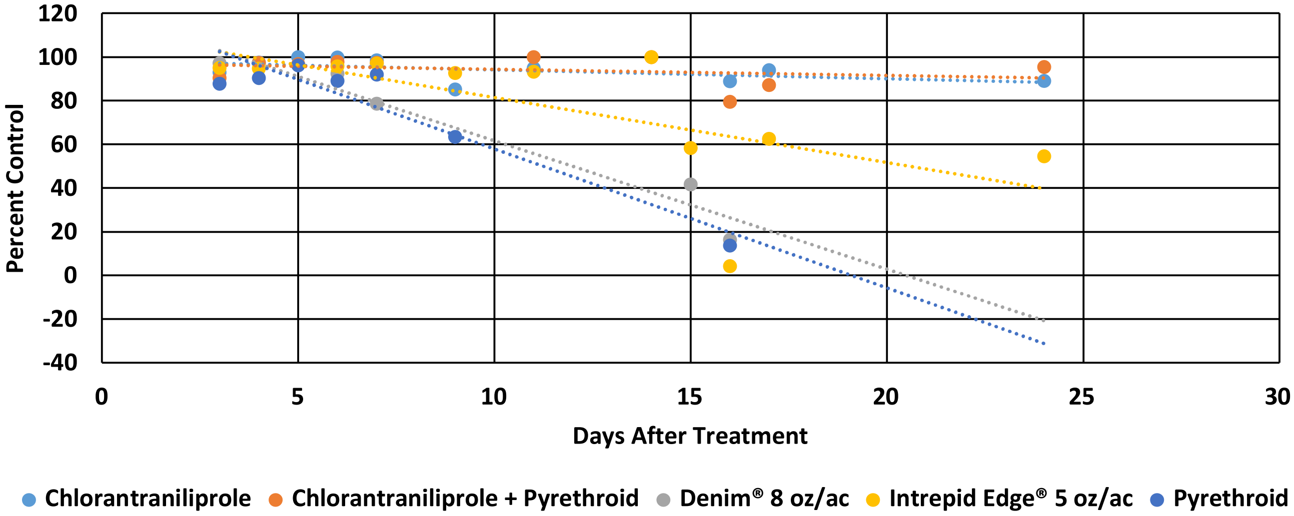

Fig. 1. Percent control of corn earworm (*Helicoverpa zea*) with selected insecticides over time.

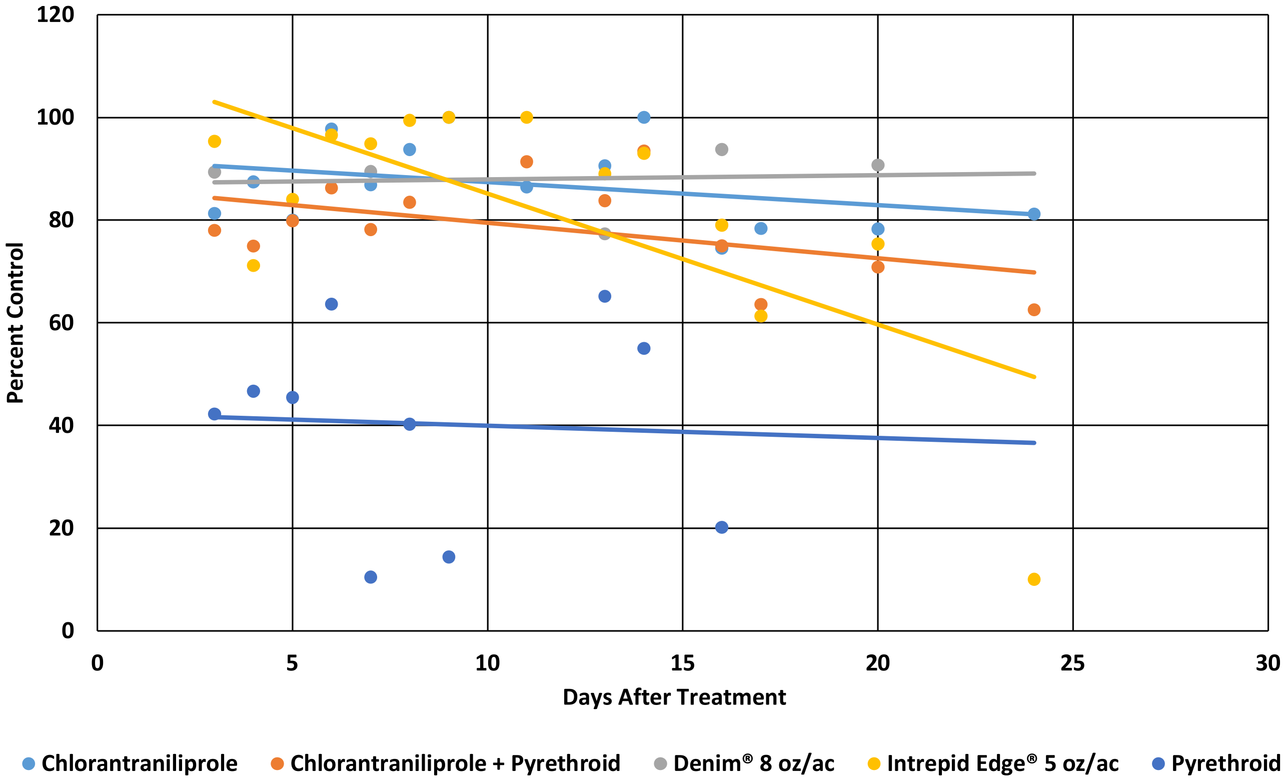

Fig. 2. Percent control of soybean looper (*Chrysodeixis includens*) with selected insecticides over time.

Understanding the Glufosinate Resistance Mechanism in a Mississippi County Palmer amaranth Population

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T.H. Avent,[1] and L.B. Piveta[1]*

Abstract

Resistance to glufosinate in Palmer amaranth [*Amaranthus palmeri* (S.) Watson] was first reported in 2021 in Arkansas, and evaluating alternative control options for these resistant populations is a high priority. Enhanced herbicide detoxification by glutathione S-transferase (GST) enzymes is one of the possible resistance mechanisms responsible for glufosinate resistance. Therefore, experiments were designed to evaluate if adding a GST-inhibitor would overcome glufosinate resistance in Palmer amaranth and quantify the number of chloroplastic glutamine synthetase (*GS2*) gene copies present in resistant plants. Seedlings of the resistant (20-59) and susceptible (SS) accessions were transplanted into a field at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark. The treatments were glufosinate applied at 10 a.m., glufosinate at 10 p.m., and glufosinate + GST-inhibitor [NBD-Cl (4-chloro-7-nitrobenzofurazan)] at 10 p.m. The total number of plants per accession in each plot was counted prior to and 2 weeks after application to calculate mortality (%). Concomitantly with the field experiment, a gene copy number assay was conducted with DNA extracted from nontreated plants from 2 different susceptible accessions and glufosinate survivors from accession 20-59. *GS2* copy number was calculated relative to 2 standard genes. Overall, mortality was 17% and 97% for 20-59 and SS, respectively. Mortality did not differ among treatments. Relative to 2 reference genes, the gene copy number in the resistant accession was significantly higher than the susceptible tested. The resistant accession had 85 and 86 copies, while the 2 SS accessions had an average of only 2 *GS2* copies. An increase in the chloroplastic glutamine synthetase copy number in the resistant plants enables the production of enough enzymes to survive glufosinate, which explains why the addition of a GST-inhibitor had no impact on the control of glufosinate-resistant Palmer amaranth.

Introduction

According to a survey conducted in 2016, Palmer amaranth [*Amaranthus palmeri* (S.) Watson] is the most troublesome and common weed in soybean [*Glycine max* (L.) Merr.] (Van Wychen, 2019; Schwartz-Lazaro et al., 2018). Thus far, this weed has developed resistance to 9 distinct sites of action, including glufosinate (Heap, 2022; Priess, 2021). Glufosinate controls susceptible plants by inhibiting the glutamine synthetase enzyme and ultimately leading to the generation of detrimental amounts of reactive oxygen species (Takano et al., 2019). Even though resistance has been confirmed in Palmer amaranth, the mechanism that endows resistance is still unclear. Resistance mechanisms are divided into target-site resistance (TSR) and non-target-site resistance (NTSR). The TSR mechanism consists of alterations in the gene conferring resistance, while NTSR consists of mechanisms that decrease the amount of herbicide reaching the target protein (i.e., glutamine synthetase) (Délye et al., 2013; Powles and Yu, 2010). Since NTSR involves several metabolic changes in the plants, this resistance may be overcome with the addition of metabolic inhibitors such as glutathione S-transferase (GST) inhibitors to glufosinate. Previous research showed that control of Palmer amaranth with glufosinate has increased with the addition of a GST-inhibitor when sprayed under low-light conditions (Priess and Norsworthy, 2020). Therefore, the objectives of this study were to evaluate if adding a GST-inhibitor to glufosinate will impact the control of glufosinate-resistant Palmer amaranth, as well as quantify the number of glutamine synthetase gene copies present in resistant and susceptible plants.

Procedures

Palmer amaranth seedlings of the glufosinate-resistant (20-59) and susceptible (SS) Palmer amaranth accessions were grown in a greenhouse and then transplanted into a field located at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension

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Center in Fayetteville, Ark., in 2021. All plots had both accessions transplanted with the SS on the right and 20-59 on the left. Treatments were organized in a randomized complete block design with 4 replications. The treatments were Interline® (glufosinate, UPL Limited, King of Prussia, Penn., USA) applied at 10 a.m., Interline® at 10 p.m., and Interline® + GST-inhibitor [NBD-Cl (4-chloro-7-nitrobenzofurazan)] at 10 p.m. The rates for Interline® and NBD-Cl were 32 fl oz/ac and 0.11 lb/ac, respectively. All plots received a broadcast application of MoccasinTM (*S*-metolachlor, UPL Limited, King of Prussia, Penn., USA) at 21 fl oz/ac prior to transplant. The total number of plants per accession in each plot was counted prior to and 2 weeks after application to calculate mortality (%). Mortality data assumed a beta distribution and were subjected to analysis of variance using PROC Glimmix in SAS (v9.4). If significant, means were separated using Fisher's protected least significance difference ($\alpha = 0.05$).

Concomitantly with the field experiment, a gene copy number assay was conducted with DNA extracted from nontreated plants from two different susceptible accessions and glufosinate survivors from accession 20-59 sprayed with Interline® at 32 fl oz/ac. A quantitative real-time polymerase chain reaction (qPCR) was conducted to quantify the chloroplastic glutamine synthetase (*GS2*) copy number. The primer pair *GS2*-F (5'- ATCGTGGTTGCTCTATCCGTG-3') and *GS2*-R (5'-GTTTCTGCGAGCAAACCTGTT-3') were designed to amplify the *GS2* gene. The genomic copy number of *GS2* was calculated relative to reference genes previously used, Cinnamoyl-CoA reductase (CCR) and peter Pan-like (*PPAN*) (González-Torralva and Norsworthy, 2021). The assay was conducted in a CFX96 Real-Time System under the following conditions: 98 °C for 3 min, 40 cycles of 98 °C for 10 s, and 61 °C for 30 s. Dissociation curves were generated by raising the temperature from 65 °C to 95 °C, 0.5 °C every 5 s. Each accession had 4 biological samples tested, and each biological sample had 2 technical replicates for all primer pairs. The experiment was repeated in time. Blank controls with primers without DNA (substituted by deionized water) were included in each plate. Threshold cycles (Ct) were produced by CFX Maestro software. The genomic copy number of *GS2* was calculated using a modified version of the $2^{-\Delta\Delta}$Ct method (Gaines et al., 2010). Data were subjected to analysis of variance using JMP Pro 15 and separated using Fisher's protected least significance difference ($\alpha = 0.05$).

Results and Discussion

Overall, mortality was 17% and 97% for 20-59 and SS, respectively (Fig. 1). Similarly, Priess (2021), working with accession 20-59, obtained a low level of control with glufosinate applications. Although the addition of the GST-inhibitor showed a slight numerical increase, Palmer amaranth mortality did not differ among treatments to any of the accessions (Fig. 2). These results indicate that conjugation with glutathione *S*-transferases is not conferring glufosinate-resistance in the Palmer amaranth accession tested.

Relative to 2 reference genes, the gene copy number in the resistant accession was significantly higher than the 2 susceptible accessions tested (Fig. 3). The resistant accession had 85- and 86-copies, while the 2 SS accessions had an average of only 2 *GS2* copies. Copy number increase of the herbicide targeted gene has been seen before in Palmer amaranth. Gene amplification of the enzyme 5-enolpyruvylshikimate-3-phosphate synthase, the enzyme targeted by glyphosate, is one of the resistance mechanisms encountered in glyphosate-resistant Palmer amaranth accessions. Gene amplification of an herbicide target enzyme enables resistant plants to survive following herbicide application (Gaines et al., 2010; Singh et al., 2018).

Practical Applications

Glufosinate resistance in the Palmer amaranth accession tested is due to a target-site resistance mechanism (gene amplification). Therefore, the addition of metabolic inhibitors such as glutathione *S*-transferase inhibitors will unlikely affect its control. Even though metabolic resistance was not detected in this population, reliance on a single herbicide group should be avoided. Glufosinate is one of the foundational postemergence herbicides in Enlist®, Liberty Link®, and XtendFlex® technologies, and control of glufosinate-resistant Palmer amaranth in these systems is more likely to be achieved earlier in the season with the use of a residual herbicide program.

Acknowledgments

The authors would like to thank the fellow Weed Science graduate students at the Crop Science Laboratory for assisting in conducting this experiment and the University of Arkansas System Division of Agriculture for supporting this research. The authors also acknowledge the support provided by Arkansas soybean producers through checkoff funds administered by the Arkansas Soybean Promotion Board.

Literature Cited

Délye, C., M. Jasieniuk, and V. Le Corre. 2013. Deciphering the evolution of herbicide resistance in weeds. Trends Genet. 29(11):649-658.

Gaines, T.A., W. Zhang, D. Wang, B. Bukun, S.T. Chisholm, D.L. Shaner, S.J. Nissen, W.L. Patzoldt, P.J. Tranel, A.S. Culpepper, T.L. Grey, T.M. Webster, W.K. Vencill, R.D. Sammons, J. Jiang, C. Preston, J.E. Leach, and P. Westra. 2010. Gene amplification confers glyphosate resistance in Amaranthus palmeri. PNAS 107(3):1029-1034.

González-Torralva, F., and J.K. Norsworthy. 2021. Understanding resistance mechanisms to trifluralin in an Arkansas Palmer amaranth population. Genes 12(8):1225.

Heap, I. 2022. The international herbicide-resistant weed database. Accessed 18 Jan. 2022. Available at http://roadsideweeds.com/Summary/SpeciesbySOATable.aspx

Powles, S.B., and Q. Yu. 2010. Evolution in action: plants resistant to herbicides. Annu. Rev. Plant Biol. 61:317-347.

Priess, G.L., and J.K. Norsworthy. 2020. Making a better glufosinate: improving efficacy and alleviating environmental variability. WSSA/WSWS joint meeting. Accessed: 18 Jan. 2022. Available at https://wssa.net/wp-content/uploads/WSSA-WSWS-2020-Proceedings.html

Priess, G.L. 2021. Optimization and resistance mitigation of dicamba and glufosinate in XtendFlex® crops. Theses and Dissertations.

Schwartz-Lazaro, L.M., J.K. Norsworthy, L.E. Steckel, D.O. Stephenson, M.D. Bish, K.W. Bradley, and J.A. Bond. 2018. A midsouthern consultant's survey on weed management practices in soybean. Weed Technol. 32(2):116-125.

Singh, S., V. Singh, A. Lawton-Rauh, M.V. Bagavathiannan, N. Roma-Burgos. 2018. EPSPS gene amplification primarily confers glyphosate resistance among Arkansas Palmer amaranth (*Amaranthus palmeri*) populations. Weed Sci. 66(3):293-300.

Takano, H.K., R. Beffa, C. Preston, P. Westra, and F.E. Dayan. 2019. Reactive oxygen species trigger the fast action of glufosinate. Planta 249(6):1837-1849.

Van Wychen, L. 2019. 2019 Survey of the most common and troublesome weeds in broadleaf crops, fruits & vegetables in the United States and Canada. Weed Science Society of America National Weed Survey Dataset. Accessed: 18 Jan. 2022. Available at https://wssa.net/wp-content/uploads/2019-Weed-Survey_broadleaf-crops.xlsx

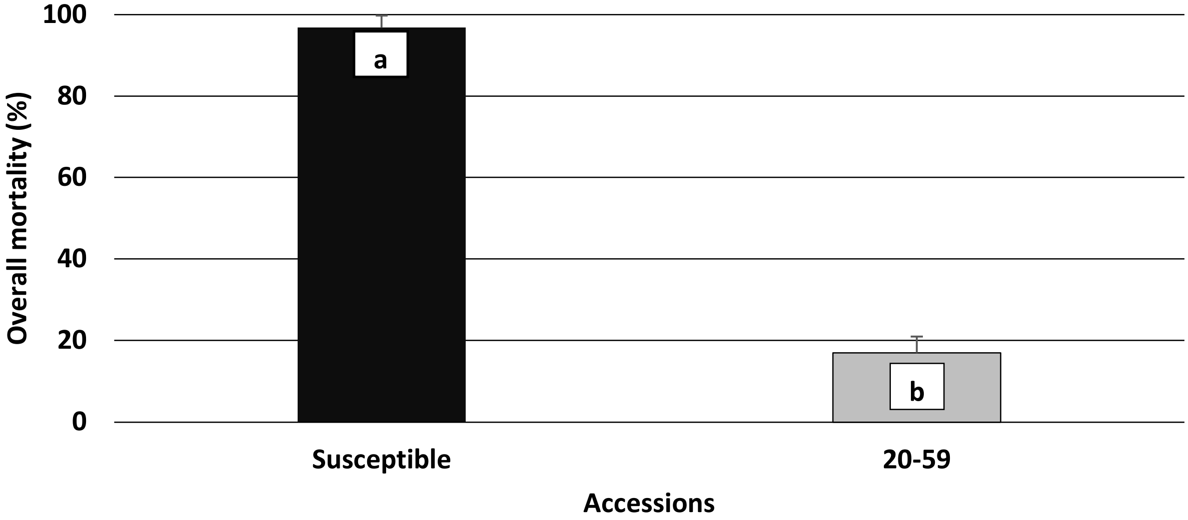

Fig. 1. Overall mortality across treatments by resistant (20-59) and susceptible accessions at 2 weeks after treatment. Treatments with the same lowercase letters are not significantly different according to Fisher's protected least significant difference at α = 0.05.

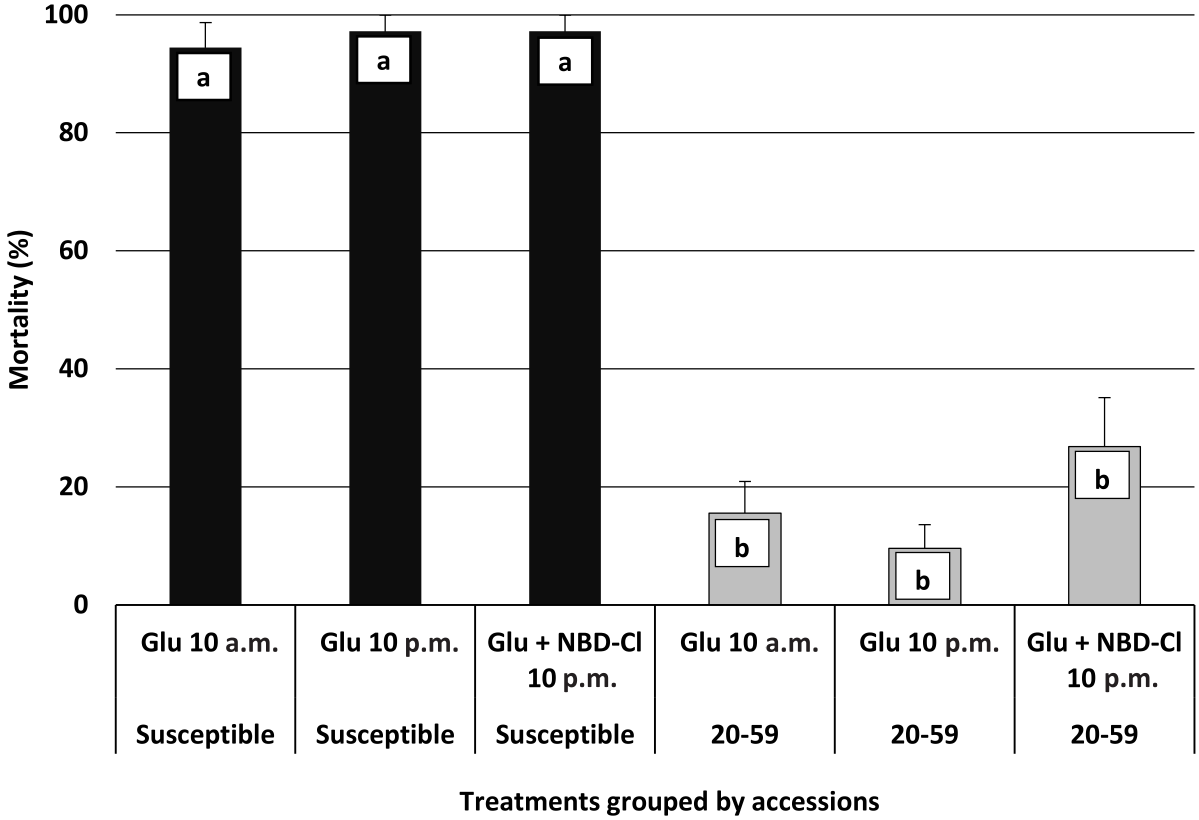

Fig. 2. Mortality per glufosinate (Glu) treatments with or without 4-chloro-7-nitrobenzofurazan (NBD-Cl) grouped by resistant (20-59) and susceptible at 2 weeks after treatment. Treatments with the same lowercase letters are not significantly different according to Fisher's protected least significant difference at α = 0.05.

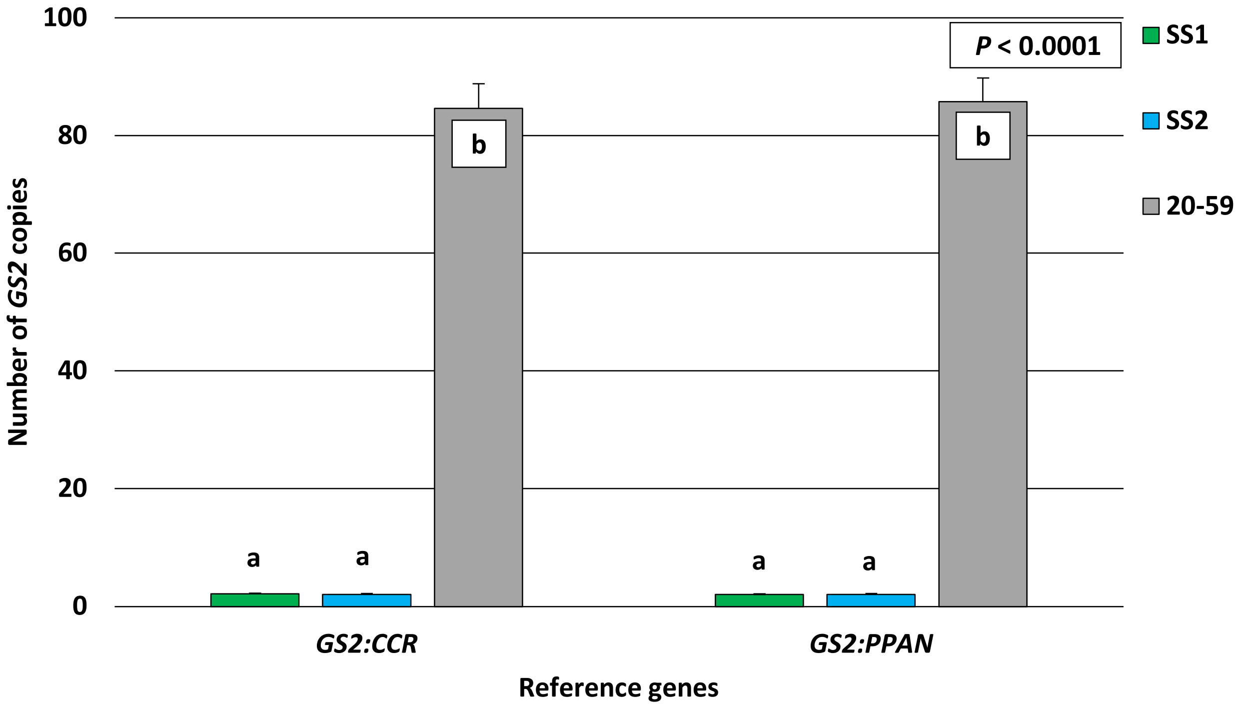

Fig. 3. Chloroplastic glutamine synthetase (*GS2*) copy number quantification calculated against Cinnamoyl-CoA reductase (CCR) and peter Pan-like (PPAN) genes in glufosinate-resistant (20-59) and two susceptible standards (SS1 and SS2). Treatments with the same lowercase letters are not significantly different according to Fisher's protected least significant difference at α = 0.05.

PEST MANAGEMENT: WEED CONTROL

Minimizing Off-Target Movement of Florpyrauxifen-benzyl to Drill-Seeded Soybean

B.L. Cotter,[1] J.K. Norsworthy,[1] M.C. Castner,[1] T.R. Butts,[2] and L.T. Barber[2]

Abstract

The commercial launch of florpyrauxifen-benzyl (Loyant™) in 2018 was followed by observed soybean [*Glycine max* (L.) Merr.] injury due to off-target movement of the herbicide. Hence, a field experiment was conducted in 2020 and 2021 in Fayetteville, Arkansas, to evaluate soybean injury following low rates (0 to 0.094 oz ai/ac) of florpyrauxifen-benzyl applied either as a liquid spray or coated on urea at the V3 growth stage. In both years, soybean response was evaluated at 21 days after applications of florpyrauxifen-benzyl were made to drill-seeded (7-in. rows) soybean. In both years, the greatest soybean injury (100%) was observed following sprayed applications of florpyrauxifen-benzyl at 0.094 oz ai/ac. However, when florpyrauxifen-benzyl was coated on urea at 0.094 oz ai/ac, only 24% and 19% visual soybean injury was observed in 2020 and 2021, respectively. Regardless of year, coating florpyrauxifen-benzyl on urea was less injurious to soybean when compared to sprayed applications at every herbicide rate and rating timing. Likewise, no deleterious effect on yield was observed when florpyrauxifen-benzyl was coated on urea, but all sprayed applications negatively impacted yield. Overall, coating florpyrauxifen-benzyl on urea reduced soybean injury by 68 to 94 and 64 to 92 percentage points at 21 days after treatment in 2020 and 2021, respectively. Coating florpyrauxifen-benzyl on urea appears to substantially reduce soybean injury and the risk of an off-target movement occurrence. Future research is needed to establish the effectiveness of this application technique on weed control.

Introduction

Florpyrauxifen-benzyl is a Weed Science Society of America (WSSA) group 4 synthetic auxin herbicide commercialized in rice (*Oryza sativa* L.) in 2018 as Loyant®. As a rice herbicide, florpyrauxifen-benzyl offers greater than 75% control of broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright) R.D. Webster], barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.], Amazon sprangletop [*Diplachne panicoides* (J. Presl) McNeil], large crabgrass [*Digitaria sanguinalis* (L.) Scop.], northern jointvetch [*Aeschynomene virginica* (L.) Britton, Sterns & Poggenb.], hemp sesbania [*Sesbania herbacea* (Mill.) McVaughn], pitted morningglory (*lpomoea lacunosa* L.), Palmer amaranth (*Amaranthus palmeri* S. Watson), yellow nutsedge (*Cyperus esculentus* L.), rice flatsedge (*Cyperus iria* L.), and smallflower umbrellasedge (*Cyperus difformis* L.) when sprayed at 0.5 oz ai/ac (Miller and Norsworthy, 2018a).

As of 2021, soybean and rice are the top 2 agronomic grains planted and harvested in Arkansas, as well as the top 2 crops in terms of the value of production (USDA-NASS, 2021). Following the commercial launch of florpyrauxifen-benzyl in 2018, concerns of off-target movement from physical drift to adjacent soybean arose. When evaluating multiple crops {soybean, cotton (*Gossypium hirsutum* L.), corn (*Zea mays* L.), grain sorghum [*Sorghum bicolor* (L.) Moench ssp. bicolor], sunflower (*Helianthus annuus* L.)}response to florpyrauxifen-benzyl, it was concluded that soybean exhibited the greatest sensitivity to the herbicide (Miller and Norsworthy, 2018b). Following a survey of Arkansas herbicide applications in 2019, 51% of herbicide applications were reported by aerial application, and herbicide drift was identified as a primary concern (Butts et al., 2021). To reduce the potential for off-target movement of florpyrauxifen-benzyl via physical drift, coating the herbicide onto fertilizer may be one possible solution to the problem. In conservation tillage systems, herbicide-coated fertilizers helped 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-application can lead to increased crop injury (Wells and Green, 1991). Due to risks associated with off-target movement of florpyrauxifen-benzyl and the sensitivity of soybean, experiments were conducted to determine if coating florpyrauxifen-benzyl onto urea would reduce soybean injury from a physical drift occurrence and allow for florpyrauxifen-benzyl to be safely applied to rice without concern of soybean injury linked to an application.

Procedures

A field experiment evaluating the risk of off-target movement to soybean of florpyrauxifen-benzyl coated on urea was conducted in 2020 and 2021 at the University of Arkansas

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System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark. Both years, the experiment was conducted as a 2-factor randomized complete block design where 7 florpyrauxifen-benzyl rates (0 to 0.094 oz ai/ac) and 2 application methods (foliar spray and coated) were the factors with 4 replications. Credenz soybean (LibertyLink®, BASF Corporation, 100 Park Avenue, Florham Park, N.J.) variety 4410GTLL (2020) and 4539GTLL (2021) were drilled at a 7-in. row spacing into a tilled-flat seedbed at a seeding rate of 145,000 seeds/ac. Soybean varieties differed between years due to the discontinuation of 4410GTLL. The exact width (6 ft.) of each plot was treated, and at least 2 feet of bare ground was between each plot within a rep to prevent contamination from adjacent plots. Sprayed 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 that may occur from physical spray drift. Herbicide-coated urea was weighed at each rate to treat 120 ft^2 of each plot for coated applications. Florpyrauxifen-benzyl at 0.5 oz ai/ac was coated onto 283 lb/ac of urea, and rates equivalent to sprayed applications were measured and applied to compare injury directly between sprayed and coated applications. Estimated visual injury ratings were recorded 21 days after the application and evaluated using a 0%–100% scale, where 0% represents no injury and 100% crop death (Frans and Talbert, 1977). Grain yield was harvested from the center 120 ft^2 of each plot using a small-plot combine. 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. Additionally, all data were analyzed utilizing the non-linear fit model function within JMP 16.0 (SAS Institute Inc., 100 SAS Campus Drive, Cary, N.C.).

Results and Discussion

In both years, coating florpyrauxifen-benzyl onto urea decreased levels of soybean injury (Figs. 1 and 2). At 21 days after treatment with florpyrauxifen-benzyl at 0.094 oz ai/ac, the maximum visual soybean injury caused by the herbicide coated on urea was 24% and 19% in 2020 and 2021, respectively. Conversely, the same rate of florpyrauxifen-benzyl caused complete loss of the crop (100% injury) in both years when the herbicide was sprayed on soybean. Likewise, as rates of sprayed florpyrauxifen-benzyl applications increased, soybean injury increased, similar to what was presented in Miller and Norsworthy, 2018b. Across all rating timings, coating florpyrauxifen-benzyl onto urea decreased soybean injury by 50 to 91 and 55 to 96 percentage points in 2020 and 2021, respectively. Coating florpyrauxifen-benzyl onto urea caused no deleterious effect on yield in both years, whereas low rates applied as a foliar spray caused a significant reduction in yield (Figs. 3 and 4). Just as soybean injury increased as sprayed rates of florpyrauxifen-benzyl increased, soybean yield decreased as sprayed rates increased. In both years, experiments resulted in complete soybean yield loss when florpyrauxifen-benzyl was sprayed at 0.094 oz ai/ac. Coating florpyrauxifen-benzyl onto urea appears to be an effective application method to reduce potential injury from the off-target movement of the herbicide.

Practical Applications

Florpyrauxifen-benzyl is currently being aerially-applied in limited amounts in Arkansas due to the risk of injuring soybean. Coating florpyrauxifen-benzyl onto urea would provide a safer, low-drift means of herbicide application and potentially decrease the required number of aerial applications at the pre-flood timing in rice by combining herbicide and fertilizer application. Urea granules are larger in diameter and denser than spray droplets and would be less likely to move off-target from a physical drift occurrence due to increased downward terminal velocity (Hofstee, 1992). Florpyrauxifen-benzyl is needed as an additional herbicide option with the increasing amounts of herbicide-resistant weeds in rice.

Acknowledgments

This research was conducted in cooperation with Corteva Agriscience Inc. We want to thank Corteva for providing the florpyrauxifen-benzyl. Support for this research was also provided by the Arkansas Rice Checkoff Program administered by the Arkansas Rice Research and Promotion Board and the Arkansas Soybean Promotion Board. Lastly, the facilities were made possible by the University of Arkansas System Division of Agriculture.

Literature Cited

Butts, T.R., L.T. Barber, J.K. Norsworthy, and J. Davis. 2021. Survey of ground and aerial herbicide application practices in Arkansas agronomic crops. Weed Technol 35:1-11.

Frans, R.E. and R.E. Talbert. 1977. Design of field experiments and the measurement and analysis of plant responses in Research Methods in Weed Science. B Truelove, ed. Pp. 15-23.

Hofstee, J.W. 1992. Handling and spreading of fertilizers: part 2, physical properties of fertilizers, measuring methods and data. J Agric Eng Res 53:141-162.

Kells, J.J. and W.F. Meggit. 1985. Conservation tillage and weed control. Pages 123-129 in A Systems Approach to Conservation Tillage (1st edition).

Miller, M.R. and J.K. Norsworthy. 2018a. Florpyrauxifen-benzyl weed control spectrum and tank-mix compatibility with other commonly applied herbicides in rice. Weed Technol 32:319-325.

Miller, M.R. and J.K. Norsworthy. 2018b. Row crop sensitivity to low rates of foliar-applied florpyrauxifen-benzyl. Weed Technol 32:398-403.

USDA-NASS. 2021. United States Department of Agriculture National Agricultural Statistics Service. 2021 State Agriculture Overview. Arkansas. Accessed April 18, 2022. Available at https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=ARKANSAS

Wells, K.L. and J.D. Green. 1991. Using solid, bulk blended mix-grade fertilizers. Soil Science News and Views 12: 1-3. University of Kentucky Plant and Soil Sciences.

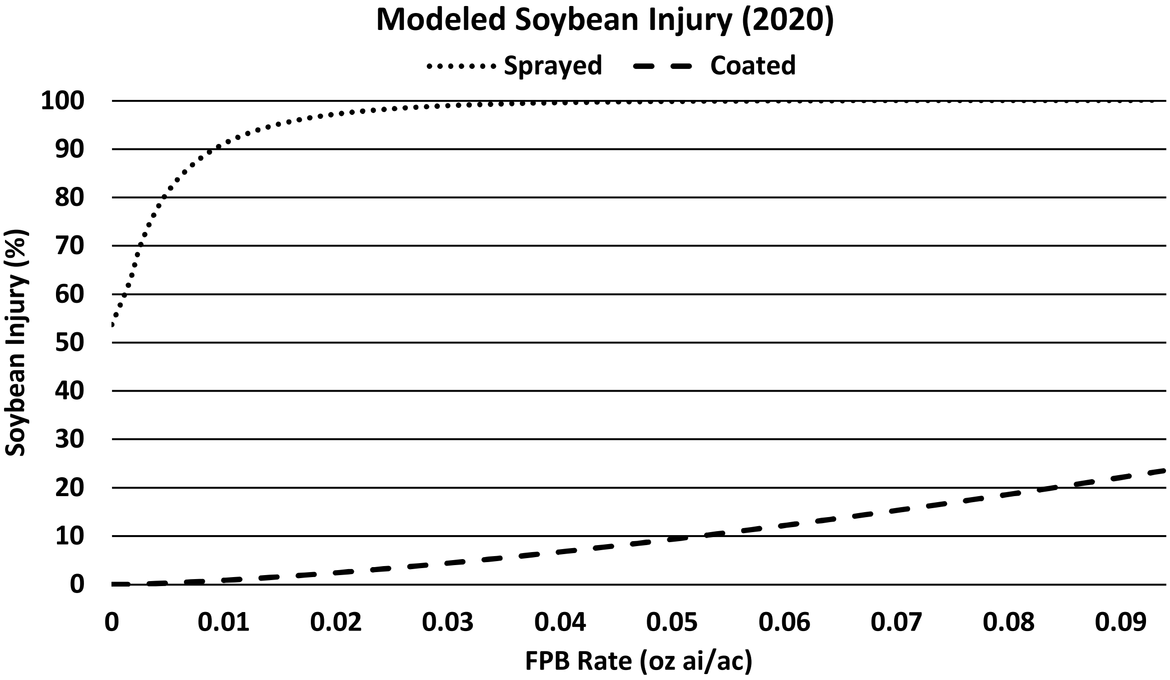

Fig. 1. Weibull growth model, Y = a(1-EXP(-(FPB rate/b)c)), of predicted soybean visual injury 21 days after treatment of florpyrauxifen-benzyl (FPB) applications in 2020. Model elements are as follows: a = asymptote, b = inflection point, and c = growth rate. Sprayed treatments produced an R^2 = 0.993, and coated treatments produced an R^2 = 0.942.

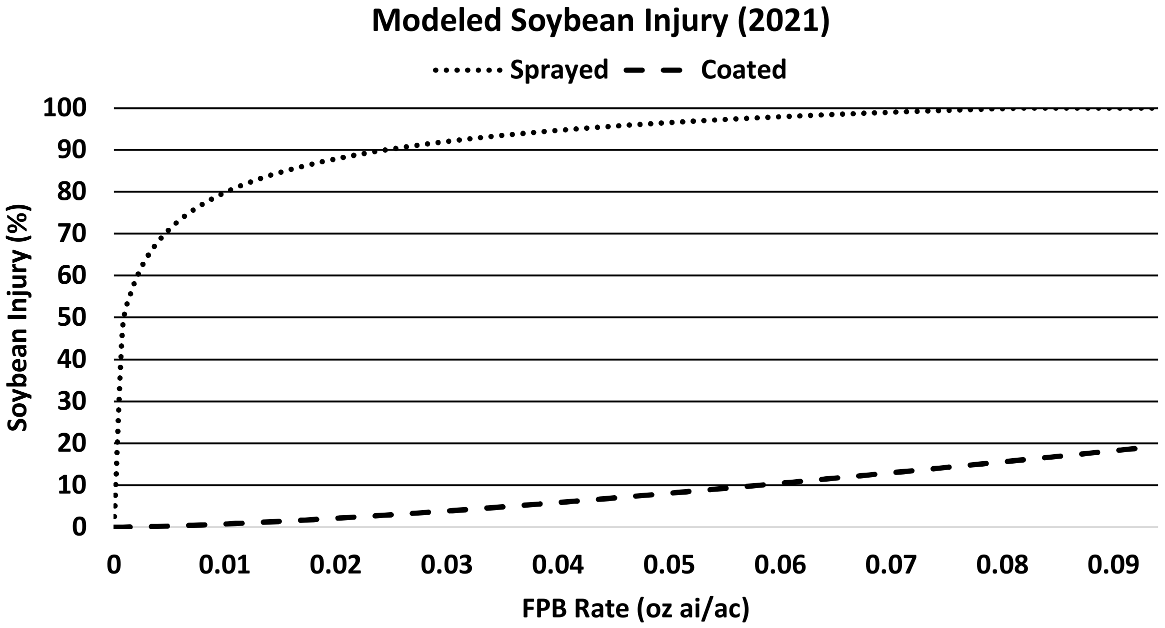

Fig. 2. Weibull growth model, Y = a(1-EXP(-(FPB rate/b)c)), of predicted soybean visual injury 21 days after treatment of florpyrauxifen-benzyl (FPB) applications in 2021. Model elements are as follows: a = asymptote, b = inflection point, and c = growth rate. Sprayed treatments produced an $R^2 = 0.995$, and coated treatments produced an $R^2 = 0.921$.

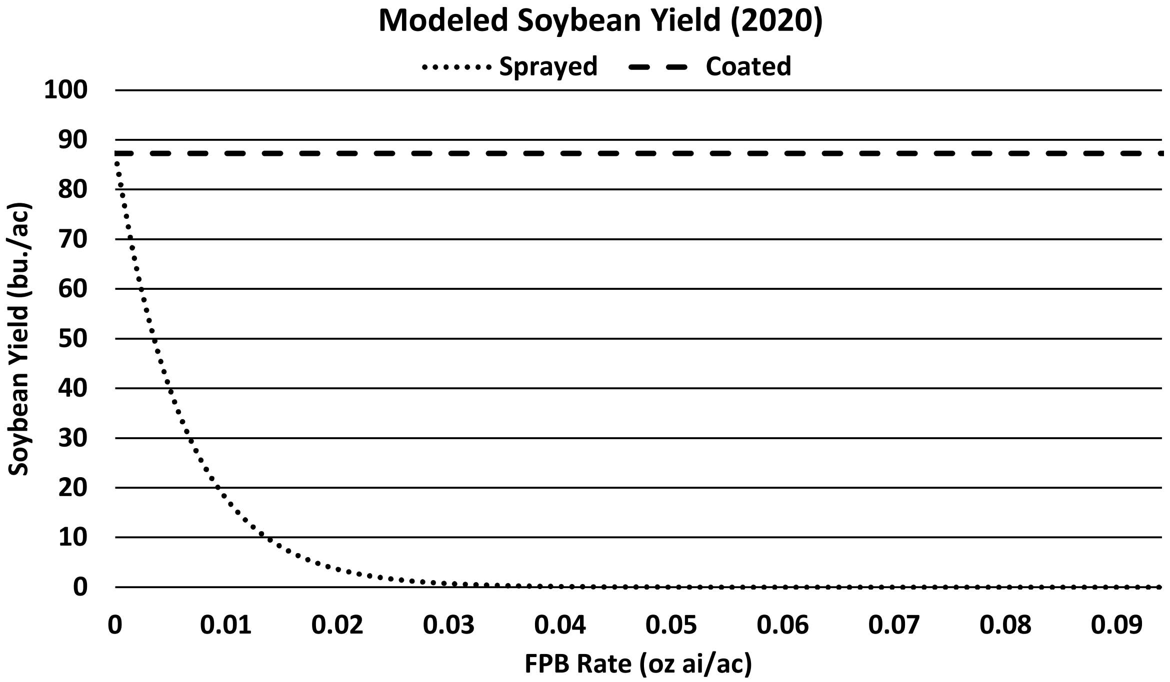

Fig. 3. Exponential 2P model, Y = a(EXP(b*FPB rate)), of drill-seeded soybean yield in 2020 following applications of florpyrauxifen-benzyl (FPB). Model elements are as follows: a = asymptote and b = growth rate. Sprayed treatments produced an $R^2 = 0.905$, and coated treatments were averaged due to no differences.

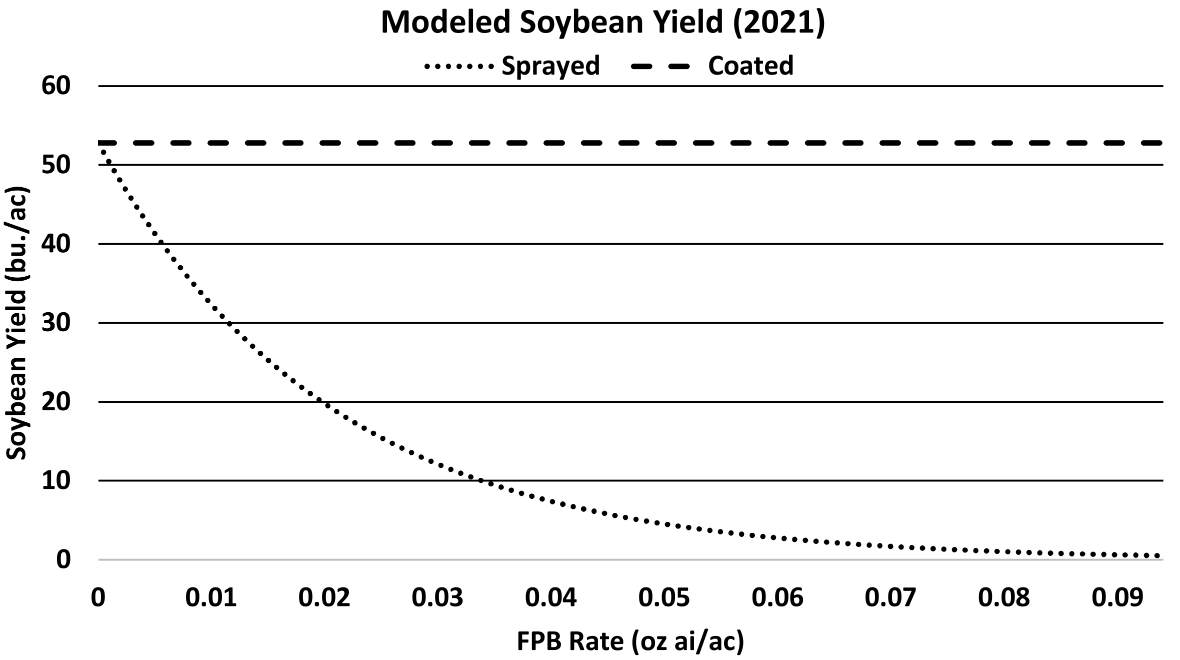

Fig. 4. Exponential 2P model, Y = a(EXP(b*FPB rate)), of drill-seeded soybean yield in 2021 following applications of florpyrauxifen-benzyl (FPB). Model elements are as follows: a = asymptote and b = growth rate. Sprayed treatments produced an $R^2 = 0.836$, and coated treatments were averaged due to no differences.

Johnsongrass Resistance to Commonly Used Soybean Herbicides

J.A. Fleming,[1] J.K. Norsworthy,[1] L.T. Barber,[2] and T.R. Butts[2]

Abstract

Johnsongrass [*Sorghum halepense* (L.) Pers.] escapes and infestations have been a growing issue for soybean [*Glycine max* (L.) Merr.] producers across the mid-south. Reliance on glyphosate and acetyl CoA carboxylase (ACCase) inhibitors for grass control could have increased resistant populations. A greenhouse study was conducted in Fayetteville, Ark., in 2020 and 2021 to determine the extent of johnsongrass in Arkansas with resistance to aryloxyphenoxypropionate herbicides and glyphosate. Johnsongrass seeds were collected from 63 locations within 6 counties in eastern Arkansas. These accessions were seeded in the greenhouse and treated with fluazifop at 0.9 lb ai/ac, quizalofop at 0.04 lb ai/ac, and glyphosate at 0.77 lb ae/ac. The only treatment resulting in 100% mortality of all accessions was quizalofop. Some escapes were observed to fluazifop, but all accessions, outside of one from Crittenden County, had greater than 90% control. Variable levels of mortality, ranging from 10% to 100%, were observed with glyphosate. Overall, Arkansas johnsongrass accessions showed high levels of variability in control when treated with glyphosate, while fluazifop and quizalofop applications appeared effective on the accessions tested.

Introduction

Herbicide resistance has been one of the leading concerns for producers throughout Arkansas in recent years, specifically with Palmer amaranth [*Amaranthus palmeri* (S.) Watson] in soybean. Recent studies have found Palmer amaranth populations resistant to multiple herbicide modes of action (Norsworthy et al., 2014). Additionally, johnsongrass [*Sorghum halepense* (L.) Pers.] has shown the potential for resistance but has not been heavily researched in Arkansas since discovering the first glyphosate-resistant population in 2007 (Riar et al., 2011). Johnsongrass is a perennial grass weed that reproduces through both seed and rhizomes. One johnsongrass plant can produce more than 10,000 seeds and 5,000 rhizomes per plant, causing up to 90% yield loss in soybean, making it one of the most prolific weeds in the Midsouth (McWhorter, 1971; Klein and Smith, 2020). In the most recent study of herbicide resistance in johnsongrass, populations from roadsides in Arkansas were found to have a 36-fold resistance to fluazifop and 2.8-fold resistance to glyphosate (Bagavathiannan and Norsworthy, 2014). Therefore, heavy reliance on both glyphosate and acetyl CoA carboxylase (ACCase) inhibitors for johnsongrass control could potentially have led to an increase in the number of herbicide-resistant populations in Arkansas.

Procedures

A greenhouse study was conducted in 2020 and 2021 in Fayetteville, Ark., to evaluate johnsongrass' resistance to glyphosate and ACCase inhibitors from the aryloxyphenoxypropionate (AOP) family. This experiment was a single factor completely randomized design. Seedheads from 63 different johnsongrass populations were collected throughout six counties (Crittenden, Greene, Poinsett, Cross, Mississippi, and Craighead) in 2020. The seed was hand-harvested from seedheads and placed into cold storage for 2 weeks before planting to break seed dormancy. Trays were filled with standard potting mix, and johnsongrass seed was sown at 100 seeds per tray. Four trays were planted per accession, 1 for each of the 3 herbicides and 1 nontreated for comparison (Table 1). Trays of seedlings were sprayed when johnsongrass reached the 2- to 3-leaf stage. Applications were made at 1 mph and 20 gal/ac in a spray chamber using flat fan 1100067 nozzles at 40 psi. Both AOP herbicides received 1% v/v of crop oil concentrate as recommended by the label. Before application, the total number of plants in each tray was recorded. The final number of living plants was recorded again, 28 days after application (DAA), and used to calculate percent mortality. Visual johnsongrass control was evaluated every 7 days until 28 DAA on a scale of 0 to 100, where 0 represents no johnsongrass control, and 100 represents no living johnsongrass plants. Data were analyzed using SAS 9.4. Means were separated using Fisher's protected least significant difference, and boxplots were assembled.

Results and Discussion

Overall, 100% johnsongrass control was achieved on the majority of accessions evaluated. Quizalofop was the only herbicide that resulted in 100% visual control and percent mortality on all evaluated johnsongrass accessions from eastern Arkansas, while fluazifop reached 99% johnsongrass visual control and 98% mortality. Glyphosate resulted in lower johnsongrass visual control and mortality at 94% and 93%, respectively (Table 1). While average values are important, the accessions most concerning are the outliers, which

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are specific accessions that did not have control levels that fit 90% of the data. No outliers were observed with quizalofop since 100% mortality and visual control were achieved across all accessions. Four accessions were considered outliers after applying fluazifop. While 3 of these accessions had visual control and mortality levels greater than 90%, one accession from Crittenden county resulted in only 73% mortality (Figs. 1 and 2). Glyphosate resulted in the largest variation and the most outliers with mortality ranging from 10% to 100%, with 5 outliers present (Fig. 2). Johnsongrass accessions observed as outliers following applications of glyphosate were all located in Crittenden and Mississippi County. Bagavathiannan and Norsworthy (2014) observed a similar trend with johnsongrass collected from roadsides throughout Arkansas when treated with fluazifop and glyphosate, with accessions exhibiting 36-fold resistance to fluazifop and 2.8-fold resistance to glyphosate. This study correlates with their assumption that if resistance is present on roadsides near the production field, similar results could be observed within the field.

Practical Applications

Johnsongrass accessions resistant to fluazifop and glyphosate are the most concern of this study. Most soybean producers across Arkansas utilize glyphosate-resistant cultivars and rely on glyphosate for johnsongrass control. In these instances, other control options will be vital to mitigate the spread of these resistant populations. An ACCase inhibitor would be the best substitute for glyphosate for johnsongrass control. From the herbicides evaluated, quizalofop would be an effective alternative for producers with known or suspected glyphosate or fluazifop resistance since no resistance was observed in the johnsongrass accessions evaluated. Integrated weed management strategies that utilize cultural, mechanical, and biological control methods and chemical control methods are needed to improve the management of resistant johnsongrass populations and preserve currently effective herbicides.

Acknowledgments

The authors would like to thank the University of Arkansas Systems Division of Agriculture and the Arkansas Soybean Promotion Board for supporting this study and the Crittenden, Mississippi, Poinsett, Greene, Cross, and Craighead county Extension Agents for their assistance in collecting johnsongrass samples.

Literature Cited

Bagavathiannan, M.V., and J.K. Norsworthy. 2014. Do roadside herbicide applications select for resistance in johnsongrass populations? Proc. South. Weed Sci. Soc. 67:105.

Klein, P., and C.M. Smith. 2020. Invasive johnsongrass, a threat to native grasslands and agriculture. Biologia. 76:413-420.

McWhorter, C.G. 1971. Anatomy of johnsongrass. Weed Sci. 19:385-393.

Norsworthy, J.K., G.M. Griffith, T. Griffin, M. Bagavathiannan, E.E. Gbur. 2014. In-field movement of glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) and its impact on cotton lint yield: evidence supporting a zero-threshold strategy. Weed Sci. 62:237-249.

Riar, D.S., J.K. Norsworthy, D.B. Johnson, R.C. Scott, and M. Bagavathiannan. 2011. Glyphosate resistance in a johnsongrass (*Sorghum halepense*) biotype from Arkansas. Weed Sci. 59:299–304

Table 1. Control and mortality of johnsongrass accessions collected in eastern Arkansas in 2020 by herbicide averaged over accession.[†]

Herbicide	lb ai/ac[‡]	Visual control		Mortality	
		---------------------------	%	--------------------------	
Fluazifop	0.9	99	A	99	A
Quizalofop	0.04	100	A	100	A
Glyphosate	0.77[§]	94	B	93	B

[†] Values in each column with different letters are statistically different based on Fisher's protected least significant difference (α = 0.05).

[‡] lb ai/ac = pounds of active ingredient per acre.

[§] lb ae/ac = pounds of acid equivalent per acre.

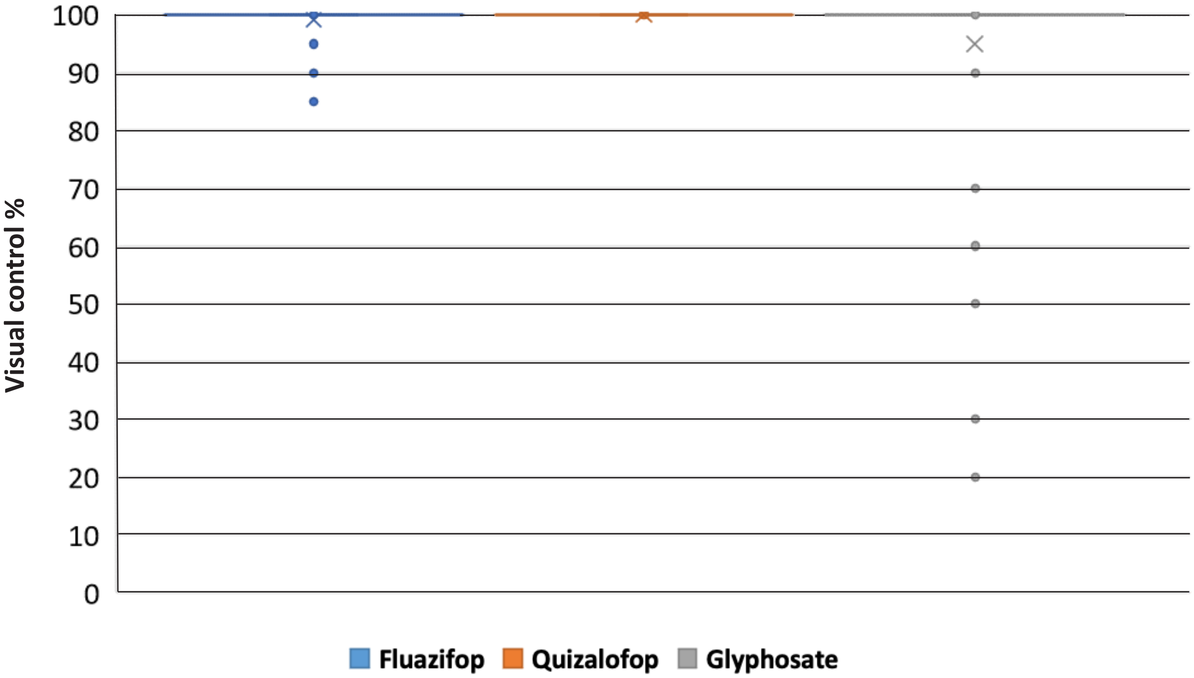

Fig. 1. Box and whisker plots representing visual control of johnsongrass accessions collected in eastern Arkansas in 2020 by herbicide 21 days after treatment. Lines represent median control level, Xs represent the mean control, and dots represent outlier accessions that do not fall within 90% of the data.

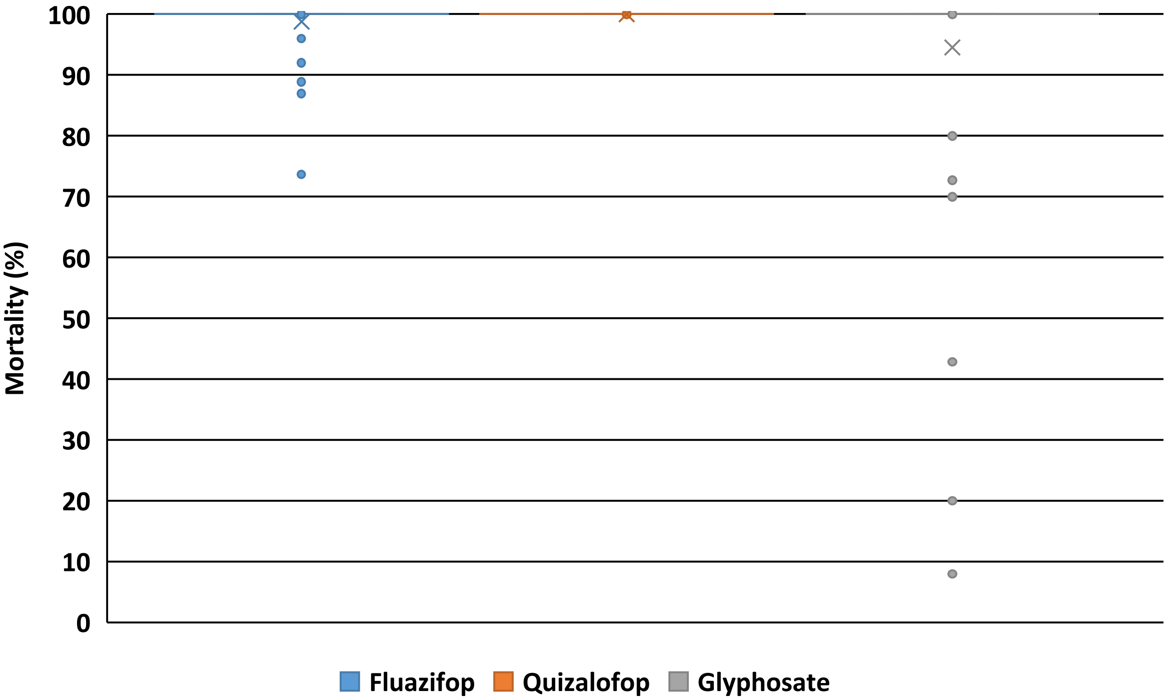

Fig. 2. Box and whisker plots representing percent mortality of johnsongrass accessions collected in eastern Arkansas in 2020 by herbicide 21 days after treatment. Lines represent median percent mortality, Xs represent the mean percent mortality, and dots represent outlier accessions that do not fall within 90% of the data.

PEST MANAGEMENT: WEED CONTROL

Response of Difficult-to-Control Palmer Amaranth Accessions to Ten Herbicide Groups

N. Godara,[1] J.K. Norsworthy,[2] G.L. Priess,[1] L.T. Barber,[3] and T.R. Butts[3]

Abstract

Palmer amaranth [*Amaranthus palmeri* (S.) Wats.] is one of the most troublesome soybean weeds [*Glycine max* (L). Merr.]. Chemical control options are limited with the evolution of resistance to 9 herbicide sites of action (SOAs) in Palmer amaranth. In 2021, a greenhouse experiment was conducted at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark., to evaluate the response of Arkansas Palmer amaranth populations to commonly used row crop herbicides with differing SOAs. Two experimental runs were conducted as a completely randomized design with 3 spatial replications. Three difficult-to-control accessions (A2019, A2020, and B2020) along with 1 standard susceptible accession (SS2001) were treated with 10 different herbicide SOAs, including pendimethalin and *S*-metolachlor as a preemergence application and imazethapyr, 2,4-D, dicamba, atrazine, diuron, glyphosate, glufosinate, fomesafen, paraquat, mesotrione, and tembotrione as a postemergence application. All difficult-to-control accessions were observed to have at least 20 percentage points less mortality than a susceptible standard to 5 herbicide SOAs. Mortality of A2019 accession was at least 20 percentage points less than the susceptible standard to herbicides from 9 differing SOAs. Additionally, A2020 and B2020 showed reduced sensitivity to 5 herbicide SOAs. Furthermore, atrazine and paraquat provided >86% mortality and are still viable options for controlling challenging Palmer amaranth populations.

Introduction

Palmer amaranth [*Amaranthus palmeri* (S.) Wats.] is one of the most troublesome and pervasive weeds in soybean [*Glycine max* (L). Merr.] throughout the United States due to having high fecundity, rapid growth rate, wide genetic diversity, and the capability of evolving resistance to herbicides (Van Wychen 2019; Ward et al. 2013). Palmer amaranth has already evolved resistance to 9 herbicide sites of action (SOAs), including a single biotype with harbored resistance to 6 different SOAs (Heap 2021; Shyam et al. 2020). With the evolution of multiple resistance, the number of effective herbicides available for Palmer amaranth control in soybean has diminished.

The evolution of multiple herbicide resistance in Palmer amaranth threatens the herbicide-resistant (HR) crop technologies and sustainability of chemical weed control programs from a resistance management standpoint. Therefore, it was hypothesized that Arkansas Palmer amaranth populations will have reduced sensitivity to commonly used herbicide SOAs in row crop production systems. Thus, the objective of this study was to evaluate the response of difficult-to-control Arkansas Palmer amaranth populations to commonly used row crop herbicides with differing SOAs.

Procedures

A greenhouse experiment was conducted at the University of Arkansas System Division of Agriculture's Altheimer Laboratory at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark., in the spring of 2021. The experiment included 1 susceptible accession (SS2001) collected from Monroe County, Ark. in 2001 and 3 difficult-to-control accessions (A2019) collected from Crittenden County, Ark. in 2019; (A2020) and (B2020) collected from Mississippi County, Ark. in 2020. The experiment evaluated the response of at least 100 plants per postemergence herbicide and 300 seeds per preemergence (PRE) herbicide.

Preemergence herbicide treatments were replicated 3 times with 2 temporal runs. Field soil characterized as Leaf silt loam (Fine, mixed, active, thermic Typic, Albaqualts) with 34% sand, 53% silt, 13% clay, 1.5% organic matter, and a pH of 5.9 was collected from the Milo J. Shult Agricultural Research and Extension Center. The collected soil was sieved and filled into 4.8 × 3.7 × 2.2-in. flats and used to evaluate accession response to preemergence-applied herbicides, pendimethalin, and *S*-metolachlor (Table 1). Each flat was presoaked and allowed to drain until field capacity moisture level was reached. Afterward, 50 seeds were scattered over the soil surface of each flat and covered with a 0.2 to 0.4-in. soil layer. Preemergence herbicides were applied over the flats and were irrigated over the top to simulate approximately 0.6 in. of rainfall for incorporating the herbicides.

For postemergence herbicide treatments, seeds of the susceptible standard and resistant populations were planted separately in 21 × 11 × 4-in. plastic trays using the commercial potting mixture. After emergence, seedlings (0.8- to 1-in.

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tall) from each population were individually transplanted into a 50-cell tray representing an experimental unit for each tested herbicide. Postemergence herbicide treatments were evaluated with 2 temporal runs, and herbicide treatments, including 8 different herbicide groups, were applied to Palmer amaranth plants at the 6- to 8-leaf stage (Table 1). The use rate of the herbicides evaluated was representative of 1X labeled rates applied in cotton (*Gossypium hirsutum*) or soybean.

All herbicide treatments were applied using a research track sprayer equipped with 2 flat fan 1100067 nozzles (Teejet, Wheaton, Ill.) calibrated to deliver 20 gallons/ac. (GPA) at 1 mph. For preemergence herbicides, emerged plants with 1 true leaf were counted for each flat at 14 days after application (DAA), and percent mortality values were determined relative to emerged plants in the nontreated to account for variability in germination rates among accessions. For postemergence herbicides, live plants were counted for each treatment at the timing of application and at 28 DAA to estimate the percent mortality; plants with green meristem were considered alive. Analysis of variance showed no differences between experimental runs with a *P*-value of 0.6857, allowing for data pooling over 2 runs.

Results and Discussion

SS2001 mortality ranged from 77% to 100% for the evaluated herbicides, except imazethapyr which caused no mortality and is likely resistant to the herbicide (Table 2). A2019 mortality was 20 percentage points less than the susceptible standard (SS2001) following pendimethalin, *S*-metolachlor, 2,4-D, diuron, glyphosate, glufosinate, fomesafen, mesotrione, and tembotrione, and is likely to harbor resistance to 9 herbicide SOAs (Table 2). In addition, A2020 showed at least a 20 percentage points reduction in mortality compared to SS2001 after 2,4-D, glyphosate, glufosinate, and mesotrione applications and is likely resistant to 5 herbicide SOAs (Table 2). After labeled rates of glyphosate, glufosinate, fomesafen, and mesotrione were applied to accession B2020, it showed 20 percentage points less mortality compared to standard susceptible accession SS2001 (Table 2). Similarly, B2020 showed reduced susceptibility to imazethapyr, glyphosate, glufosinate, fomesafen, and mesotrione and is likely to harbor resistance to five SOAs.

Palmer amaranth populations with resistance to acetolactate synthase-inhibitors, including imazethapyr, were documented in 1994 in Arkansas (Heap, 2021), justifying the 0% mortality of the evaluated accessions to imazethapyr. Furthermore, atrazine and paraquat caused >86% mortality of the difficult-to-control accessions and are still effective options for managing these challenging Palmer amaranth accessions. A2019, A2020, and B2020 are the first known Palmer amaranth accessions to have confirmed resistance to glufosinate (Priess et al., 2021). Future research needs to be conducted to determine the resistance/susceptible ratios for each herbicide's reduced sensitivity.

Practical Applications

All 3 difficult-to-control Palmer amaranth accessions were likely to harbor multiple herbicide resistance and had already been documented for glufosinate resistance. The count of available effective herbicide SOAs is diminishing for weed control in soybean. Furthermore, it is required to identify the most effective integrated weed management strategies that can be used for soybean and other crops to be successfully growing in fields infested with these difficult-to-control Palmer amaranth accessions.

Acknowledgments

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Literature Cited

Heap, I.M. 2021. International survey of herbicide-resistant weeds. Weed Science Society of America. Accessed: 11 Jan. 2021. Available at: www.weedscience.org

Priess, G.L., J.K. Norsworthy, N. Godara, A. Mauromoustakos, T.R. Butts, T.L. Roberts, and L.T. Barber. 2021. Discovery of glufosinate- and 2,4-D-resistant Palmer amaranth and determination of resistance profile. Weed Technol. (accepted pending revision).

Shyam, C., E.A. Borgato, D.E. Peterson, J.A. Dille, and M. Jogulam. 2020. Predominance of metabolic resistance in a six-way resistant Palmer amaranth (*Amaranthus palmeri*) population. Plant Sci. 11:614-618.

Van Wychen, L. 2019. Survey of the Most Common and Troublesome Weeds in Broadleaf Crops, Fruits, and Vegetables in the United States and Canada. Weed Science Society of America National Weed Survey Dataset. Accessed March 16, 2022. Available at: https://wssa.net/wssa/weed/surveys/

Ward, S.M., T.M. Webster, and L.E. Steckel. 2013. Palmer amaranth (*Amaranthus palmeri*): a review. Weed Technol. 27:12–27.

Table 1. Timing of applications, herbicides, product names, mechanism of action, Weed Science Society of America (WSSA) group number (s), and use rates of the treatments applied to Palmer amaranth accessions SS2001, A2019, A2020, and B2020.

Application timing	Herbicide	Product	Mechanism of action	WSSA group	Rate	
					g ai/ha or g ae/ha	lb ai/ac
PRE	pendimethalin	Prowl H2O® 3.8 L	Microtubule inhibitor	3	970	0.5
PRE	*S*-metolachlor	Dual II Magnum® 7.64 EC	Long-chain fatty acid inhibitor	15	1067	0.95
POST	imazethapyr†	Pursuit® 2 L	Acetolactate synthase-inhibitors	2	72	0.063
POST	2,4-D dicamba†	Enlist One® 3.8 L XtendiMax® plus VaporGrip® 2.9 L	Synthetic auxin Synthetic auxin	4	1064 560	0.71 0.5
POST	atrazine‡	Aatrex 4 L	Photosystem II inhibitor	5	1120	1.0
POST	diuron	Direx 4 L	Photosystem II inhibitor	5	894	0.4
POST	glyphosate	Roundup Powermax II® 4.5 L	EPSP synthase inhibitor	9	866	1.0
POST	glufosinate	Liberty® 2.34 L	Glutamine synthetase inhibitor	10	595	0.53
POST	fomesafen†	Reflex® 2 SL	PPO-inhibitor	14	395	0.235
POST	paraquat‡	Gramoxone® 3 SL	Photosystem I electron diverter	22	709	0.25
POST	mesotrione† tembotrione§	Callisto® 4 SC Laudis® 3.5 L	HPPD inhibitor HPPD inhibitor	27	105 92	0.094 0.068

† Nonionic surfactant (NIS) at 0.25% (v/v) was included.

‡ Crop coil concentrate (COC) at 1% (v/v) was included.

§ Methylated seed oil at 1% (v/v) was included.

Table 2. Percent mortality of Palmer amaranth accessions A2019, A2020, and B2020 following applications of various preemergence (PRE) and postemergence (POST) herbicides.

Timing of application	Herbicide treatment	WSSA[†] group number	Palmer amaranth mortality			
			SS2001	A2019	A2020	B2020
				-------% (percentage point difference from standard accession) ------		
PRE	pendimethalin	3	97	77 (20)*	86 (11)	87 (10)
PRE	*S*-metolachlor	15	100	48 (52)*	88 (12)	98 (2)
POST	imazethapyr[‡]	2	0	0 (0)	4 (-4)	0 (0)
POST	2,4-D	4	86	47 (39)*	43 (43)*	77 (9)
POST	dicamba[‡]	4	90	72 (18)	74 (16)	87 (3)
POST	atrazine[§]	5	100	86 (14)	100 (0)	97 (3)
POST	Diuron	5	100	58 (42)*	100 (0)	100 (0)
POST	glyphosate	9	84	0 (84)*	4 (80)*	2 (82)*
POST	glufosinate	10	100	80 (20)*	46 (54)*	6 (94)*
POST	fomesafen[‡]	14	87	4 (83)*	82 (5)	62 (25)*
POST	paraquat[§]	22	100	100 (0)	100 (0)	100 (0)
POST	mesotrione[‡]	27	78	2 (76)*	9 (69)*	45 (33)*
POST	tembotrione[¶]	27	77	7 (70)*	73 (4)	73 (4)

[†] WSSA = Weed Science Society of America.

[‡] Nonionic surfactant (NIS) at 0.25% (v/v) was included.

[§] Crop coil concentrate (COC) at 1% (v/v) was included.

[¶] Methylated seed oil at 1% (v/v) was included.

* Indicates at least a 20 percentage point reduced mortality compared to standard accession.

Dicamba and Glyphosate Spray Solution pH, Droplet Size, and Weed Control as Impacted by Volatility Reduction Agents

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Abstract

The introduction of Xtend™ soybean [*Glycine max* (L.) Merr.] to the market has allowed the use of dicamba and glyphosate for postemergence weed control. Regulations in 2021 also required the addition of volatility reduction agents (VRAs) to dicamba spray mixtures. Understanding the impact of these VRAs paired with dicamba and glyphosate alone and in tank mixture on weed control, droplet size, velocity, and spray pH is essential. A field experiment was conducted in 2021 at the University of Arkansas System Division of Agriculture's Rohwer Research Station near Rohwer, Ark., to evaluate the impact of VRAs on dicamba (Engenia®) and glyphosate (Roundup PowerMax® II) spray solution pH and weed control. A laboratory experiment was conducted in 2022 at the University of Arkansas System Division of Agriculture's Lonoke County Extension Center, Lonoke, Ark., to measure the droplet size of the spray solutions evaluated in the field experiments. Adding glyphosate to dicamba decreased the pH of the solutions below 5.0. VRAs increased the pH of the spray solutions but did not affect weed control except for a minor reduction (5 percentage points) in barnyardgrass control 27 days after application (DAA). Results revealed an antagonistic interaction between dicamba and glyphosate for the control of Palmer amaranth (Amaranthus palmeri S. Wats.) 27 DAA and barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] 19 and 27 DAA. Glyphosate and dicamba in tank mixture reduced Palmer amaranth control by 14 percentage points 27 DAA compared to dicamba alone and reduced barnyardgrass control by 6% and 12% 19 and 27 DAA, respectively, compared to glyphosate alone. Across VRAs, dicamba alone produced droplets of the largest size with a Dv0.5 of 846 µm. Adding glyphosate to dicamba increased the driftable fines (droplets < 200 µm) from 1.56% to 4.13%. Across herbicides, VaporGrip® Xtra VRA produced the largest Dv0.5 of 763 µm. Spray droplet velocity was not different between VRAs when dicamba alone or in tank mixture was used. VaporGrip® Xtra VRA produced droplets with greater velocity when glyphosate alone was used.

Introduction

The increase in dicamba use for herbicide-resistant weed control in recent years has raised off-target movement concerns across the country. Despite the use of new dicamba formulations with reduced volatility, substantial off-target dicamba movement has occurred following commercial applications. Thousands of complaints were reported from 2017 to 2019, with approximately 3.6 million acres of soybean fields affected by the off-target movement of dicamba in 2017 (WSSA, 2018). Spray solution pH and droplet size are 2 parameters that greatly influence the drift potential of dicamba. Dicamba spray solutions with pH values lower than 5.0 were connected to more off-target movement of the herbicide (Striegel et al., 2021). Even though tank-mixing dicamba with glyphosate is not allowed in Arkansas, growers in many other states use it to manage troublesome weeds. However, adding glyphosate to dicamba decreases solution pH, thereby increasing the drift potential of dicamba spray solutions. Droplet size is also a crucial parameter that impacts the off-target movement of herbicides, as reductions in droplet size can increase drift potential (Hewitt, 1997). Herbicide formulations (Fritz et al., 2010) and spray mixtures (Bouse et al., 1990) can influence spray solution droplet size. Dicamba labels approved for within-season herbicide applications to dicamba-resistant crops require the use of volatility reduction agents (VRAs). However, the impacts of VRAs on the droplet size, spray solution pH, and weed control of dicamba and glyphosate spray solutions are unclear. Therefore, the objective of this research was to evaluate the impact of VRAs on spray solution pH, droplet size and velocity, and weed control from dicamba and glyphosate spray solutions.

Procedures

A field experiment was conducted in 2021 at the University of Arkansas System Division of Agriculture's Rohwer Research Station near Rohwer, Ark., to evaluate the influence

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of VRAs on weed control and spray solution pH from glyphosate (Roundup PowerMax® II) and dicamba (Engenia®) alone and in a tank mixture. A randomized complete block design was established using 4 replications and an XtendFlex™ soybean [*Glycine max* (L.) Merr.] variety. The treatment design was a 2-factor factorial using 3 herbicide levels (dicamba, glyphosate, dicamba + glyphosate) and 3 VRA levels [none, potassium carbonate (Sentris™), potassium acetate (VaporGrip® Xtra)] (Table 1). A nontreated control was added as a reference for weed control evaluations. The experimental unit had 4 soybean rows with a 38-in. row spacing, and the treated plot was 12-ft wide by 30-ft long. *S*-metolachlor (Dual Magnum®) was applied at 1.33 pt/ac following treatment applications for residual control of secondary weed flushes. Major weeds were Palmer amaranth (*Amaranthus palmeri* S. Wats.) and barnyardgrass [*Echinochloa crus-galli* (L.) P. Beauv.] and herbicide applications occurred at the soybean V3 growth stage when Palmer amaranth and barnyardgrass were 1–8 and 4–8 in. tall, respectively. Herbicides were applied using a sprayer calibrated to deliver 15 gal/ac with TTI110015 nozzles. Visual assessments of weed control were recorded on a scale of 0% to 100% (0 being no control and 100 being complete control) and were done at 19 and 27 days after herbicide application (DAA). pH measurements of the herbicide spray solution were similar to those described by Striegel et al. (2021). The solution pH of each treatment was measured using a Milwaukee MW102 PRO pH/Temperature Meter (Milwaukee Instruments, Rocky Mount, N.C.) after a thorough agitation of the solution. Three readings were done for each treatment, with the electrode rinsed between measurements. A laboratory experiment was conducted at the University of Arkansas System Division of Agriculture's Lonoke County Extension Center near Lonoke, Ark., in the winter of 2021–2022 to evaluate the impact of VRAs on the droplet size and velocity of dicamba and glyphosate spray solutions (Table 1). The experiment was conducted as a completely randomized design with 3 replications. A VisiSize P15 Portable Particle Analyzer (Oxford Lasers, Imaging Division, Oxford, U.K.) was installed within a Generation 4 Research Track Sprayer (Devries Manufacturing, Hollandale, Minn.) equipped with a single TTI110015 nozzle. The distance between the nozzle tip and the measurement zone was 20 in. for droplet size and velocity measurements, and the nozzle was traversed to sample droplets from the entire spray plume. Data acquisition was set to measure the diameter and velocity of 2,500 droplets per replication for a total of 7,500 individual droplets measured per treatment.

Data Analysis

Weed control data were subjected to analysis of variance (ANOVA) using the GLIMMIX procedure in SAS version 9.4 (SAS Institute Inc, Cary, N.C.), assuming a beta distribution (Gbur et al., 2012). Blocks were considered random effects for the analysis, and treatment means were separated using Fisher's protected east significant difference (LSD, α = 0.1). The use of Colby's equation allowed the type of interaction between glyphosate and dicamba in tank mixture (additive, synergistic, or antagonistic) to be determined by calculating expected control rates (Eq. 1) (Colby, 1967) and using a t-test to compare expected and observed control rates (Ganie and Jhala, 2017) within SAS.

$$E = (D+G) - DG/100 \qquad \text{Eq. 1}$$

where E was the expected weed control rate when glyphosate and dicamba were applied in a tank mixture, and G and D were the observed weed control rates when glyphosate and dicamba were applied alone, respectively. According to Colby (1967), a synergistic combination is determined by an observed response greater than expected, an antagonistic combination determined by an observed response smaller than expected, and an additive combination when the observed and expected responses are equal. The Dv0.5 droplet size (droplet diameter in which 50% of the spray volume was contained in droplets of smaller diameter) and average velocity data were also subjected to ANOVA using the GLIMMIX procedure (SAS Institute Inc, Cary, N.C.) and assumed a gamma distribution (Butts et al., 2019). Treatment means were separated using Fisher's protected LSD (α = 0.1). The percent of the spray volume contained in droplets 200 µm in diameter and below, often used as an indicator of the "driftable" portion of a spray, was predicted using the Rosin–Rammler equation (Nie et al., 2019).

Results and Discussion

The herbicide-by-VRA interaction and the VRA effects were not significant (Table 2) except for a minor reduction (5 percentage points) in barnyardgrass control 27 DAA. Pooled across VRA, dicamba alone provided the highest control of Palmer amaranth 19 and 27 DAA, and glyphosate alone provided the highest control of barnyardgrass 19 and 27 DAA (Table 2). Colby's equation allowed the detection of an additive interaction for Palmer amaranth control 19 DAA. In contrast, antagonistic interactions were detected for Palmer amaranth control 27 DAA and for barnyardgrass control 19 and 27 DAA. Pooled across VRAs, glyphosate, and dicamba in the tank mixture reduced Palmer amaranth control by 14 percentage points 27 DAA compared to dicamba alone, and the tank mixture decreased barnyardgrass control by 6 and 12 percentage points by 19 and 27 DAA, respectively, compared to glyphosate alone (Table 2). The pH of the water used was 5.95 (Table 3), indicating the acidity of the water source. Spray solutions' pH varied between 4.67 and 6.52. Dicamba alone spray solution had a pH of 5.32. The addition of Sentris™ (potassium carbonate) to dicamba induced a 1.2 pH unit increase. The addition of VaporGrip® Xtra to dicamba induced a 0.31 pH unit increase. The glyphosate alone spray solution pH was 4.67. The addition of VRA increased glyphosate spray solution pH (Table 3). Adding glyphosate to dicamba decreased the solution pH by 0.63, leading to a spray solution pH below 5.0 (Table 3). The addition of VRA consistently increased the pH of tank-mixed spray solutions.

Sentris™ (potassium carbonate) increased the pH of the tank-mixed solutions by 1.25 pH units, while VaporGrip® Xtra (potassium acetate) raised the pH by 0.53 pH units (Table 3). The herbicide-by-VRA interaction for the $D_{v0.5}$ was not significant (Table 4). Across VRAs, dicamba alone produced a larger droplet size, while glyphosate alone and in a tank mixture with dicamba was not different. Across VRAs, the $D_{v0.5}$ of dicamba alone was 846 µm, while the $D_{v0.5}$ of glyphosate alone and in a tank mixture with dicamba was 702 and 713 µm, respectively (Table 4). Across herbicides, VaporGrip® Xtra (potassium acetate) produced a larger droplet size than Sentris™ (potassium carbonate) (Table 4). The herbicide-by-VRA interaction for average velocity was significant (Table 5). VRAs did not affect average velocity when dicamba was used alone or in a tank mixture. However, the velocity of droplets produced by VaporGrip® Xtra was higher compared to that produced by both Sentris™ and water when glyphosate was used (Table 5). The addition of glyphosate to dicamba shifted the Rosin–Rammler curve to the left, thereby increasing the percentage of driftable fines (Fig. 1).

Practical Applications

VRAs increased solution pH but did not affect weed control except for a minor reduction (5 percentage points) in barnyardgrass control 27 DAA. Across herbicides, VaporGrip® Xtra (potassium acetate) produced droplets of larger size than Sentris™ (potassium carbonate), indicating a slightly reduced particle drift potential may be present when VaporGrip® Xtra (potassium carbonate) is used. This research reported an antagonistic combination of dicamba and glyphosate in a tank mixture to control barnyardgrass and Palmer amaranth. Additionally, glyphosate and dicamba in the tank mixture decreased the solution pH below 5.0 and increased the percent of driftable fines leading to increased drift potential risk both from volatility and particle drift. Glyphosate and dicamba should not be applied in tank mixture as it is illegal in Arkansas, but it should also not be recommended elsewhere due to increased off-target movement potential and reduced control of both broadleaves and grasses. A sequential application would be more profitable in dicamba-resistant crops to improve weed control and reduce dicamba off-target movement concerns.

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Literature Cited

Bouse, L.F., I.W. Kirk, and L.E. Bode. 1990. Effect of spray mixture on droplet size. Transactions of the ASAE. 33:783-788.

Butts, T.R., L.E. Butts, J.D. Luck, B.K. Fritz, W.C. Hoffmann, and G.R. Kruger. 2019. Droplet size and nozzle tip pressure from a pulse-width modulation sprayer. Biosyst. Eng. 178:52-69.

Colby, S.R. 1967. Calculating synergistic and antagonistic responses of herbicide combinations. Weeds 15, 20–22. Accessed 5 May 2022. Available at: https://dx.doi.org/10.2307/4041058

Fritz, B.K., W.C. Hoffmann, and W.E. Bagley. 2010. Effects of spray mixtures on droplet size under aerial application conditions and implications on drift. Appl. Eng. Agric. 26:21-29.

Ganie, Z.A., and A.J. Jhala. 2017. Interaction of 2,4-D or dicamba with glufosinate for control of glyphosate-resistant giant ragweed (*Ambrosia trifida* L.) in glufosinate-resistant maize (*Zea mays* L.). Front. Plant Sci. 8.

Gbur, E.E., W.W. Stroup, K.S. McCarter, S. Durham, L.J. Young, M. Christman, M. West, and M. Kramer. 2012. Analysis of generalized linear mixed models in the agricultural and natural resources sciences. Madison, Wisc.: American Society of Agronomy, Soil Science Society of America, Crop Science Society of America. 298 p.

Hewitt, A. 1997. Droplet size and agricultural spraying. 1. Atomization, spray transport, deposition, drift, and droplet size measurement techniques. At. Sprays 7:235-244.

Nie, A., Z.Q. Cai, Z.M. Gao, Z.M. Wang, and A. Eaglesham. 2019. Droplet characteristics in the multi-staged high-speed disperser with single inlet. Chin. J. Chem. Eng. 27:1756-1764.

Striegel, S., M.C. Oliveira, N. Arneson, S.P. Conley, D.E. Stoltenberg, and R. Werle. 2021. Spray solution pH and soybean injury as influenced by synthetic auxin formulation and spray additives. Weed Technol. 35:113-127.

WSSA. 2018. Weed Science Society of America research workshop for managing dicamba off-target movement: Final report.

Table 1. List of treatments, herbicides common and trade names, manufacturers, and rates used for evaluating weed control and spray solution pH at the University of Arkansas System Division of Agriculture's Rohwer Research Station near Rohwer, Ark. (2021) and droplet size at the Lonoke Extension Center, Lonoke, Ark. (2022)

Treatment	Trade name	Common name	Manufacturer	Rate
				fl oz/ac
1	Nontreated Control		–	–
2	Engenia®	Dicamba	BASF, Research Triangle Park, N.C.	12.8
3	Engenia®	Dicamba	BASF, Research Triangle Park, N.C.	12.8
			BASF, Research Triangle Park, N.C.	
	Sentris™	Potassium Carbonate		8
4	Engenia®	Dicamba	BASF, Research Triangle Park, N.C.	12.8
	Verified VaporGrip® Xtra	Potassium Acetate	Helena Agri-Enterprises, LLC	20
5	Roundup PowerMax® II	Glyphosate	BAYER Crop Science	32
6	Roundup PowerMax II	Glyphosate	BAYER Crop Science	32
	Sentris™	Potassium Carbonate	BASF, Research Triangle Park, N.C.	8
7	Roundup PowerMax® II	Glyphosate	BAYER Crop Science	32
	Verified VaporGrip® Xtra	Potassium Acetate	Helena Agri-Enterprises, LLC	20
8	Engenia®	Dicamba	BASF, Research Triangle Park, N.C.	12.8
	Roundup PowerMax® II	Glyphosate	BAYER Crop Science	32
9	Engenia®	Dicamba	BASF, Research Triangle Park, N.C.	12.8
	Roundup PowerMax® II	Glyphosate	BAYER Crop Science	32
	Sentris™	Potassium Carbonate	BASF, Research Triangle Park, N.C.	8
10	Engenia®	Dicamba	BASF, Research Triangle Park, N.C.	12.8
	Roundup PowerMax® II	Glyphosate	BAYER Crop Science	32
	Verified VaporGrip® Xtra	Potassium Acetate	Helena Agri-Enterprises, LLC	20

Table 2. Control of Palmer amaranth and barnyardgrass at the University of Arkansas System Division of Agriculture's Rohwer Research Station near Rohwer, Ark. (2021) using dicamba and glyphosate alone and in tank mixture as affected by VRAs.[†]

Herbicide	Palmer amaranth[‡]				Barnyardgrass[§]			
	19 DAA		27 DAA		19 DAA		27 DAA	
	O	E	O	E	O	E	O	E
Dicamba	95 a	-	99 a	-	0 a	-	0 a	-
Glyphosate	40 b	-	3 b	-	100 b	-	95 b	-
Dicamba + glyphosate	93 aA	97 A	85 cA	99 B	94 cA	100 B	83 cA	95 B
VRA								
None	75 a	-	62 a	-	66 a	-	61 a	
Sentris™	75 a	-	61 a	-	64 a	-	58 b	
VaporGrip® Xtra	78 a	-	65 a	-	65 a	-	58 b	
	Pr>F		***Pr>F***		***Pr>F***		***Pr>F***	
Herbicide	<0.0001		<0.0001		<0.0001		0.0002	
VRA	0.4561		0.4223		0.2749		0.0788	
Herbicide*VRA	0.8806		0.5527		0.2760		0.2017	

[†] Abbreviations: VRA = volatility reduction agent; DAA = days after application; O = observed weed control rate; E = expected weed control rate for glyphosate and dicamba in tank-mixture calculated using the Colby's equation.

[‡] Means within a column followed by the same lowercase letter are not different based on Fisher's protected least significant difference (α = 0.1).

[§] Observed and expected control rate within a row (for the same species and evaluation date) followed by the same uppercase letter are not different based on the t-test (α = 0.1).

Table 3. Spray solution pH of dicamba and glyphosate alone and in tank mixture as affected by volatility reduction agents (VRAs[†]) at the University of Arkansas System Division of Agriculture's Rohwer Research Station in 2021.

Herbicide	VRA[§]	pH (SD[‡])
None	None	5.95 (0.01)
Glyphosate	None	4.67 (0.02)
Glyphosate	Sentris™	5.88 (0.02)
Glyphosate	VaporGrip® Xtra	5.21 (0.02)
Dicamba	None	5.32 (0.01)
Dicamba	Sentris™	6.52 (0.01)
Dicamba	VaporGrip® Xtra	5.63 (0.02)
Dicamba + glyphosate	None	4.69 (0.00)
Dicamba + glyphosate	Sentris™	5.94 (0.00)
Dicamba + glyphosate	VaporGrip® Xtra	5.22 (0.01)

[†] Abbreviations: VRA = volatility reduction agent.

[‡] SD is the standard deviation.

[§] Sentris™ (potassium carbonate, Sentris™), VaporGrip® Xtra (potassium acetate, Verified VaporGrip® Xtra).

Table 4. $D_{v0.5}$ and percentage of total volume (%) of droplets smaller than 200 µm in diameter for the spray solutions of dicamba and glyphosate alone and in tank mixture as affected by VRAs.[†]

Herbicide	$D_{v0.5}$[‡]	< 200 µm[§]
	µm	%
Dicamba	846 a	1.56
Glyphosate	713 b	3.97
Dicamba + Glyphosate	702 b	4.13
VRA		
VaporGrip® Xtra	763 a	3.05
None	758 ab	3.10
Sentris™	741 b	3.47
	Pr > F	
Herbicide	<0.0001	-
VRA	0.0775	-
Herbicide*VRA	0.3419	-

[†] Abbreviations: VRA = volatility reduction agent.

[‡] $D_{v0.5}$, droplet diameter in which 50% of the spray volume was contained in droplets of smaller diameter.

[§] % spray volume as droplets < 200 µm.

Table 5. Average velocity for the spray solutions of dicamba and glyphosate alone and in tank mixture as affected by VRAs.[†]

Herbicide	VRA	Average velocity
		mph
Dicamba	None	3.56a
	Sentris™	3.58a
	VaporGrip® Xtra	3.56a
Glyphosate	None	3.29b
	Sentris™	3.18b
	VaporGrip® Xtra	3.42c
Dicamba + Glyphosate	None	3.33d
	Sentris™	3.33d
	VaporGrip® Xtra	3.38d
		Pr > F
Herbicide		<.0001
VRA		0.0521
Herbicide*VRA		0.0505

[†]Abbreviations: VRA = volatility reduction agent.

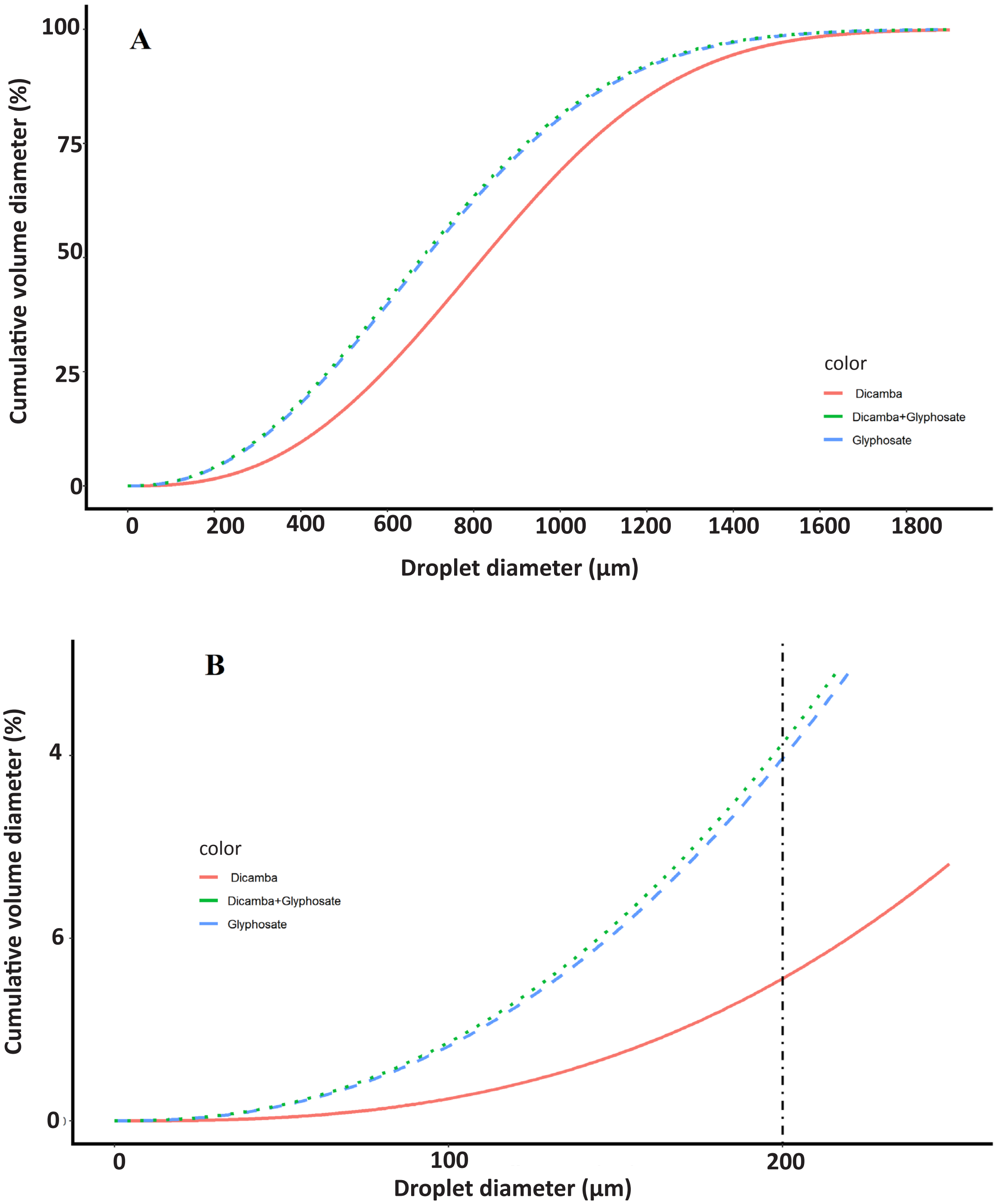

Fig. 1. Cumulative volumetric droplet size distribution of dicamba, glyphosate, and dicamba + glyphosate spray solutions, averaged across volatility reduction agents. Data were obtained from the laboratory experiment conducted in 2022 at the University of Arkansas System Division of Agriculture's Lonoke County Extension Center to measure the droplet size of the spray solutions evaluated in the field experiment.

PEST MANAGEMENT: WEED CONTROL

Soybean Tolerance and Early-Season Weed Control from Preemergence Treatments Using Metribuzin and Pyroxasulfone

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Abstract

A field experiment was conducted in 2021 to evaluate the preemergence activity of metribuzin (group 5) and pyroxasulfone (group 15) herbicide combinations in the control of several weed species and to determine their effectiveness as preemergence options in soybean [*Glycine max* (L.) Merr.] weed management systems. All treatments provided nearly ideal control of Palmer amaranth [*Amaranthus palmeri* (S.) Wats.] (99%), pitted morningglory [*Ipomoea lacunosa* (L.)] (better than 95%), and prickly sida [*Sida spinosa* (L.)] (better than 97%) by 35 days after preemergence application (DA PRE). No significant impact of preemergence treatments was observed on stand loss. Overall, preemergence treatments resulted in less than 6% chlorosis and necrosis by 35 DA PRE. Additionally, only treatments with Glory® at 1.25 lb/ac (metribuzin) or 5.75 fl oz/ac of Zidua® (pyroxasulfone) plus Glory at 1.25 lb/ac resulted in 7% and 5% of crop stunting, respectively, by 35 DA PRE. In contrast, other treatments resulted in less than 1% visible stunting. Therefore, all herbicide treatments tested resulted in desirable weed control and minimal impact on early crop development. Utilizing a combination of herbicide sites of action could minimize the expansion of herbicide resistance. Generally, preemergence treatments do not provide robust weed control persisting for the entire critical weed-free period of soybean (from emergence to V4). Therefore, timely postemergence applications should be recommended to reduce possible yield impacts.

Introduction

Palmer amaranth (*Amaranthus palmeri*), morningglories (*Ipomoea spp.*), barnyardgrass (*Echinochloa crus-galli*), and horseweed (*Conyza canadensis*) have been considered by crop consultants as the most challenging weeds for soybean production in the mid-South (Riar et al., 2013). This is important because herbicide-resistant weeds continue to spread, particularly Palmer amaranth, now resistant to very-long-chain-fatty-acid inhibitors (group 15), glutamine synthetase inhibitors (group 10), and synthetic auxin mimic herbicides (group 4), as well as four other sites-of-action(Heap, 2022). Furthermore, providing new chemical weed control options is a great challenge, as only a single new herbicide site of action has been introduced since the early 1980s (Heap, 2022).

Thus, it is fundamental to combine multiple tools to achieve high control of these challenging weeds. Therefore, starting the season with an effective preemergence herbicide application is critical. Weed control recommendations have listed metribuzin (a photosystem II inhibitor; group 5) as an essential component of weed control programs to provide high levels of control to early-season emerging Palmer amaranth in soybean production systems (Barber et al., 2022). Some soybean cultivars may present significant injury levels to metribuzin treatments, and soil pH may impact soybean response as metribuzin persistence increases as pH increases (Ladlie et al., 1976; Wax et al., 1976).

No single herbicide application can effectively combat weeds, and an integrated approach using herbicides and timely applications is required to manage weeds throughout the growing season (Barber et al., 2022). Therefore, this research aimed to evaluate herbicide weed control options that included preemergence options to control a broad spectrum of weed species in Xtend® soybean without negatively affecting the early development of the crop.

Procedures

A field study was conducted in 2021 at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center in Keiser, Ark. The soil at the site was a Steele loamy sand, with a pH of 6.4. Xtendflex® soybean (AG 46XF0, Asgrow Seed Co., Creve Coeur, Mo.) was planted on 21 April 2021, at the seeding rate of 145,000 seeds/ac on 38-in. row spacing. The plot size was 12.7 × 20 ft, and the experiment was set up as a randomized complete block design with 14 treatments (preemergence treatments) and 4 replications.

Herbicide treatments were applied on the day of planting using a CO_2 pressurized backpack sprayer equipped with a 4-nozzle boom with AIXR 110015 nozzles (TeeJet Technologies, Wheaton, Ill.), calibrated to deliver a constant carrier volume of 15 gal/ac. The preemergence herbicide treatments included metribuzin (Glory®, Adama Agricultural Solutions,

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Raleigh, N.C.) and pyroxasulfone (Zidua®, BASF Corporation, Research Triangle Park, N.C.). The preemergence herbicide treatments and rates used in this research can be found in Tables 1 to 3. A nontreated check was included for reference. All plots were maintained according to the University of Arkansas System Division of Agriculture Cooperative Extension Service recommendations for soybean (Barber et al., 2022).

Data collection included Palmer amaranth, pitted morningglory, and prickly sida control at 14 and 28 days after preemergent application (DA PRE). Additionally, assessments of stand count and crop injury consisting of chlorosis, necrosis, and visual stunting, were conducted from 14 to 35 DA PRE. Data were subjected to analysis of variance in JMP Pro 16.1 (SAS Institute Inc., Cary, N.C.), and means were separated using Tukey's honestly significant difference (HSD) with $\alpha = 0.05$.

Results and Discussion

The preemergence treatments tested did not impact the crop emergence compared to nontreated, as crop stand ranged from 9 to 12 plants per ft of row by 28 DA PRE. Additionally, low levels of crop injury were observed up to 35 DA PRE (Tables 1 and 2). Analysis of variance showed that visible chlorosis and necrosis results were not significantly influenced by preemergence treatments ($P \geq 0.05$). Overall, treatments containing metribuzin or metribuzin plus pyroxasulfone resulted in low levels of chlorosis (ranging from 1% to 6%) at 14 DA PRE, which was reduced to 1% or less by 35 DA PRE (Table 1). Similarly, these treatments resulted in low levels of visible necrosis (less than 2%) at 14 DA PRE, that slightly increased to no more than 6% by 35 DA PRE (Table 1). Visible stunting of plants was influenced by treatments on 14 DA PRE ($P = 0.0011$) and 35 DA PRE ($P = 0.0002$). Treatments containing pyroxasulfone resulted in more stunting (up to 7%), while treatments with only metribuzin did not cause stunting of plants on 14 DA PRE (Table 2). By 35 DA PRE, differences in soybean stunting were reduced, and only treatments 10 and 11 resulted in 7% and 5% stunting, respectively, while other treatments equaled less than 1% (Table 2). Prior research reported that temporary injury could appear to soybean following the application of herbicides, which include metribuzin and pyroxasulfone (Mahoney et al., 2014). These levels of injury were deemed acceptable and unlikely could cause an impact on canopy closure or yield.

Analysis of variance showed that weed control results were not significantly influenced by preemergence treatments ($P \geq 0.05$), but all herbicide treatments provided better weed control than nontreated. All preemergence herbicide treatments provided 99% Palmer amaranth control up to 35 DA PRE (Table 3). Even though resistance to group 15 was identified in Arkansas (Brabham et al., 2019), results from this study show that pyroxasulfone, a group 15 herbicide, could still have efficacy in the control of some Palmer amaranth populations. Pitted morningglory control was also high for all treatments, ranging from 95% to 99% by 35 DA PRE; however, it was numerically higher for metribuzin-containing treatments (Table 3). According to the label, pyroxasulfone only provides suppression of pitted morningglory, and combinations with other herbicides are recommended (Anonymous, 2017). Additionally, prickly sida control was generally high, ranging from 97% to 99% by 35 DA PRE (data not shown).

Practical Applications

Overall, all preemergence herbicide treatments tested provided a high level of early weed control while preserving commercially acceptable crop safety. Although no treatment has improved weed control and applicators often opt for the most economical treatments, increasing the number of effective modes of action could help reduce the likelihood of spreading herbicide resistance. The soybean critical weed-free period which should be maintained to prevent yield loss is from emergence to V4 (Van Acker et al., 1993). In general, preemergence treatments do not provide adequate long-lasting control for the duration of the critical weed-free period, and postemergence treatments are necessary.

Acknowledgments

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Literature Cited

Anonymous. 2017. Zidua Herbicide Label. BASF Corporation Publ. No. 7969-338. Research Triangle Park, N.C.: BASF Corporation.

Barber, L.T., T.R. Butts, J.W. Boyd, K. Cunningham, G. Selden, J.K. Norsworthy, N.R. Burgos, and M. Bertucci. 2022. Recommended chemicals for weed and brush control. University of Arkansas System Division of Agriculture Cooperative Extension Service, MP44 2022.

Brabham, C., J.K. Norsworthy, M.M. Houston, V.K. Varanasi, and T. Barber. 2019. Confirmation of *S*-metolachlor resistance in Palmer amaranth (*Amaranthus palmeri*). Weed Technol. 33:720-726.

Heap, I. 2022. The international survey of herbicide resistant weeds. Internet. Accessed 21 April 2022. Available at: http://www.weedscience.org/

Ladlie, J.S., W.F. Meggitt, and D. Penner. 1976. Effect of pH on metribuzin activity in the soil. Weed Sci. 24:505-507.

Mahoney, K.J., F.J. Tardif, D.E. Robinson, R.E. Nurse, and P.H. Sikkema. 2014. Tolerance of soybean (*Glycine max* L.) to protoporphyrinogen oxidase inhibitors and very long chain fatty acid synthesis inhibitors applied preemergence. Amer. J. Plant Sci. 5:1117-1124.

Riar, D.S., J.K. Norsworthy, L.E. Steckel, D.O. Stephenson, T.W. Eubank, and R.C. Scott. 2013. Assessment of weed management practices and problem weeds in the midsouth United States—soybean: a consultant's perspective. Weed Technol. 27:612-622.

Van Acker, R.C., C.J. Swanton, and S.F. Weise. 1993. The critical period of weed control in soybean [*Glycine max* (L.) Merr.]. Weed Sci. 41:194-200.

Wax, L.M., E.W. Stoller, and R.L. Bernard. 1976. Differential Response of Soybean Cultivars to Metribuzin. Agron. J. 68:484-486.

Table 1. Visible chlorosis and necrosis of Xtendflex® soybean at 14 and 35 days after preemergence application (DA PRE) affected by preemergence treatment.[†]

Treatment #	Herbicide treatment[‡]	Rates (per acre)	Visible chlorosis		Visible necrosis	
			14 DA PRE	35 DA PRE	14 DA PRE	35 DA PRE
			--------------------- % of nontreated ---------------------			
1	Nontreated	–	–	–		
2	Zidua®	2.5 fl oz	2	0	0	0
3	Zidua	3.75 fl oz	2	0	0	0
4	Zidua	5.75 fl oz	3	0	1	0
5	Zidua	7 fl oz	3	0	2	0
6	Glory®	0.33 lb	1	0	1	1
7	Glory	0.5 lb	3	0	1	3
8	Glory	0.66 lb	4	0	1	3
9	Glory	1 lb	3	0	2	4
10	Glory	1.25 lb	6	1	2	5
11	Zidua + Glory	2 fl oz + 0.33 lb	3	0	1	0
12	Zidua + Glory	2.5 fl oz + 0.5 lb	3	0	1	1
13	Zidua + Glory	3.75 fl oz + 0.66 lb	2	0	2	2
14	Zidua + Glory	5.75 fl oz + 1.25 lb	5	1	2	6

[†] Analysis of variance results showed no significant treatment impact over visible soybean chlorosis and necrosis at 14 and 35 DA PRE; therefore, averages were shown.

[‡] Zidua = 4.17 lb/gal pyroxasulfone (group 15); Glory = 75% wt. metribuzin (group 5).

Table 2. Visible stunting of Xtendflex® soybean at 14 and 35 days after preemergence application (DA PRE) influenced by preemergence treatment.[†]

Treatment #	Herbicide treatment[‡]	Rates (per acre)	Visible stunting 14 DA PRE	35 DA PRE
			------------- % of nontreated	-------------
1	Nontreated	–	–	–
2	Zidua®	2.5 fl oz	1 ab	0 b
3	Zidua	3.75 fl oz	4 ab	0 b
4	Zidua	5.75 fl oz	5 ab	1 b
5	Zidua	7 fl oz	7 a	1 b
6	Glory®	0.33 lb	0 b	0 b
7	Glory	0.5 lb	0 b	0 b
8	Glory	0.66 lb	0 b	0 b
9	Glory	1 lb	0 b	0 b
10	Glory	1.25 lb	2 ab	7 a
11	Zidua + Glory	2 fl oz + 0.33 lb	2 ab	0 b
12	Zidua + Glory	2.5 fl oz + 0.5 lb	4 ab	0 b
13	Zidua + Glory	3.75 fl oz + 0.66 lb	4 ab	1 b
14	Zidua + Glory	5.75 fl oz + 1.25 lb	5 ab	5 a

[†] Means followed by the same letter within a column are not statistically different according to Tukey's honestly significant difference test with α = 0.05.

[‡] Zidua = 4.17 lb/gal pyroxasulfone (group 15); Glory = 75% wt. metribuzin (group 5).

Table 3. Palmer amaranth (*Amaranthus palmeri*) and pitted morningglory (*Ipomoea lacunosa*) control at 28 and 35 days after preemergence application (DA PRE) influenced by preemergence treatment.[†]

Treatment #	Herbicide treatment[‡]	Rates (per acre)	Palmer amaranth 28 DA PRE	Palmer amaranth 35 DA PRE	pitted morningglory 28 DA PRE	pitted morningglory 35 DA PRE
			--------------- % of nontreated			---------------
1	Nontreated	–	–	–	–	–
2	Zidua®	2.5 fl oz	99	99	96	95
3	Zidua	3.75 fl oz	99	99	97	95
4	Zidua	5.75 fl oz	99	99	98	96
5	Zidua	7 fl oz	99	99	96	97
6	Glory®	0.33 lb	99	99	99	98
7	Glory	0.5 lb	99	99	98	98
8	Glory	0.66 lb	99	99	98	98
9	Glory	1 lb	99	99	96	97
10	Glory	1.25 lb	99	99	99	99
11	Zidua + Glory	2 fl oz + 0.33 lb	99	99	97	97
12	Zidua + Glory	2.5 fl oz + 0.5 lb	99	99	97	99
13	Zidua + Glory	3.75 fl oz + 0.66 lb	99	99	97	98
14	Zidua + Glory	5.75 fl oz + 1.25 lb	99	99	98	99

[†] Analysis of variance results showed no significant treatment influence over Palmer amaranth and pitted morningglory control at 28 and 35 DA PRE; therefore, averages were displayed.

[‡] Zidua = 4.17 lb/gal pyroxasulfone (group 15); Glory = 75% wt. metribuzin (group 5).

PEST MANAGEMENT: WEED CONTROL

Soybean Varietal Tolerance to Preemergence Metribuzin

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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 is widely used in the mid-South to control Palmer amaranth [*Amaranthus palmeri* (S.) Wats] in soybean and can cause severe injury and yield loss if a highly sensitive soybean 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 2021 to evaluate current soybean varieties and their tolerance to a labeled rate of soil-applied metribuzin. Injury, which was evaluated at 21 and 28 days after treatment (DAT), showed that nearly 37% of the tested varieties showed adequate field tolerance. Forty-seven percent of the tested varieties showed injury symptoms and were labeled moderately tolerant to the herbicide. The remaining 16% of the varieties screened exhibited severe injury when treated with a full rate of metribuzin. Therefore, regardless of the herbicide technology chosen by a grower, there are sufficient varieties that allow metribuzin to be integrated at a full rate into weed control programs that focus on controlling Palmer amaranth.

Introduction

Metribuzin is a very effective residual herbicide, with activity on broadleaf and some annual grass weeds. It also offers a unique herbicide mode of action to soybean weed control as a PSII inhibitor (Group 5). Research has shown that when applied at or above 500 grams of active ingredient per hectare (g ai ha-1) or 0.45 pounds of active ingredient per acre (lb ai/ac), PRE metribuzin significantly reduced the emergence of junglerice [*Echinochloa colona* (L.) Link], large crabgrass [*Digitaria sanguinalis* (L.) Scop.], and Palmer amaranth [*Amaranthus palmeri* (S.) Wats] among other weeds (Meyers et al., 2017; Tuti and Das, 2011). In Arkansas, with Palmer amaranth already confirmed resistant to 8 Weed Science Society of America sites of action, metribuzin-containing, PRE-applied herbicide programs are necessary for soybean producers to control multi-resistant Palmer amaranth (Barber et al., 2022).

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). Several key factors must be evaluated for using this herbicide in a potential weed control program, such as soil pH, herbicide rate, soil organic matter, soil texture, amount of rainfall or overhead irrigation, and variety selection. Naturally, selecting a soybean variety with adequate metribuzin tolerance is essential to avoid crop injury when using this herbicide. Due to the importance of this herbicide to Arkansas soybean producers, varieties entered into the University of Arkansas System Division of Agriculture's Official Variety Testing Program were screened for metribuzin tolerance (https://www.mssoy.org/uploads/files/metribuzin-screening-all-yr-ua_3.pdf).

Procedures

In the fall of 2021, 159 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 using a Captina silt-loam (fine-silty, siliceous, active, mesic Typic Fagiudult) soil with a pH of 6.8 and organic matter content of 1.34%. All 159 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 consisted of 10 seeds per replication, with a maximum of 2 distinct varieties per container and a metribuzin-sensitive variety (Osage). Each variety was replicated 4 times. 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 (187 L/ha). The 2-nozzle boom, which was set at the 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 metribuzin-sensitive variety at 21 and 28 days after treatment (DAT) and subsequently converted into 3 categorical groupings based on the level of injury observed relative to the metribuzin-sensitive check Osage. 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, dependent on target soil type; Moder-

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ate–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 when used in a field setting.

Results and Discussion

There were 59 varieties categorized as having a Slight response (37.1%) (Table 1), 75 as a Moderate response (47.2%) (Table 2), and 25 as a Severe response (15.7%) (Table 3). The varieties severally injured included: Armor 48-D25, Asgrow AG53XF2, Asgrow AG54XF0, Delta Grow DG46E10, Delta Grow DG49E90, Delta Grow DG49F22/STS, Delta Grow DG53E30, Delta Grow DG54F20, Dyna-Gro S46XF31S, Local LS4795XS, Local LS4805XFS, Local LS5009XS, Local LS5614XF, NK 42-T5XF, NK S48-2E3S, Pioneer P47A64X, Progeny P4816RX, Progeny P4821RX, Progeny P4921XFS, Progeny P5121E3S, Progeny P5424XF, R16-1445, R17-3488, R17-4177, and S16-14801C. 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 for 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-herbicide 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 conjunction with metribuzin. 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

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Literature Cited

Barber, T., T. Butts, J.W. Boyd, K. Cunningham, G. Selden, J.K. Norsworthy, N. Burgos, and M. Bertucci. 2022. Recommended Chemicals for Weed and Brush Control – MP44. Accessed 13 April 2022. Available at: https://www.uaex.uada.edu/publications/pdf/mp44/mp44.pdf

Ladlie, J.S., W.F. Meggitt, and D. Penner. 1976. Effect of soil pH on microbial degradation, adsorption, and mobility of metribuzin. Weed Sci. 24:447–481.

Meyers, S.L., K.M. Jennings, and D.W. Monks. 2017. Sweetpotato tolerance and Palmer amaranth control with metribuzin and oryzalin. Weed Tech. 31:903-907.

Tuti, M.D. and T.K. Das, 2011. Sequential application of metribuzin on weed control, growth and yield of soybean (*Glycine max*). Indian J. Agron. 56:57-61.

Table 1. Slight categorical injury rating of 2021 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 G4615XF	RR2XF	4.6
AgriGold G4813XF	RR2XF	4.8
AgriGold G4900XF	RR2XF	4.9
Amp 4448X	RR2X	4.4
Amp 4690XF	RR2XF	4.6
Amp 4850XF	RR2XF	4.8
Armor 44-D49	RR2X	4.4
Armor 45-F81	RR2XF	4.5
Armor 46-D09	RR2X	4.6
Armor 46-F13	RR2XF	4.6
Armor 48-F01	RR2XF	4.8
Asgrow AG43XF2	RR2XF	4.3
Asgrow AG47XF0	RR2XF	4.7
Asgrow AG48XF2	RR2XF	4.8
Asgrow AG52XF0	RR2XF	5.2
Axis 4611ES	Enlist E3	4.6
Axis 4641XFS	RR2XF	4.6
Delta Grow DG50E10	Enlist E3	5.0
Delta Grow DG52E80	Enlist E3	5.2
DONMARIO DM45X61	RR2X	4.5
DONMARIO DM46F62	RR2XF	4.6
DONMARIO DM48F61	RR2XF	4.8
Dyna-Gro S43XS70	RR2X	4.3
Dyna-Gro S46ES91	Enlist E3	4.6
Dyna-Gro S46XS60	RR2X	4.6
Dyna-Gro S48XF61S	RR2XF	4.8
Dyna-Gro S48XT40	RR2X	4.8
Dyna-Gro S48XT90	RR2X	4.8
Dyna-Gro S56XT99	RR2X	5.6
Integra 54891NS	RR2X	4.8
Integra 74551NS	RR2XF	4.5
Local IS4324E3	Enlist E3	4.3
Local LS4506XS	RR2X	4.5
Local LS4517XFS	RR2XF	4.5
Local LS5418XFS	RR2XF	5.4
NK 43-V8XF	RR2XF	4.3
NK 44-J4XFS	RR2XF	4.4
NK 45-P9XF	RR2XF	4.5
NK 45-V9E3	Enlist E3	4.5
NK S44-C7X	RR2X	4.4
NK S47-Y9X	RR2X	4.7
Progeny P4431E3	Enlist E3	4.4
Progeny P4505RXS	RR2X	4.5
Progeny P4521XFS	RR2XF	4.5

Continued

Table 1. Continued.

Variety[a,b]	Herbicide Technology Trait[c]	Maturity Group
Progeny P4604XFS	RR2XF	4.6
Progeny P4775E3S	Enlist E3	4.7
Progeny P5003XF	RR2X	5.0
R13-13997[b]	Conv.	5.4
R14-1422[b]	Conv.	5.0
R18-14142[b]	Conv.	4.6
R18-14147[b]	Conv.	4.3
R18-14229[b]	Conv.	4.3
R18-14272[b]	Conv.	4.6
R18C-13283[b]	Conv.	4.6
S16-7922C[b]	Conv.	4.9
S17-2243C[b]	Conv.	4.5
UA46i20C	Conv.	4.6
USG 7461XFS	RR2XF	4.6
XO 4371E	Enlist E3	4.3

[a] Abbreviations: USG = UniSouth Genetics; XO = Xitavo Soybean Seed.

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

[c] Abbreviations: Conv. = Conventional; Enlist E3 = Enlist E3®; RR2X = Roundup Ready 2 Xtend®; RR2XF = Roundup Ready 2 XtendFlex®.

Table 2. Moderate categorical injury rating of 2021 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 G4820RX	RR2X	4.8
Amp 4950X	RR2X	4.9
Armor 47-E03	Enlist E3	4.7
Armor 48-D03	RR2X	4.8
Armor 48-E82	Enlist E3	4.8
Armor 48-F22	RR2XF	4.8
Asgrow AG42XF0	RR2XF	4.2
Asgrow AG45XF0	RR2XF	4.5
Asgrow AG48XF0	RR2XF	4.8
Asgrow AG55XF0	RR2XF	5.5
Axis 4522XF	RR2XF	4.5
Credenz CZ 4202XF	RR2XF	4.2
Credenz CZ 4562XF	RR2XF	4.5
Credenz CZ 4742XF	RR2XF	4.7
Credenz CZ 4892XF	RR2XF	4.8
Credenz CZ 4912XF	RR2XF	4.9
Credenz CZ 5282XF	RR2XF	5.2
Delta Grow DG45E10	Enlist E3	4.4
Delta Grow DG46F17/STS	RR2XF	4.6
Delta Grow DG46X65/STS	RR2X	4.6
Delta Grow DG47E20/STS	Enlist E3	4.7
Delta Grow DG48E49/STS	Enlist E3	4.8
Delta Grow DG48E59	Enlist E3	4.8
Delta Grow DG48F20	RR2XF	4.8
Delta Grow DG48X45	RR2X	4.8
Delta Grow DG49E20	Enlist E3	4.9
Delta Grow DG51E60	Enlist E3	5.1
DONMARIO DM46E62	Enlist E3	4.6
DONMARIO DM48E62S	Enlist E3	4.8
Dyna-Gro S45ES10	Enlist E3	4.5
Dyna-Gro S52XT91	RR2X	5.2
Eagle Seed ES4890XF	RR2XF	4.8
Integra 54606NS	RR2X	4.6
Integra 54660NS	RR2X	4.6
Integra 54816N	RR2X	4.8
Integra 74621NS	RR2XF	4.6
Integra 74731NS	RR2XF	4.7
Integra 74852NS	RR2XF	4.8
Local IS4684E3S	Enlist E3	4.6
Local IS5067E3	Enlist E3	5.0
Local IS5232E3	Enlist E3	5.2
Local LS4415XF	RR2XF	4.4
Local LS4606XFS	RR2XF	4.6
Local LS4707XF	RR2XF	4.9

Continued

Table 2. Continued.

Variety[a,b]	Herbicide Technology Trait[c]	Maturity Group
Local LS4806XS	RR2X	4.8
Local LS4919XFS	RR2XF	4.9
Local LS5119XF	RR2XF	5.1
NK S45-J3X	RR2X	4.5
NK S46-E3S	Enlist E3	4.6
NK S49-F5X	RR2X	4.9
NK S51-E3	Enlist E3	5.1
Pioneer P48A60X	RR2X	4.8
Progeny P4501XFS	RR2XF	4.5
Progeny P4541E3S	Enlist E3	4.5
Progeny P4806XFS	RR2XF	4.8
Progeny P4931E3S	Enlist E3	4.9
Progeny P4970RX	RR2X	4.9
Progeny P5521E3	Enlist E3	5.5
R13- 14635RR:0010[b]	RR1	4.6
R15-1587[b]	Conv.	5.3
R15-2422[b]	Conv.	4.7
R15-5695[b]	Conv.	5.5
R16-253[b]	Conv.	4.6
R17-283F[b]	Conv.	5.3
R18-14287[b]	Conv.	4.3
R18-14502[b]	Conv.	4.9
R18-14753[b]	Conv.	4.6
R18-3048[b]	Conv.	5.3
R18-3250[b]	Conv.	5.3
R18C-1450[b]	Conv.	4.3
UA54i19GT	RR1	5.4
USG 7481XF	RR2XF	4.8
USG 7489XT	RR2X	4.8
USG 7491XFS	RR2XF	4.9
XO 4681E	Enlist E3	4.6

[a] Abbreviations: USG = UniSouth Genetics; XO = Xitavo Soybean Seed.

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

[c] Abbreviations: Conv. = Conventional; Enlist E3 = Enlist E3®; RR1 = Roundup Ready®; RR2X = Roundup Ready 2 Xtend®; RR2XF = Roundup Ready 2 XtendFlex®.

Table 3. Severe categorical injury rating of 2021 soybean varieties to preemergence (PRE) metribuzin application (0.5 lb ai/ac). Rating taken at 28 days after treatment (DAT).

Variety[a]	Herbicide Technology Trait[b]	Maturity Group
Armor 48-D25	RR2X	4.8
Asgrow AG53XF2	RR2XF	5.3
Asgrow AG54XF0	RR2XF	5.4
Delta Grow DG46E10	Enlist E3	4.6
Delta Grow DG49E90	Enlist E3	4.9
Delta Grow DG49F22/STS	RR2XF	4.8
Delta Grow DG53E30	Enlist E3	5.3
Delta Grow DG54F20	RR2XF	5.4
Dyna-Gro S46XF31S	RR2XF	4.6
Local LS4795XS	RR2X	4.7
Local LS4805XFS	RR2XF	4.8
Local LS5009XS	RR2X	5.0
Local LS5614XF	RR2XF	5.6
NK 42-T5XF	RR2XF	4.2
NK S48-2E3S	Enlist E3	4.8
Pioneer P47A64X	RR2X	4.7
Progeny P4816RX	RR2X	4.8
Progeny P4821RX	RR2X	4.8
Progeny P4921XFS	RR2XF	4.9
Progeny P5121E3S	Enlist E3	5.1
Progeny P5424XF	RR2X	5.4
R16-1445[a]	Conv.	5.5
R17-3488[a]	Conv.	5.5
R17-4177[a]	Conv.	5.6
S16-14801C[a]	Conv.	5.0

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

[b] Abbreviations: Conv. = Conventional; Enlist E3 = Enlist E3®; RR2X = Roundup Ready 2 Xtend®; RR2XF = Roundup Ready 2 XtendFlex®.

Exploring Gene Expression in a Trifluralin-Resistant Palmer Amaranth Accession from Arkansas

F. González-Torralva,[1] J.K. Norsworthy,[1] L.T. Barber,[2] and T.R. Butts[2]

Abstract

Resistance mechanisms to trifluralin have been explored in a Palmer amaranth (*Amaranthus palmeri* S. Watson) accession collected in eastern Arkansas. However, gene expression has not yet been studied. Thus, the objective of this research was to describe the basal gene expression levels of the *α*- and *β-tubulin* genes in a trifluralin-resistant Palmer amaranth accession. Basal gene expression levels of the *α*- and *β-tubulin* genes were measured relative to *Cinnamoyl-CoA reductase* (*CCR*) and *peter Pan-like* (*PPAN*) in non-treated tissue of both resistant and susceptible Palmer amaranth accessions. Results demonstrated that the basal expression levels found in both the *α*- and *β-tubulin* genes were in the range of 0.4–1.0-fold. No significant differences were found between the resistant and susceptible accessions in either of the reference genes used. These results further corroborate the presence of non-target site resistance mechanisms in this trifluralin-resistant accession collected in eastern Arkansas.

Introduction

Herbicides have effectively controlled non-desirable plant species in different cropping systems and situations (Kraehmer et al., 2014). However, the gradual overuse of herbicides, the lack of rotation to other weed control practices, or the implementation of an effective Integrated Weed Management program led to herbicide resistance issues, a worldwide threat (Chauhan et al., 2017).

Palmer amaranth (*Amaranthus palmeri* S. Watson) has been ranked in the top 10 of the most problematic weed species in cotton (*Gossypium hirsutum* L.) and soybean [*Glycine max* (L.) Merr.] in the United States (Van Wychen 2020). This ranking is due to its great capacity to produce seeds that are easily dispersed by different means, its ability to cross-pollinate, and its ability to evolve resistance to herbicides (Smith et al., 2011; Sosnoskie et al., 2012; Ward et al., 2013). Palmer amaranth has evolved resistance to different herbicides' sites of action. Several accessions resistant to photosystem II inhibitors, acetolactate synthase inhibitors (ALS), 5-enolpyruvylshikimate-3-phosphate synthase inhibitors (EPSPS), 4-hydroxyhenyl-pyruvatedioxygenase inhibitors (HPPD), protoporphyrinogen oxidase inhibitors (PPO), auxin mimics, very long chain fatty acid inhibitors (VLCFA) and microtubule assembly-inhibiting herbicides have been reported (Heap, 2022).

Trifluralin herbicide was commercialized in 1964 and fell into the microtubule assembly-inhibiting herbicide family. Its mode of action is based on the inhibition of microtubule formation. Such microtubules are formed by the *α*- and *β-tubulin* heterodimers (Anthony and Hussey, 1999; Senseman, 2007). Inhibition of microtubule formation produces a mitosis alteration that provokes a deficient root and shoots growth, leading to plant death (Nogales et al., 1998). In a trifluralin-resistant accession of Palmer amaranth, resistance mechanisms pointed out glutathione-*S*-transferases (GSTs) contributing to trifluralin resistance since gene amplification and target-site mutations were not found in the resistant accession described (González-Torralva and Norsworthy, 2021). On the other hand, gene expression of the target-site gene has been correlated to resistance mechanisms in different herbicide-resistant weed species (Gaines et al., 2020).

The objective of this research was to assess the basal levels of gene expression in the *α*- and *β-tubulin* genes in a trifluralin-resistant Palmer amaranth accession from eastern Arkansas.

Procedures

Trifluralin-resistant and -susceptible accessions used in this study have been previously characterized (González-Torralva and Norsworthy, 2021). Leaf tissue of trifluralin-resistant plants that survived a commercial field rate of trifluralin (16 oz/ac) along with non-treated susceptible plants was harvested and quickly frozen in liquid nitrogen. Frozen tissue was stored at -80 °C until ribonucleic acid (RNA) extraction.

Total RNA was extracted using the Monarch Total RNA Miniprep Kit (New England Biolabs, Ipswich, Mass.). Evaluation and quantification of RNA were assessed spectrophotometrically (Nanodrop 2000c, Thermo Scientific, Waltham, Mass.). Complementary DNA (cDNA) was obtained using 1 µg of total RNA as a template and following the instructions of the iScript Reverse Transcription Supermix (Bio-Rad Laboratories Inc., Hercules, Calif.) kit.

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Complementary DNA was used to estimate the basal levels of gene expression in the *α*- and *β-tubulin* genes of trifluralin-resistant and -susceptible Palmer amaranth accessions using a quantitative real-time polymerase chain reaction (qPCR). Target gene primers were designed using the Primer3Plus software (Untergasser et al., 2007). *Cinnamoyl-CoA reductase* (*CCR*) and *peter Pan-like* (*PPAN*) were used as reference genes. Quantitative real-time polymerase chain reactions were run in a CFX Connect Real-Time System (Bio-Rad Laboratories Inc., Hercules, Calif.). Each reaction of 20 µL included 10 µL of 2× SsoAdvanced Universal SYBR Green Supermix (Bio-Rad Laboratories Inc., Hercules, Calif.), 0.8 µL (10 µM) of each sense and antisense primers, 2.5 µL of cDNA (5-fold dilution), and 5.9 µL water. After cycling, dissociation curves were created to discard non-specific amplification. Basal levels of gene expression relative to reference genes were obtained using the $2^{-\Delta\Delta Ct}$ method described elsewhere (Livak and Schmittgen, 2001). Three biological replicates and 3 technical replicates per accession were used in the experiment.

Results and Discussion

Gene expression, a target-site resistance mechanism, has been frequently found in different herbicide-resistant weeds. It has been reported, for instance, in glyphosate-resistant *Lolium rigidum* [Gaudin], in *Descurainia sophia* [(L.) Webb ex Prantl] resistant to tribenuron-methyl or *Echinochloa crus-galli* [(L.) P. Beauv.] resistant to penoxsulam (Fang et al., 2019; Yang et al., 2016; Yanniccari et al., 2017). Overexpression of the target-site gene means more enzyme is produced to avoid herbicide damage. In addition, overexpression can be an effect of genetic changes and/or gene amplification of the target-site gene, which triggers gene overexpression (Gaines et al., 2020).

In our experiments, dissociation curves produced at the end of qPCRs corroborated that a single amplicon was amplified (Fig. 1 A-B). When using the *CCR* as a reference gene, the basal expression levels of the resistant accession were very low (≈ 0.3-fold change) compared to the basal expression levels observed in the susceptible (≈ 1-fold-change). Both the *α*- and *β-tubulin* genes displayed similar values in either the trifluralin-resistant or susceptible accessions (Fig. 2).

In addition, when using the *PPAN* as a second reference gene, similar results were obtained. Thus, basal expression levels were in the range of ≈ 0.4-fold-change for the resistant accession compared to ≈ the 1-fold-change obtained in the susceptible. Both the *α*- and *β-tubulin* genes showed similar basal expression values in both accessions (Fig. 2).

It has been stated that the *α*- and *β-tubulin* genes are stable to keep normal cell growth in the plant. Hence gene amplification or overexpression would not be a resistance mechanism unless both genes are acting together (Chen et al., 2021). Our results agree with the latter statement and suggest that gene overexpression is not taking part, at least in those non-treated accessions. In addition, these results further propose that gene amplification is not taking part in the trifluralin resistance mechanism as described before (González-Torralva and Norsworthy, 2021).

Practical Applications

Our results suggest the involvement of mechanisms other than target-site resistance in this trifluralin-resistant accession collected in eastern Arkansas. Therefore, different measures should be taken to avoid the dispersion of any herbicide-resistant plant accession and minimize the evolution of non-target site resistance mechanisms.

Acknowledgments

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Literature Cited

Anthony, R.G., and P.J. Hussey. 1999. Dinitroaniline herbicide resistance and the microtubule cytoskeleton. Trends Plant Sci. 4:112–116.

Chauhan, B.S., A. Matloob, G. Mahajan, F. Aslam, S.K. Florentine, and P. Jha. 2017. Emerging challenges and opportunities for education and research in weed science. Front. Plant Sci. 8:1537.

Chen, J., Q. Yu, E. Patterson, C. Sayer, and S. Powles. 2021. Dinitroaniline herbicide resistance and mechanisms in weeds. Front. Plant Sci. 12:634018.

Fang, J., Y. Zhang, T. Liu, B. Yan, J. Li, and L. Dong. 2019. Target-site and metabolic resistance mechanisms to penoxsulam in barnyardgrass (*Echinochloa crus-galli* (L.) P. Beauv). J. Agric. Food Chem. 67:8085–8095.

Gaines, T.A., S.O. Duke, S. Morran, C.A.G. Rigon, P.J. Tranel, A. Küpper, and F.E. Dayan. 2020. Mechanisms of evolved herbicide resistance. J. Biol. Chem. 295:10307–10330.

González-Torralva, F., and J.K. Norsworthy. 2021. Understanding resistance mechanisms to trifluralin in an Arkansas Palmer amaranth population. Genes. 12:1225.

Heap, I. 2022 The international herbicide-resistant weed database. Accessed 28 June 2021. Available at: www.weedscience.org

Kraehmer, H., B. Laber, C. Rosinger, and A. Schulz. 2014. Herbicides as weed control agents: State of the art: I. Weed control research and safener technology: The path to modern agriculture. Plant Physiol. 166:1119–1131.

Livak, K.J. and T.D. Schmittgen. 2001. Analysis of relative gene expression data using real-time quantitative PCR and the $2^{-\Delta\Delta CT}$ method. Methods. 25:402–408.

Nogales, E., S.G. Wolf, and K.H. Downing. 1998. Structure of the αβ tubulin dimer by electron crystallography. Nature. 391:199–203.

Senseman, S.A. 2007. Herbicide Handbook. 9th Edition, Weed Science Society of America. 2007th ed. Champaign, Ill. 458 p.

Smith, K.L., R.C. Doherty, J.A. Bullington, J.R. Meier, and M.V. Bagavathiannan. 2011. Seed production potential of Palmer amaranth in Arkansas. Pages 40–43 in D.E. Oosterhuis, ed. Summaries of Arkansas Cotton Research. Little Rock, Ark. University of Arkansas System Division of Agriculture's Arkansas Agricultural Experiment Station.

Sosnoskie, L.M., T.M. Webster, J.M. Kichler, A.W. MacRae, T.L. Grey, and A.S. Culpepper. 2012. Pollen-mediated dispersal of glyphosate-resistance in Palmer amaranth under field conditions. Weed Sci. 60:366–373.

Untergasser, A., H. Nijveen, X. Rao, T. Bisseling, R. Geurts, and J.A.M. Leunissen. 2007. Primer3Plus, an enhanced web interface to Primer3. Nucleic Acids Res. 35:W71–W74.

Van Wychen, L. 2020. Survey of the most common and troublesome weeds in grass crops, pasture, and turf in the United States and Canada. Weed Science Society of America National Weed Survey Dataset. Accessed 4 June 2021. Available at: https://wssa.net/wp-content/uploads/2020-Weed-Survey_grass-crops.xlsx

Ward, S.M., T.M. Webster, and L.E. Steckel. 2013. Palmer Amaranth (*Amaranthus palmeri*): A Review. Weed Technol. 27:12–27.

Yang, Q., W. Deng, X. Li, Q. Yu, L. Bai, and M. Zheng. 2016. Target-site and non-target-site based resistance to the herbicide tribenuron-methyl in flixweed (*Descurainia sophia* L.). BMC Genomics. 17:551.

Yanniccari, M., M.E. Gómez-Lobato, C. Istilart, C. Natalucci, D.O. Giménez, and A.M. Castro. 2017. Mechanism of resistance to glyphosate in *Lolium perenne* from Argentina. Front. Ecol. Evol. 5:123.

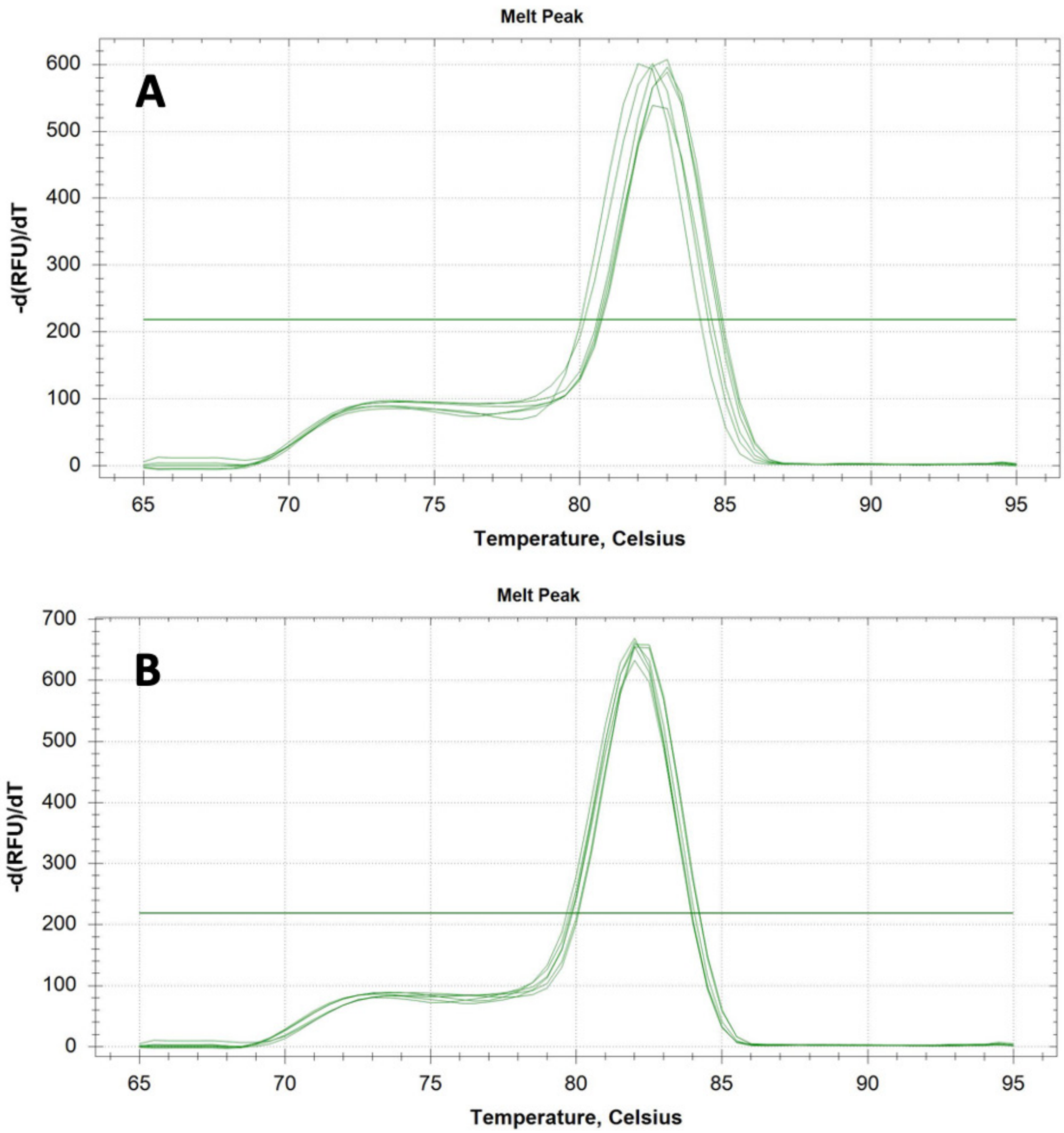
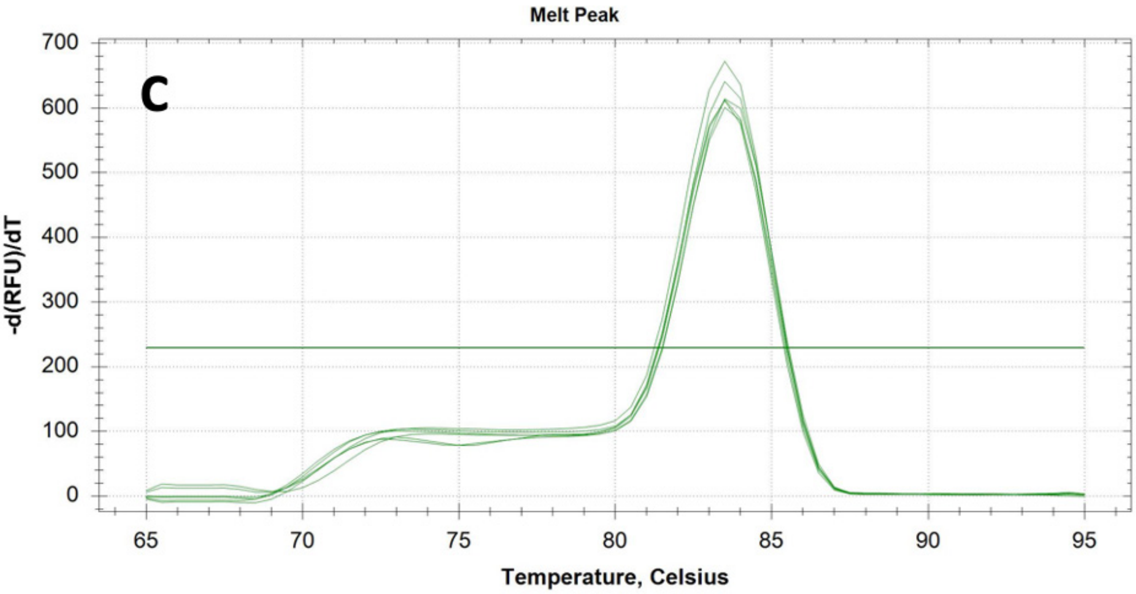


Fig. 1 A. Dissociation curves generated for the target *α*-(A) and *β-tubulin* (B) genes.



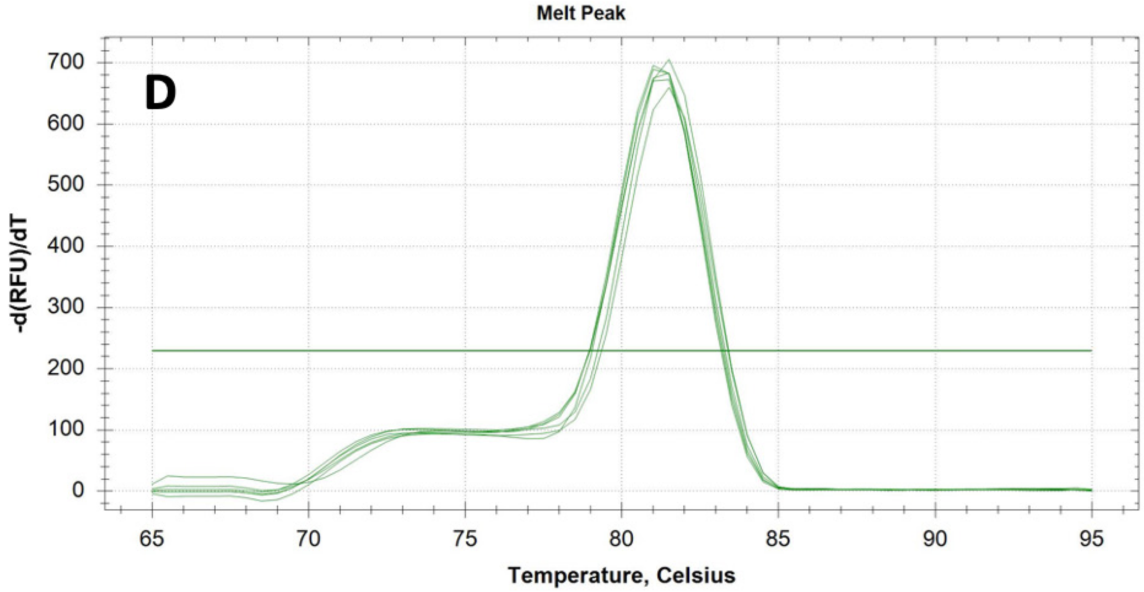


Fig. 1 B. Dissociation curves generated for *Cinnamoyl-CoA reductase* (*CCR*) (C) and *Peter Pan-like* (*PPAN*) (D) genes which were used as reference genes.

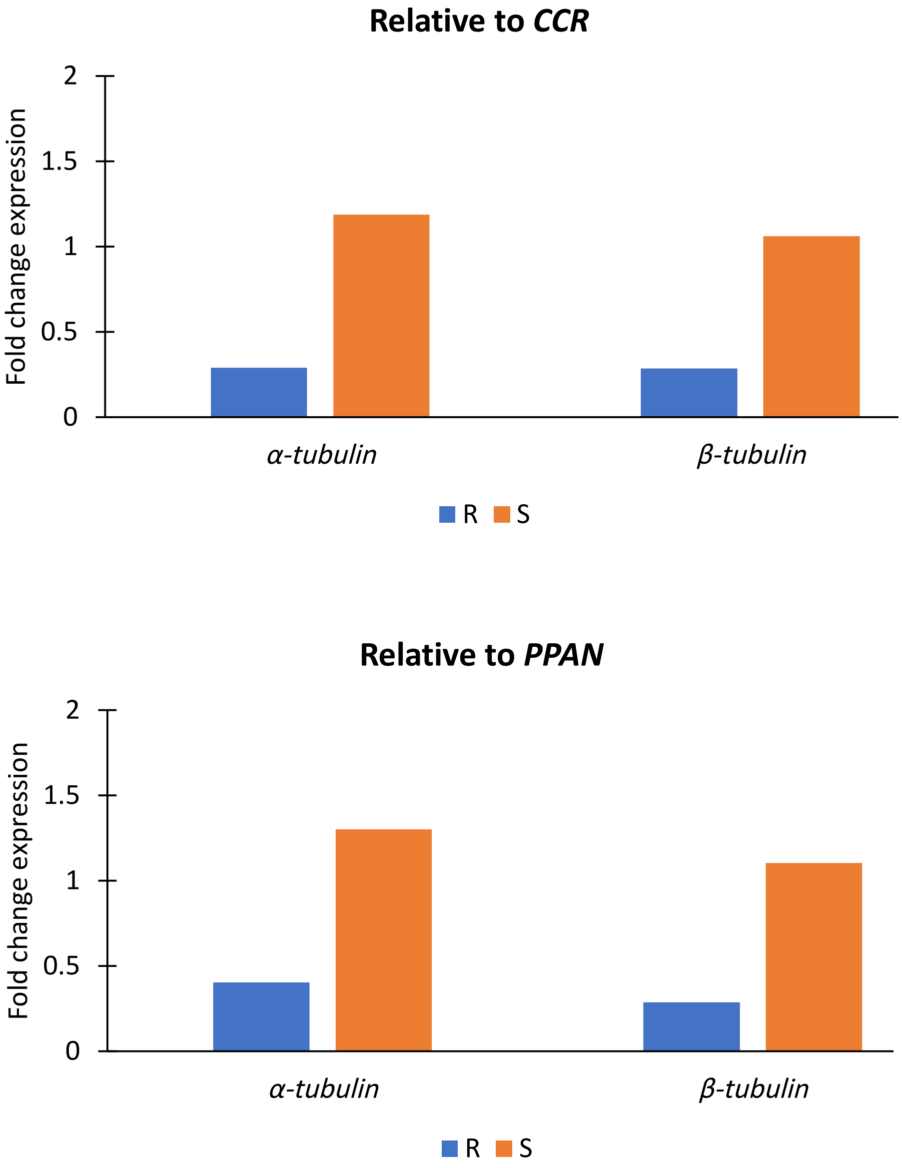


Fig 2. Fold change gene expression in trifluralin-resistant (R) and susceptible (S) Palmer amaranth plants. *CCR = Cinnamoyl-CoA reductase; PPAN = peter Pan-like.*

PEST MANAGEMENT: WEED CONTROL

Impact of Desiccation and the Use of Harvest Weed Seed Control on Palmer Amaranth Entering the Soil Seedbank

T.C. Smith,[1] J.K. Norsworthy,[1] T. Butts,[2] and L.T. Barber[2]

Abstract

Soybean [*Glycine max* (L.) Merr.] cropping systems are an essential part of agriculture in the United States. Palmer amaranth [*Amaranthus palmeri* (S.) Watson] is one of the most troublesome weeds in these systems and can reduce yields for producers. Herbicide resistance has posed new obstacles to controlling Palmer amaranth. Methods such as mechanical seed destruction can add another option for producers to combat this troublesome weed. Field trials were initiated at both the University of Arkansas System Division of Agriculture's Jackson County Extension Center located near Newport, Arkansas, and the Northeast Research and Extension Center located in Keiser, Arkansas, to assess how desiccation of soybean infested with Palmer amaranth affects shattering of the weed and the effectiveness of a Redekop™ seed destructor. Treatments of 5 different desiccants were applied to plots, and plots were then split with harvest weed seed control and no harvest weed seed control being the subplot factor. Results showed that harvest weed seed control significantly reduced the number of viable seeds returning to the soil seed bank by 60% at the Keiser location and 64% at the Newport location. Treatment and the interaction between treatment and harvest weed seed control were insignificant. With Palmer amaranth resistance making it harder to control, using methods such as a Redekop seed destructor as a harvest weed seed control tactic can help combat the growing problem.

Introduction

Palmer amaranth [*Amaranthus palmeri* (S.) Watson] has been ranked the most troublesome weed among broadleaf crops in the United States (Wychen, 2019). One characteristic that makes Palmer amaranth problematic is the large number of seeds that a plant can produce during the growing season. In 1989, Keely and Thullen showed that a single female Palmer amaranth plant could produce up to 600,000 seeds per growing season. Wind, water, animal waste, tillage, and farm equipment contribute to dispersing the small seeds allowing Palmer amaranth to spread rapidly (Norsworthy et al., 2014). In soybean [*Glycine max* (L.) Merr.], Palmer amaranth densities of 0.33 to 10 plants per yard of row can reduce yields by 17% to 68% (Klingaman and Oliver, 1994). Herbicide resistance is another concern when it comes to Palmer amaranth in soybean. Today, Palmer amaranth is resistant to 8 herbicide modes of action (Heap, 2020). This resistance makes Palmer amaranth more challenging to control with herbicides, leading to the need for other means of control. Harvest weed seed control is a method used to prevent viable weed seeds from entering the soil seed bank while prolonging the effectiveness of herbicide programs (Walsh et al., 2013).

Procedures

A field trial was initiated in 2021 at the University of Arkansas System Division of Agriculture's Jackson County Extension Center located near Newport and at the Northeast Research and Extension Center located in Keiser, Arkansas, to study the effects of desiccation of soybean infested with Palmer amaranth on shattering of the weed and the effectiveness of a Redekop™ (Redekop Manufacturing, Saskatchewan, Canada) seed destructor as a mean of harvest weed seed control. Soybean was planted at 145,000 seeds/ac at a 38-in. row spacing at Keiser and 30-in at Newport, and plots were 25-ft by 225-ft. These trials had a split-plot design, with desiccant (Table 1) being the whole plot factor and harvest weed seed control being the split-plot factor. To evaluate Palmer amaranth's seed shattering from the application of desiccants, a single female plant, representative of the population in the plot, was selected, and 4 trays were placed under the base of the plant to collect shattered seeds. Once trays were set, the plots were sprayed with 1 of the 5 different desiccation treatments using a MudMaster plot sprayer with TeeJet® AIXR 110015 nozzles at 15 gal/ac.

Two weeks after treatments were applied, trays in the field were collected, and soybean was harvested. Plots were harvested with a John Deere S690 at the Keiser location and an S670 at the Newport location. Both combines were equipped with a Redekop™ seed destructor, a 25 ft platform header at Keiser, and a 30 ft platform header at Newport.

Four 10 ft^2 trays were placed in the plots to collect samples to evaluate the effectiveness of the Redekop™ seed destructor. Two trays were placed under the header to evaluate the number of Palmer amaranth seeds returning to the plot due to shattering at the header. Two were placed directly

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under the center of the combine to collect header losses and those passing through the combine. Trays were emptied after each plot, and the chaff from each tray was kept separate based on where the chaff was collected. Chaff was then sieved to separate trash from the Palmer amaranth seed, and seeds were planted in trays and grown out in a greenhouse. As the seeds germinated, counts were taken weekly. Weed germination was totaled, data were subjected to analysis of variance using JMP Pro 16.1, and means were separated using Fisher's protected least significance difference ($\alpha = 0.05$).

Results and Discussion

Statistical analysis showed that header loss of Palmer amaranth seed ranged from 3% to 30% at both locations. The reduction of viable seeds entering the soil seed bank was most significant in plots using the Redekop seed destructor. The number of viable seeds was reduced in these plots by 60% at the Keiser and 64% at Newport compared to plots that did not include harvest weed seed control (Fig. 1). A study by Schwartz-Lazaro et al. (2017) showed that harvest weed seed control could reduce Palmer amaranth emergence by 98.8% using a Harrington seed destructor. The desiccant program was non-significant at both locations. Although there were no significant differences among treatments, the paraquat treatments numerically resulted in lower emergence of Palmer amaranth.

Practical Applications

Herbicide resistance is one of the main effects of the continuous use of the same herbicide program in a cropping system. Harvest weed seed control can effectively reduce selective pressure for herbicide resistance when resistance allele frequencies are low (Somerville et al., 2018). Using a Redekop seed destructor would allow producers to reduce the number of viable seeds entering the seed bank and reduce selective pressure for herbicide resistance while prolonging the effectiveness of herbicide programs in their soybean cropping systems.

Acknowledgments

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Literature Cited

Heap, I. 2020. The International Herbicide-Resistant Weed Database. Accessed 25 April 2022. Available at https://weedscience.org/Home.aspx

Keeley, P.E., and R.J. Thullen. 1989. Growth and competition of black nightshade (*Solanum nigrum*) and Palmer amaranth (*Amaranthus palmeri*) with cotton (*Gossypium hirsutum*). Weed Sci 37:326–334.

Klingaman, T.E. and L.R. Oliver. 1994, Palmer amaranth (*Amaranthus palmeri*) interference in soybeans (*Glycine max*). Weed Sci 42:523–527.

Norsworthy, J.K., G. Griffin, T. Griffin, M. Bagavathiannan, and E.E. Gbur. 2014. In-field movement of glyphosate-resistant Palmer amaranth (*Amaranthus palmeri*) and its impact on cotton lint yield: evidence supporting a zero-threshold strategy. Weed Sci 62:237–249.

Schwartz-Lazaro, L.M., J.K. Norsworthy, M.J. Walsh, and M.V. Bagavathiannan. 2017. Efficacy of the integrated Harrington Seed Destructor on weeds of soybean and rice production systems in the Southern United States. Crop Sci. 57:2812–2818.

Somerville, G.J., S.B. Powles, M.J. Walsh, and M. Renton. 2018. Modeling the impact of harvest weed seed control on herbicide-resistance evolution. Weed Sci. 66:395–403.

Wychen, L. 2019. Survey of the most common and troublesome weeds in broadleaf crops, fruits & vegetables in the United States and Canada. Weed Science Society of America National Weed Survey Dataset. Accessed: 27 April 2022. Available at: https://wssa.net/wp-content/uploads/2019-Weed-Survey_broadleaf-crops.xlsx

Walsh, M.J., P. Newman, and S.B. Powles. 2013. Targeting weed seeds in-crop: a new weed control paradigm for global agriculture. Weed Technol. 27:431–436.

Table 1. Herbicide programs with common names and application rates for soybean desiccation at the University of Arkansas System Division of Agriculture's Jackson County Extension Center in Newport and the Northeast Research and Extension Center in Keiser, Ark. in 2021.

Treatment	Herbicide	Rate (lb ai/ac)
1	Non-treated	-
2	Saflufenacil	0.044
	MSO	1% v/v
	AMS	2.55
3	Paraquat	0.35
	NIS	0.25% v/v
4	Paraquat	0.7
	NIS	0.25% v/v
5	Paraquat	0.35
	NIS	0.25% v/v
	Sodium Chlorate	2 gal/ac

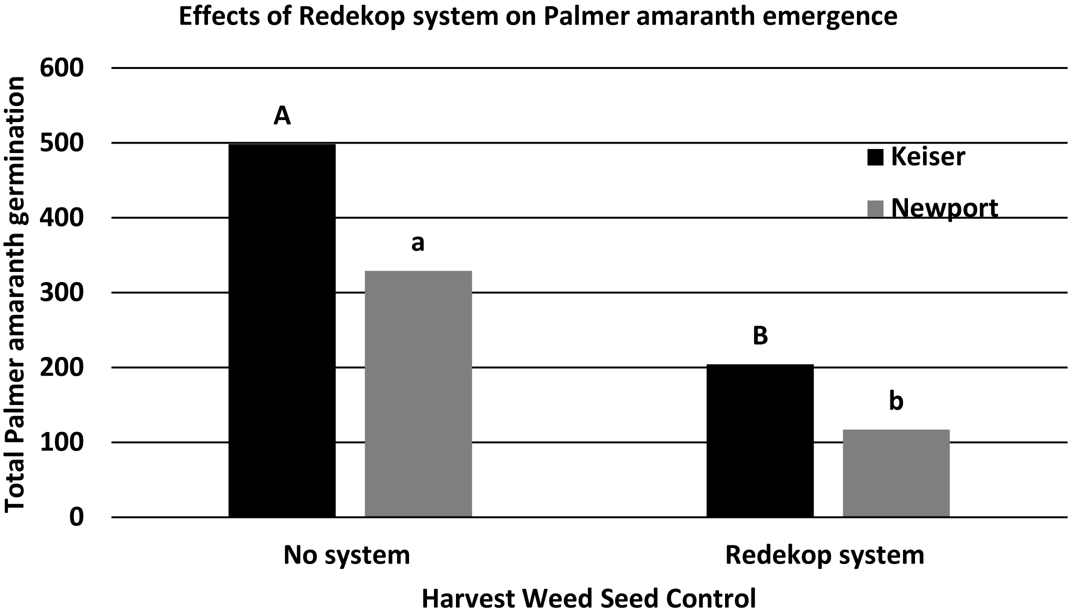

Fig. 1. Total germination of Palmer amaranth [*Amaranthus palmeri* (S.) Watson] with and without using the Redekop harvest weed seed control system at the University of Arkansas System Division of Agriculture's Jackson County Extension Center in Newport and at the Northeast Research and Extension Center located in Keiser, Ark. in 2021. Means were averaged over other factors, and means followed by the same letter are not significantly different (α = 0.05).

PEST MANAGEMENT: WEED CONTROL

Evaluation of Metobromuron on Efficacy and Crop Tolerance in Soybean

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N. Roma-Burgos,[3] and D. Long[4]

Abstract

The use of preemergence herbicide technology has become increasingly critical in the fight against weeds due to postemergence herbicide resistance. The objective of this study was to evaluate the use of metobromuron for efficacy and crop tolerance in soybean [*Glycine max* (L.) Merr.], when used alone and in combination with Tricor® (metribuzin) in comparison to Tricor, Linex® (linuron) and Trivence® (chlorimuron-ethyl, metribuzin, and flumioxazin) applied alone. Visual estimations of weed control for Palmer amaranth (*Amaranthus palmeri* S. Wats.) and soybean crop injury were collected 14, 28, and 35 days after the herbicide application. Weed control ratings ranged from 67.5% for metobromuron (2.11 pt/ac), as the least effective treatment, to 100% for Trivence at 28 days after application. No visual injury was observed on soybean from any treatment. These data demonstrate the importance of including preemergence herbicides in a successful weed management program as well as combining chemicals that utilize multiple, effective modes of action.

Introduction

Herbicide-resistant weeds have become increasingly problematic each growing season due to the repetition of the same management practices. More concerted efforts are needed in the research, education, and development of effective management strategies to preserve herbicides as essential tools of agricultural technology (Butts et al., 2022). Reliance on herbicides for weed control is expected to continue due to their ease of use and economic advantages. However, for sustainable weed management to be achieved, changes to current herbicide use patterns are required (Norsworthy et al., 2012). Residual preemergence (PRE) herbicides applied at planting are one of the recommendations for the management of herbicide-resistant Palmer amaranth (*Amaranthus palmeri* S. Wats.) (S. de Sanctis et al., 2021). The objective of this study was to evaluate metobromuron applied PRE for efficacy and soybean [*Glycine max* (L.) Merr.] tolerance. Metobromuron is not a newly discovered active ingredient. It is a selective herbicide that was labeled for PRE weed control of annual broadleaf weeds and annual grasses in potato cropping systems as early as 1973 (U.S. EPA, 1973). However, little research has been done on its use in soybean. The active ingredient belongs to the urea chemical family and is classified by the Weed Science Society of America (WSSA) as a Group 5 for inhibition of photosynthesis at photosystem 2 (PSII).

Procedures

A field trial was conducted in the summer of 2021 at the University of Arkansas System Division of Agriculture's Jackson County Extension Center near Newport, Ark. This research was conducted to evaluate the use of metobromuron for efficacy and crop tolerance in soybean when used alone and in combination with Tricor® (metribuzin) and compared to Tricor (metribuzin), Linex® (linuron), and Trivence® (chlorimuron-ethyl, metribuzin, and flumioxazin) preemergence herbicides. Soybean was drilled in 7.5-in row widths and pivot irrigated. The experimental design was a randomized complete block design with 4 replications and consisted of 10 treatments (Table 1). All treatments were applied at planting to a clean seedbed, which had been disked and field cultivated immediately prior to drilling soybean. The application was applied using a Bowman MudMaster with a 5-ft multi-boom system calibrated to deliver 10 gallons per ace (GPA) at 4 miles per hour using AIXR 110015 nozzles. Palmer amaranth was the only weed present in this study. Visual estimation of control and soybean injury were taken at 14, 28, and 35 days after application (DAA). Weed control ratings were based on a scale of 0% (no control) to 100% (complete control). Data were subjected to analysis of variance (ANOVA) using ARM 2021, and means were separated using Fisher's protected least significant difference test at α = 0.05.

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Results and Discussion

Data showed all treatments provided excellent control (≥ 90%) of Palmer amaranth at 14 DAA (Fig. 1). However, at 28 DAA, control trended downward for nearly all treatments except Trivence, and by 35 DAA, weed control decreased to less than acceptable levels (<85%) for most treatments with a single mode-of-action. Trivence provided the greatest numerical control (100%) throughout the entirety of the study (Fig. 1). Metobromuron exhibited a rate response in the level of Palmer amaranth control observed. A 2.11 pt/ac rate of the product provided 67.5% control at 35 DAA compared to the nontreated control, while the highest rate, 2.92 pt/ac, provided 88.3% when used alone. At 35 DAA, metobromuron (1.73 pt/a) in combination with Tricor increased control compared to the same rate of metobromuron alone; however, when the rate of metobromuron was increased to 2.11 pt/ac with Tricor, visual weed control was decreased indicating the ratio of these tank-mixture partners is critical to maximizing Palmer amaranth control. Linex + Tricor provided similar control as metobromuron at 1.73 pt/a + Tricor during the study. No visual soybean injury was observed from any treatments (data not shown).

Practical Applications

Overall, the results highlight the importance of using preemergence products and the use of herbicides with multiple, effective sites-of-action within an integrated weed management system. While all treatments provided successful control of Palmer amaranth, treatments that contained multiple active ingredients and multiple modes-of-actions provided an increase in visual control. Although metobromuron is not currently labeled for use in soybean, this research demonstrates a potential alternative PRE herbicide with a site-of-action that Palmer amaranth has not been confirmed resistant to in Arkansas that could be used successfully in soybean production systems.

Acknowledgments

The authors would like to thank the Arkansas Soybean Promotion Board and Belchim Crop Protection USA, LLC. for funding and support of this research.

Literature Cited

Butts, T.R., K.B.J. Kouame, J.K. Norsworthy, and L.T. Barber. 2022. Arkansas Rice: Herbicide Resistance Concerns, Production Practices, and Weed Management Costs. Frontiers in Agronomy. doi: 10.3389/fagro.2022.881667.

Norsworthy, J.K., S.M. Ward, D.R. Shaw, R. Llewellyn, R.L. Nichols, T.M. Webster, K.W. Bradley, G. Frisvold, S.B. Powles, N.R. Burgos, W. Witt, and M. Barrett. 2012. Reducing the risks of herbicide resistance: best management practices and recommendations. Weed Sci. 60(SI I):31–62.

S. de Sanctis, J.H., E.R. Barnes, S.Z. Knezevic, V. Kumar, and A.J. Jhala. 2021. Residual herbicides affect critical time of Palmer amaranth removal in soybean. Agron. J. 113(2):1920-1933.

U.S. EPA. 1973. United States Environmental Protection Agency. Pesticide Product Label. Accessed: 13 April 2022. Available at https://www3.epa.gov/pesticides/chem_search/ppls/002749-00245-19730130.pdf

Table 1. Herbicide treatment list for the evaluation of metobromuron for efficacy and crop tolerance in soybean [*Glycine max* (L.) Merr.], when used alone and in combination with Tricor® (metribuzin) in comparison to Tricor, Linex® (linuron) and Trivence® (chlorimuron-ethyl, metribuzin, and flumioxazin) at the University of Arkansas System Division of Agriculture's Jackson County Extension Center near Newport, Ark.

Treatment number	Trade name	Active Ingredient	Rate	WSSA Group
1	Nontreated Control			
2	BCP222H	metobromuron	1.73 pt/ac	5
3	BCP222H	metobromuron	2.11 pt/ac	5
4	BCP222H	metobromuron	2.92 pt/ac	5
5	Linex®	linuron	2 pt/ac	5
6	Tricor®	metribuzin	1 pt/ac	5
7	BCP222H +	metobromuron +	1.73 pt/ac +	5
	Tricor	metribuzin	1 pt/ac	5
8	BCP222H +	metobromuron +	2.11 pt/ac +	5
	Tricor	metribuzin	1 pt/ac	5
9	Linex +	linuron +	1.5 pt/ac +	5
	Tricor	metribuzin	1 pt/ac	5
10	Trivence®	chlorimuron-ethyl, metribuzin, and flumioxazin	8 oz/ac	2,5,14

WSSA = Weed Science Society of America.

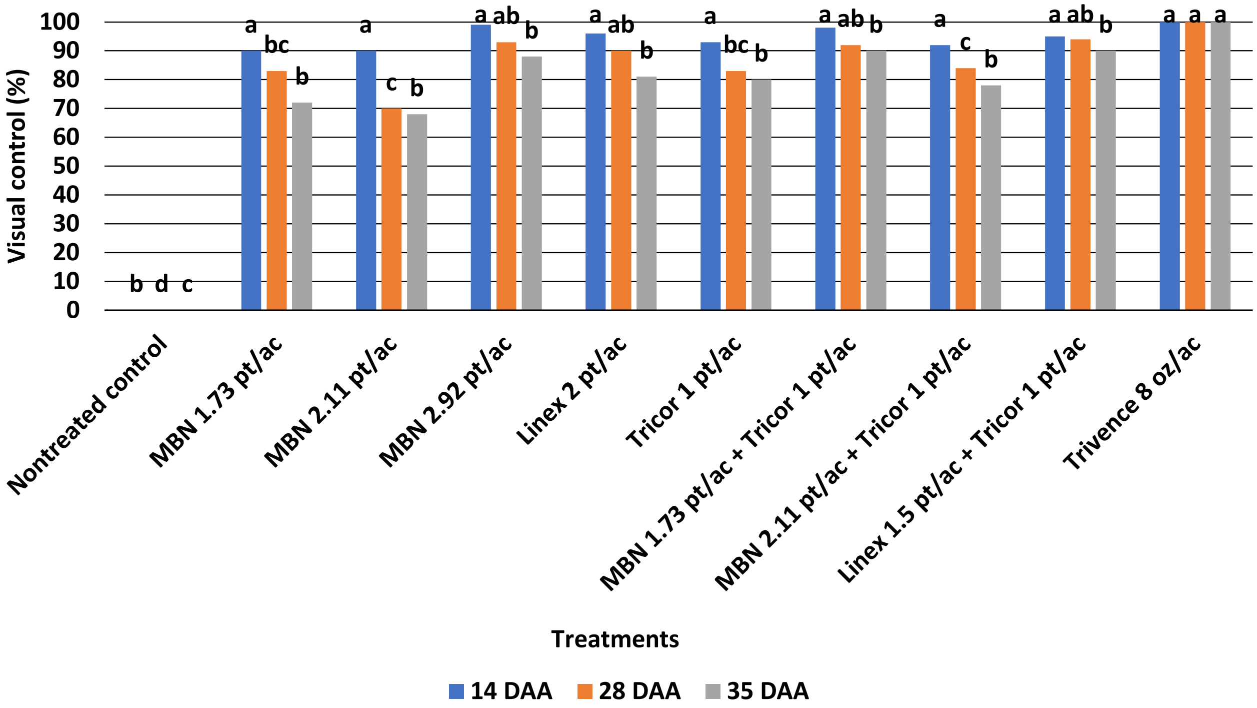

Fig 1. Assessment of visual control of Palmer amaranth at 14, 28, and 35 days after application (DAA). Treatments with the same lowercase letter within the same DAA are not different according to Fisher’s protected least significant difference at α = 0.05. Abbreviation: MBN, metobromuron.

PEST MANAGEMENT: WEED CONTROL

Evaluation of Postemergence Herbicide Tank-Mixtures in an Enlist® E3 Soybean System

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Abstract

Herbicide resistance has become increasingly problematic in production agriculture, creating a great demand for alternative control options. Field studies were conducted at the University of Arkansas System Division of Agriculture's Jackson County Extension Center near Newport, Ark. and the Rohwer Research Station near Rohwer, Ark. to evaluate postemergence (POST) herbicide tank-mixtures in an Enlist® E3 soybean [*Glycine max* (L.) Merr.] system. Treatments consisted of Enlist One® (2,4-D choline) alone and in combination with other products, including Roundup PowerMax® II (glyphosate), Moccasin® (*S*-metolachlor), Liberty® (glufosinate), and Reflex® (fomesafen). Visual estimations of weed control and soybean crop injury were collected 14 and 21 days after application (DAA) of the initial POST treatment, which was made to 4- to 6-in.ch weeds. At the Jackson County location, soybean was drilled in 7.5-in. row widths, and at the Rohwer location, soybean was planted in 38-in. row widths. Visual control of Palmer amaranth (*Amaranthus palmeri* S. Wats.) was 100% at Jackson County across all rating timings; however, there was more variability between treatments at the Rohwer location. These data demonstrate the capability of reduced row spacing to aid in successful weed management efforts. Results from the Rohwer location highlight the importance of combining a non-selective herbicide such as Roundup PowerMax II or Liberty with Enlist One to provide excellent control (≥ 90%) of barnyardgrass (*Echinochloa crus-galli* P. Beauv.), as well as adding an overlapping residual herbicide to the tank-mixture to provide weed control throughout the season.

Introduction

Herbicide-resistant Palmer amaranth (*Amaranthus palmeri* S. Wats.) is a growing challenge (Heap, 2022). It has forced the research and use of alternative herbicides and weed management tactics in soybean [*Glycine max* (L.) Merr.] production. Additionally, these herbicide systems must provide control of troublesome grass species and other broadleaf weeds (Barber et al., 2022). It is well documented that preemergence (PRE) herbicides represent the foundation for chemical weed control in soybean because they effectively control a wide range of weed species and provide growers with additional sites of action for weed control (Ribeiro et al., 2022). However, they do not provide season-long control in most cases. For this reason, postemergence (POST) herbicides are still critical to control weeds throughout the growing season. Therefore, the objective of this study was to evaluate POST herbicide tank mixtures in an Enlist® E3 soybean system.

Procedures

Two field trials were conducted in the summer of 2021, one located at the University of Arkansas System Division of Agriculture's Jackson County Extension Center near Newport, Ark., and another at the Rohwer Research Station near Rohwer, Ark. Soybean was drilled using 7.5-in. row spacing at Newport and planted using 38-in. row spacing at Rohwer. The experimental design was a randomized complete block design with four 4 replications. It consisted of 15 treatments: a nontreated control and 14 treatments containing Enlist One® alone or in combination with residual and other POST herbicides. The list of treatments, including rates, active ingredients, and Weed Science Society of America (WSSA) Group numbers, can be found in Table 1. A blanket application of Dual Magnum® (*S*-metolachlor) was made at planting to delay weed emergence to evaluate the POST herbicides in a more real-world soybean canopy development scenario. Two POST application timings were utilized: Application A was made when weeds were 4- to 6-in. in height; 14 days after application (DAA) of the A timing, a B application occurred for treatments evaluating the benefit of sequential applications. Herbicides were applied using a Bowman MudMaster with a multi-boom system calibrated to deliver 15 gal/ac at 3 miles per hour using AIXR 110015 nozzles. Palmer amaranth was the only weed species present at the Jackson County location when visual estimations of control and soybean injury were

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taken at 14 (0), 21 (7), and 28 (14) DAA of the A timing (DAA of the B timing). At the Rohwer location, visual estimation of control for Palmer amaranth and barnyardgrass, as well as visual estimations of soybean injury, were taken at 14 (0) and 21 (7) DAA of the A timing (DAA of the B timing). Weed control ratings were based on a scale of 0% (no control) to 100% (complete control). 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

Data showed that all treatments provided complete control (100%) of Palmer amaranth throughout the entirety of the study at the Jackson County location (data not shown). Complete weed control is evidence that the 7.5-in. row spacing in conjunction with the blanket PRE application enhanced weed control efforts at this location due to soybean canopy closure shading the soil surface and inhibiting weed growth. As a result, more flexibility in POST herbicide selection was provided to achieve high levels of Palmer amaranth control. The initial Palmer amaranth population was greater at Rohwer compared to Jackson County, resulting in lower control ratings at 14 DAA of the A timing (0 DAA of the B timing) but by 21 DAA of the A timing (7 DAA of the B timing) all treatments provided excellent control (≥ 90%) (Fig. 1). Treatments containing Liberty® or Roundup PowerMax® II confirmed the importance of including a grass herbicide with Enlist One®. These products provided excellent control of barnyardgrass when applied, while Enlist One alone provided no control (Fig. 2). Although high levels of control were observed at Rohwer, it should be noted that the rating timings were only taken out to 21 DAA of the A timing (7 DAA of the B timing). Due to being planted on 38-in.ch row widths, the soybean was far from canopy closure, and more control differences would likely have occurred later in the season between treatments with an overlapping residual compared to those without and those treatments receiving sequential POST applications compared to those that were single POST applications.

Practical Applications

Narrow row spacing can assist soybean weed management efforts by hastening crop canopy closure and providing POST herbicide flexibility to achieve season-long weed control. Using multiple, effective sites of action within an integrated weed management system is the best option to control both broadleaf weeds and grasses and delay the evolution of herbicide resistance. In areas where soybean canopy closure is delayed, overlapping residual herbicides and sequential POST applications are required for season-long weed control of problematic weeds, such as Palmer amaranth and barnyardgrass.

Acknowledgments

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

Literature Cited

Barber, L.T., T.R. Butts, J.W. Boyd, K. Cummingham, G. Selden, J.K. Norsworthy, N. Burgos, and M. Bertucci. 2022. MP44 Recommended chemicals for weed and brush control. University of Arkansas System Division of Agriculture, Cooperative Extension Service.

Heap, I. 2022. The international survey of herbicide-resistant weeds. Accessed 25 April 2022. Available at: http://www.weedscience.org

Ribeiro, V., M.C. Oliveira, D.H. Smith, J.B. dos Santos, and R. Werle. 2022. Control of common weeds in Wisconsin soybean cropping systems with pre-emergence herbicides. Crop, Forage and Turfgrass Management. 8:20153.

Table 1. Postemergence herbicide tank-mixture treatments evaluated for weed control at the University of Arkansas System Division of Agriculture's Jackson County Extension Center near Newport and the Rohwer Research Station near Rohwer, Ark.[a]

Treatment number	Trade name	App. Code[b]	Active Ingredient	Rate	WSSA Group
				oz/ac	
1	Nontreated control				
2	Enlist One®	A	2,4-D choline	32	4
3	Enlist One +	A	2,4-D choline	32	4
	Roundup PowerMax® II	A	glyphosate	32	9
4	Enlist One +	A	2,4-D choline	32	4
	Roundup PowerMax II +	A	glyphosate	32	9
	Moccasin®	A	*S*-metolachlor	16	15
5	Enlist One +	A	2,4-D choline	32	4
	Moccasin	A	*S*-metolachlor	16	15
6	Enlist One +	A	2,4-D choline	32	4
	Liberty®	A	glufosinate	29	10
7	Enlist One +	A	2,4-D choline	32	4
	Liberty +	A	glufosinate	29	10
	Moccasin	A	*S*-metolachlor	16	15
8	Enlist One +	A	2,4-D choline	32	4
	Reflex®	A	fomesafen	24	14
9	Enlist One +	A	2,4-D choline	32	4
	Reflex +	A	fomesafen	24	14
	Moccasin +	A	*S*-metolachlor	16	15
10	Enlist One +	A	2,4-D choline	32	4
	Roundup PowerMax II +	A	glyphosate	32	9
	Liberty +	A	glufosinate	29	10
	Moccasin	A	*S*-metolachlor	16	15
11	Enlist One	A	2,4-D choline	32	4
	Enlist One	B	2,4-D choline	32	4
12	Enlist One +	A	2,4-D choline	32	4
	Roundup PowerMax II	A	glyphosate	32	9
	Liberty	B	glufosinate	29	10
13	Enlist One +	A	2,4-D choline	32	4
	Roundup PowerMax II	A	glyphosate	32	9
	Enlist One +	B	2,4-D choline	32	4
	Liberty	B	glufosinate	29	10
14	Enlist One +	A	2,4-D choline	32	4
	Roundup PowerMax II +	A	glyphosate	32	9
	Moccasin	A	*S*-metolachlor	16	15
	Enlist One +	B	2,4-D choline	32	4
	Liberty	B	glufosinate	29	10
15	Enlist One +	A	2,4-D choline	32	4
	Liberty +	A	glufosinate	29	10
	Moccasin	A	*S*-metolachlor	16	15
	Enlist One +	B	2,4-D choline	32	4
	Roundup PowerMax II	B	glyphosate	32	9

[a] Crop oil concentrate was added at 0.5% v/v to any mixture containing Reflex (Treatments 8 and 9).

[b] Application code A = 4- to 6- in. weeds; B = 14 days after A.

WSSA = Weed Science Society of America.

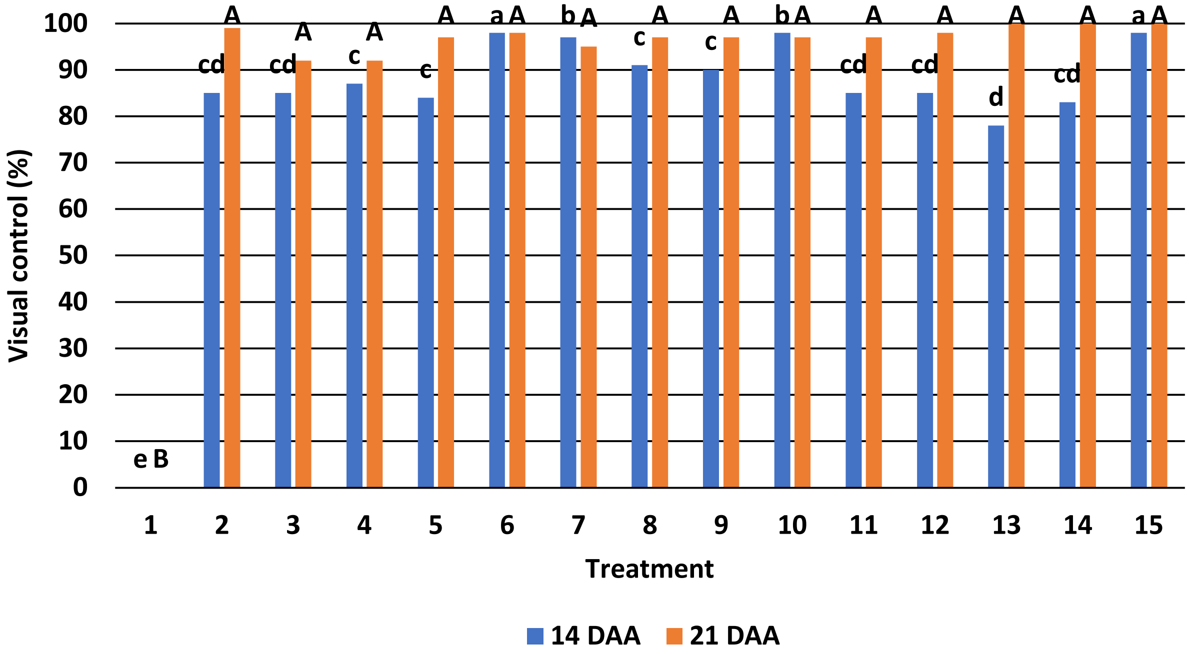

Fig. 1. Assessment of visual control of Palmer amaranth at 14 (0) and 21 (7) days after application (DAA) timing A (DAA timing B) at the University of Arkansas System Division of Agriculture's Rohwer Research Station. Treatments with the same letter within rating date are not different according to Fisher's protected least significant difference at α = 0.05. Postemergence herbicide programs corresponding to treatment number are found in Table 1.

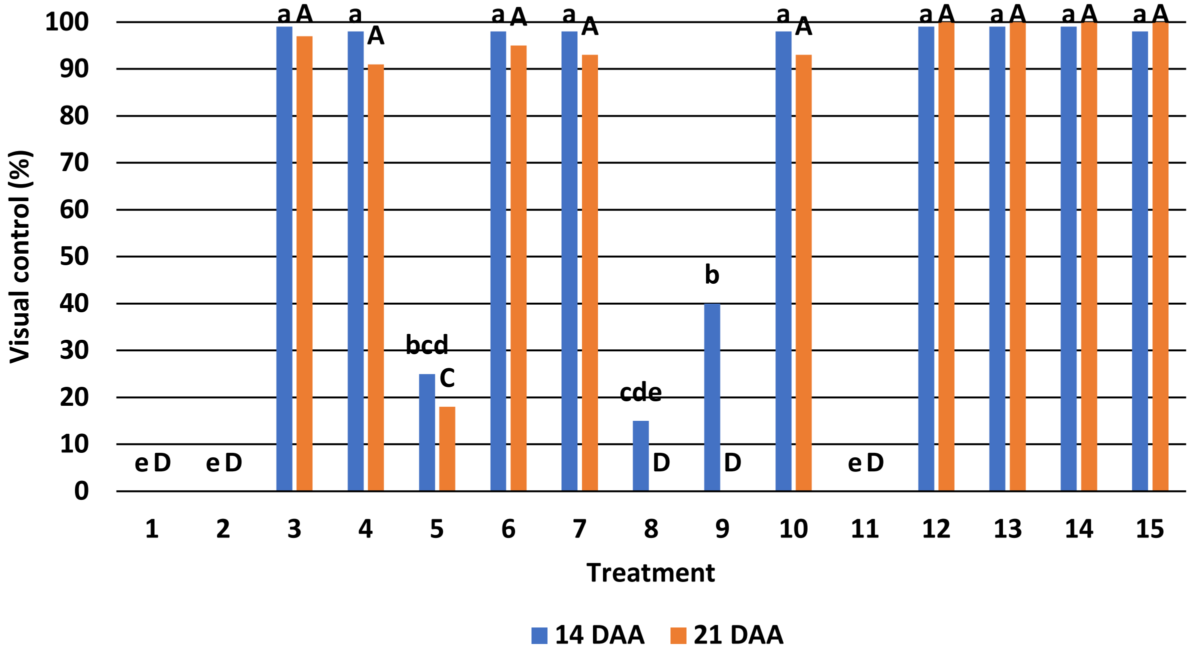

Fig. 2. Assessment of visual control of barnyardgrass at 14 and 21 days after application A (DAA) at the University of Arkansas System Division of Agriculture's Rohwer Research Station. Treatments with the same letter within rating date are not different according to Fisher's protected least significant difference at α = 0.05. Postemergence herbicide programs corresponding to treatment numbers are found in Table 1.

PEST MANAGEMENT: WEED CONTROL

Herbicide-Resistant and -Susceptible Palmer Amaranth (*Amaranthus Palmeri* S. Wats.) Transpiration Responses to Progressively Drying Soil

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Abstract

Drought events are predicted to increase in the future. Evaluating the response of herbicide-resistant and -susceptible weed ecotypes to progressive drought can provide insights into whether a resistance trait affects the fitness of resistant weed populations. Two experiments were conducted in a greenhouse between January and May 2021 to evaluate drought tolerance differences between Palmer amaranth (*Amaranthus palmeri* S. Wats.) accessions resistant to *S*-metolachlor (Dual Magnum®) or glyphosate (Roundup PowerMax™ II) and their susceptible counterparts. The accessions used were: *S*-metolachlor-resistant (17TUN-A), a susceptible standard (09CRW-A), and glyphosate-resistant and glyphosate-susceptible plants from accession 16CRW-D. The daily transpiration of each plant was measured. The daily transpiration rate was converted to normalized transpiration ratio (NTR) using a double-normalization procedure. The daily soil water content was expressed as a fraction of transpirable soil water (FTSW). The threshold FTSW (FTSWcr), after which NTR decreases linearly, was estimated using two-segment linear regression analysis. A greater FTSWcr means early stomatal closure with respect to the initiation of water deficit. The data showed differences between *S*-metolachlor- resistant and -susceptible accessions ($P \leq 0.05$). The FTSW remaining in the soil at the breakpoint for the *S*-metolachlor-susceptible accession (09CRW-A) was 0.17 ± 0.007. The FTSW remaining in the soil at the breakpoint for the *S*-metolachlor-resistant accession (17TUN-A) was 0.23 ± 0.004. The FTSW remaining in the soil at the breakpoint for the glyphosate-resistant and glyphosate-susceptible plants (16CRW-D) were 0.25 ± 0.007 and 0.25 ± 0.008, respectively. Although the mechanism endowing resistance to *S*-metolachlor might have contributed to increased drought tolerance, follow-up experiments are needed to verify this finding. Increased EPSPS copy number did not improve drought tolerance of Palmer amaranth. As droughts are predicted to increase in frequency and severity, these results suggest that *S*-metolachlor-resistant and glyphosate-resistant Palmer amaranth populations will not be at a competitive disadvantage compared to susceptible genotypes. Alternative and diverse management strategies will be required for effective Palmer amaranth control regardless of herbicide resistance status.

Introduction

Drought can negatively affect physiological and biochemical processes and cause yield reduction (Khan et al., 2018). Drought frequency and severity will likely increase in the future (Liu and Basso, 2020). Plant transpiration is a key component of soil water consumption (Li et al., 2020). Under drought, plants can sense water stress around the roots and respond by sending chemical signals to close the stomates (Saradadevi et al., 2017). Determining the threshold value for initiating stomatal closure is critical for understanding plant physiological responses to drought (Sinclair, 2012). One useful parameter to monitor soil drying and corresponding plant response to progressive drought stress is the fraction of transpirable soil water (FTSW). The FTSW is the amount of water available to plants at any given time in the drying cycle relative to the total amount of water available for transpiration at the pot-holding capacity. Plant transpiration in response to a drying soil has been well characterized by previous research and reported to display 2 phases: 1. the initial plateau where transpiration is optimal and 2. a linear decline in response to drying soil. These phases are connected by a breakpoint, also known as the threshold value for initiating stomatal closure (Ray and Sinclair, 1997). The threshold value (FTSWcr) is a crucial parameter for comparing populations, ecotypes, or genotypes. Palmer amaranth (*Amaranthus palmeri* S. Wats.) can adapt to various stress conditions (Bravo et al., 2018). It uses osmoregulation to keep stomates open during drought to continue carbon fixation (Ehleringer, 1983). This trait may be modified by biochemical, physiological, or structural modifications in the plant associated with resistance to herbicides. These coping mechanisms may positively or negatively affect the fitness of resistant weedy plants that could affect weed fecundity or competitive ability. In Arkansas, Palmer amaranth

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has evolved target-site resistance to glyphosate due to EPSPS (5-enolpyruvyl-shikimate-3-phosphate synthase) gene amplification (Singh et al., 2018) and non-target site resistance to *S*-metolachlor via upregulation of glutathione *S*-transferases (GSTs) (Rangani et al., 2021). Harboring these mechanisms may impart some latent benefits, such as increased tolerance to abiotic stress, especially with resistance to *S*-metolachlor, due to the involvement of GSTs. One indicator might be an adjustment in transpiration rate under drought stress. The objective of this research was to quantify the transpiration changes that occur in herbicide-resistant and -susceptible Palmer amaranth accessions submitted to a progressive drying cycle.

Procedures

Two experiments were conducted in the greenhouse from January to May 2021 at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center, Fayetteville, and were repeated in time. The experiments involved accessions resistant (17TUN-A) and susceptible (09CRW-A) to *S*-metolachlor as well as resistant and susceptible plants to glyphosate (accession 16CRW-D). Resistance to *S*-metolachlor was due to GST overexpression (Rangani et al., 2021), and resistance to glyphosate was due to EPSPS amplification (Singh et al., 2018). A total of 100 seeds were planted in trays filled with Sunshine® Premix #1 (Sun Gro Horticulture, Bellevue, Wash.). All healthy seedlings (3 in.) were transplanted to 5.1 in. x 4.3 in. (13 cm x 11 cm) (diameter-by-depth) pots filled with the same soil. Leaf tissue was collected from each plant to determine the relative EPSPS gene copy number (Kouame et al., 2022). Twenty-four plants of similar size (9.8 in. or 25 cm tall; 12 with increased EPSPS copy) were transplanted into pots, 19 cm diameter x 17 cm deep, at the same depth of 4.3 in. (11 cm.)

The experiment was conducted as a completely randomized design with 6 replications (Fig. 1). The experimental units were pots containing one plant per pot. The pots were rerandomized every other day during the experiment. The drought factor had 2 levels (well-watered and water-deficit). The method was adapted from previous research (King and Purcell, 2017). The evening before starting dry down, pots were saturated and allowed to drain overnight. The pots were enclosed in black plastic bags (Ray and Sinclair, 1997), and each bag opening was sealed around the plant stem with twist ties to prevent evaporation. A 6-mL syringe barrel was inserted between the base of the plant and the plastic bag for water replenishment. Newly bagged pots were weighed to determine gravimetric water content at water holding capacity. The pots were weighed daily at 4 p.m., in the same order, for the duration of the experiment. Daily transpiration was calculated as the difference in mass of each pot on successive days. To maintain well-watered conditions but prevent anaerobic conditions in the control pots, the plants were maintained at 80% of the well-watered pot-capacity weight. For the water stress treatments, the 6 plants (or replications) of each accession were watered to a target level of 50 mL below the amount of water lost via transpiration in the past 24 h, starting at the initiation of drought stress treatment. The transpiration data were analyzed using a double normalization procedure to derive the stressed plants' normalized transpiration ratio (NTR). The treatments were maintained for each resistant or susceptible accession or plant until the NTR value dropped below 0.1, defined as the endpoint of the drying cycle (Kouame et al., 2022). The initial, daily, and final pot weights were used to determine the FTSW (King and Purcell, 2017).

The relationship between NTR and FTSW was quantified using two-segment linear regression analysis (King and Purcell, 2017). The NTR calculated for each pot on each day was plotted for each accession versus the corresponding FTSW. The two-segment linear regression analysis was accomplished for the 6 drying pots studied for the *S*-metolachlor- resistant and susceptible accessions and the glyphosate-resistant and susceptible plants, using nonlinear least squares regression (nls) of R version 4.0.0 (R Core Team, 2018). The intersection of the two linear regressions is the FTSW at the breakpoint (FTSWcr) in the soil drying cycle. The resulting R2 for the regression analysis and breakpoint values for the NTR for each accession were determined, and differences between breakpoints were compared using confidence intervals ($\alpha = 0.05$) (King and Purcell, 2017).

Results and Discussion

The NTR response of *S*-metolachlor-susceptible and -resistant Palmer amaranth accessions to progressive drying soil followed the two-segmented linear regression with R^2 values ranging between 0.85 and 0.93 (Table 1). The FTSWcr of the two accessions differed ($P \leq 0.05$) (Table 1), but no differences existed between breakpoints for the same accession across runs ($P > 0.05$); therefore, data were pooled across runs for each accession. The *S*-metolachlor-resistant accession 17TUN-A had a greater FTSWcr than the *S*-metolachlor-susceptible accession 09CRW-A (Fig. 2), indicating that the *S*-metolachlor-resistant accession started reducing its transpiration at higher threshold levels (0.23 ±0.004) than the susceptible plants. The *S*-metolachlor-susceptible accession 09CRW-A started reducing its transpiration at a lower FTSWcr of 0.17 ±0.007.

S-metolachlor resistance reported in Arkansas is attributed to an increase in the herbicide metabolism in the plants catalyzed by glutathione *S*-transferases (GSTs). Data from previous and current experiments on *S*-metolachlor-resistant Palmer amaranth collectively indicate that the GST-mediated resistance mechanism could increase tolerance to drought in resistant plants. We observed this expected latent effect in this current study; however, we cannot attribute increased drought tolerance solely to the *S*-metolachlor NTSR mechanism because the reference susceptible plants did not come from the same population as the resistant plants. Therefore, the baseline tolerance to drought could differ between resistant and susceptible populations from different localities. Also, the resistance profile of the 17TUN-A has not been fully characterized yet. If this population is also resistant to other herbicide modes of action, there may be different NTSR mechanisms associated with other herbicide modes of action that could contribute to drought tolerance.

The glyphosate-susceptible and -resistant plants were chosen from 1 accession, 16CRW-D, based on the EPSPS copy number. It was determined previously that resistance to glyphosate in this population is due to increased production of the target protein, EPSPS. The field population consisted of resistant and susceptible plants; the genomic diversity among these plants would be minimal, except for the traits contributing to glyphosate resistance. The relative EPSPS gene copy number detected in 16CRW-D ranged between 3 and 226. Twelve plants with EPSPS copy numbers between 22 and 165 (considered resistant) and 12 plants with <10 EPSPS copy numbers, which were considered susceptible (Singh et al., 2018), were used for each run. The FTSWcr between plants with increased EPSPS copy number and plants with low gene copy number did not differ ($P > 0.05$). The NTR response of Palmer amaranth to progressive drying soil followed the two-segmented linear regression with R^2 values ranging between 0.90 and 0.91 (Table 2). The presence of more EPSPS copies in accession 16CRW-D did not change the breakpoint ($P > 0.05$) (Fig. 3; Table 2). In other words, increasing the production of this key enzyme in the shikimate pathway did not affect the initiation of stomatal closure under drought.

Practical Applications

The advantages of early and late breakpoints are interpreted diversely and depend on drought scenarios. With smaller FTSWcr in this study, the *S*-metolachlor-susceptible accession is likely to sustain its normal transpiration and prevent growth reduction during short-term water stress. In contrast, the *S*-metolachlor-resistant accession with greater FTSWcr has an advantage under long-term water stress and drier conditions. Greater FTSWcr means early stomatal closure with respect to the initiation of water deficit. By doing this, the plant conserves water and delays desiccation or mitigates drought stress, thereby enhancing the plant's survival under prolonged drought. In nature, this would increase the probability of survival until the next rain event. In the current study, Palmer amaranth with a high EPSPS copy number did not show a fitness penalty (mitigating desiccation by curbing transpiration sooner after the onset of drought stress) when exposed to progressive drying. Glyphosate-resistant and -susceptible plants from the same field population exhibited the same response to drought stress. As droughts are predicted to increase in frequency and severity, these results suggest that *S*-metolachlor-resistant and glyphosate-resistant Palmer amaranth populations will not be at a competitive disadvantage compared to susceptible genotypes. Instead, the *S*-metolachlor-resistant populations may be more competitive than the susceptible ones. Alternative and diverse management strategies will be required for effective Palmer amaranth control regardless of herbicide resistance status.

Acknowledgments

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Literature Cited

Bravo, W., R. Leon, J. Ferrell, M. Mulvaney, and C. Wood. 2018. Evolutionary adaptations of Palmer amaranth (*Amaranthus palmeri*) to nitrogen fertilization and crop rotation history affect morphology and nutrient-use efficiency. Weed Sci. 66: 180–189.

Ehleringer, J. 1983. Ecophysiology of Amaranthus palmeri: A Sonoran desert summer annual. Oecologia 57: 107-112.

Khan, A., X.D. Pan, U. Najeeb, D.K.Y. Tan, S. Fahad, R. Zahoor, and H.H. Luo. 2018. Coping with drought: stress and adaptive mechanisms, and management through cultural and molecular alternatives in cotton as vital constituents for plant stress resilience and fitness. Biol. Res. 51.

King, C., and L. Purcell. 2017. Evaluation of methods for estimating transpiration response to soil drying for container-grown plants. Crop Sci. 57: 2143–2148.

Kouame, K.B.J., M.C. Savin, G. Rangani, T.R. Butts, M.B. Bertucci, and N. Roma-Burgos. 2022. Transpiration responses of herbicide-resistant and -susceptible Palmer amaranth (*Amaranthus palmeri* S. Wats.) to progressively drying soil. Agriculture-Basel 12.

Liu, L., and B. Basso. 2020. Impacts of climate variability and adaptation strategies on crop yields and soil organic carbon in the US Midwest. Plos One 15.

R Core Team. R. 2018. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing, Vienna, Austria.

Rangani, G., M. Noguera, R. Salas-Perez, L. Benedetti, and N. Roma-Burgos. 2021. Mechanism of resistance to S-metolachlor in Palmer amaranth. Front. Plant Sci. 12: 13.

Ray, J., and T. Sinclair. 1997. Stomatal closure of maize hybrids in response to drying soil. Crop Sci. 37: 803–807.

Saradadevi, R., J.A. Palta, and K.H.M. Siddique. 2017. ABA-mediated stomatal response in regulating water use during the development of terminal drought in wheat. Front. Plant Sci. 8.

Singh, S., V. Singh, A. Lawton-Rauh, M. Bagavathiannan, and N. Roma-Burgos. 2018. EPSPS gene amplification primarily confers glyphosate resistance among Arkansas Palmer amaranth (*Amaranthus palmeri*) populations. Weed Sci. 66: 293–300.

Fig. 1. Set-up of greenhouse experiment to evaluate the transpiration responses of herbicide-resistant and -susceptible Palmer amaranth (*Amaranthus palmeri* S. Wats.) to progressively drying soil at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center, Fayetteville, Ark., in 2021.

Table 1. Breakpoint FTSWcr (threshold value for the initiation of stomatal closure), standard error (SE), R^2, and confidence intervals for the plateau regression analysis used to evaluate differences in drought tolerance between *S*-metolachlor- susceptible and -resistant Palmer amaranth (*Amaranthus palmeri* S. Wats.) accessions submitted to progressive drought; greenhouse experiment conducted at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center, Fayetteville, Ark., 2021.

Accessions	Breakpoint[a]	SE	R^2	Confidence intervals[b]	
09CRW-A	0.17a	0.007	0.85	0.15	0.19
17TUN-A	0.23b	0.004	0.93	0.22	0.25

[a] Means within a column, followed by different letters are different ($P \leq 0.05$).

[b] 95% confidence intervals of breakpoints.

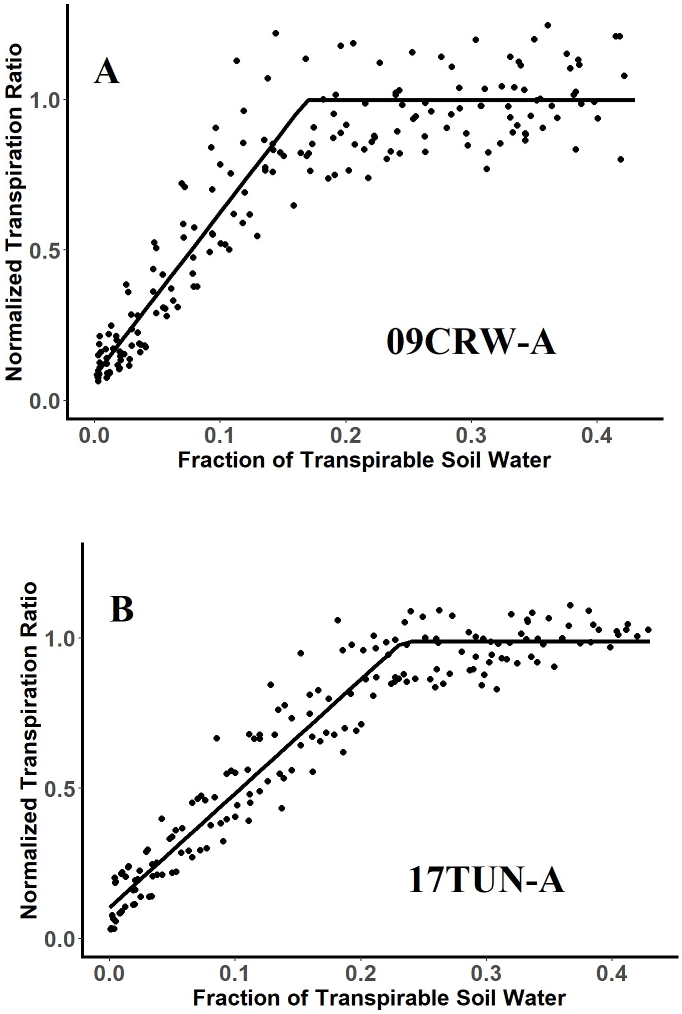

Fig. 2. Relationship between normalized transpiration ratio (NTR) and fraction of transpirable soil water (FTSW) during soil drying cycle for *S*-metolachlor- susceptible (09CRW-A) (panel A) and resistant (17TUN-A) (panel B) accessions of Palmer amaranth (*Amaranthus palmeri* S. Wats.) from a greenhouse experiment at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center, Fayetteville, Ark., in 2021.

Table 2. Breakpoint FTSWcr (threshold value for the initiation of stomatal closure), standard error (SE), R^2, and confidence intervals for the plateau regression analysis used to evaluate differences in drought tolerance between glyphosate-susceptible and -resistant Palmer amaranth (*Amaranthus palmeri* S. Wats.) differing in EPSPS gene copy number; greenhouse experiment conducted at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center, Fayetteville, Ark., 2021.

Genotype	Breakpoint[a]	SE	R^2	Confidence intervals[b]	
Glyphosate-resistant	0.25a	0.007	0.90	0.23	0.26
Glyphosate-susceptible	0.25a	0.008	0.91	0.23	0.25

[a] Means within a column, followed by the same letter are not different ($P > 0.05$).

[b] 95% confidence intervals of breakpoints.

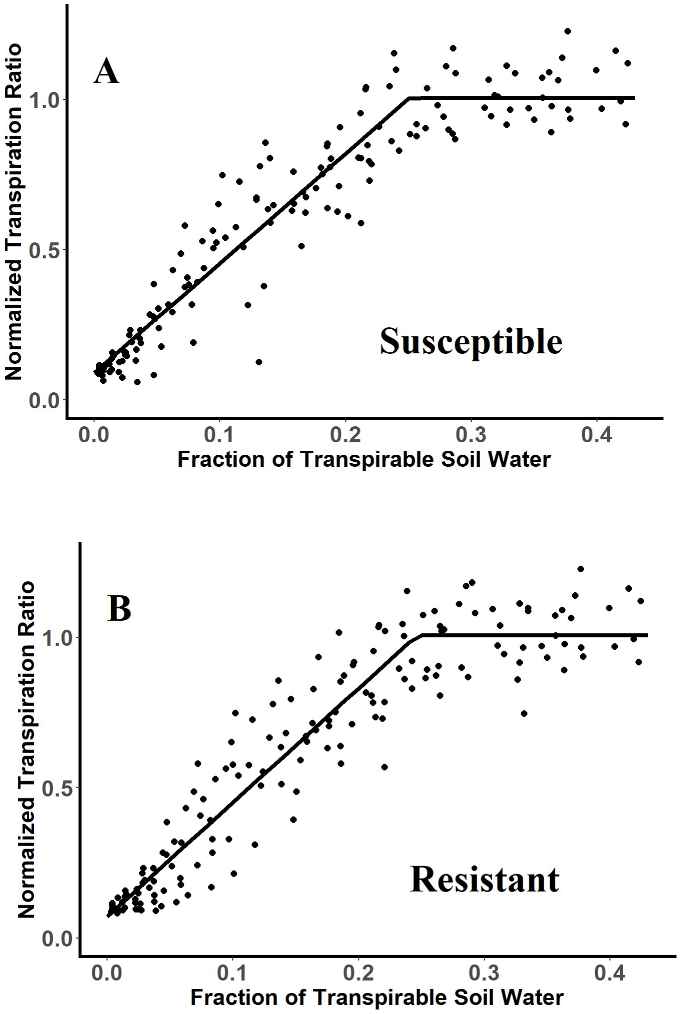

Fig. 3. Relationship between normalized transpiration ratio (NTR) and fraction of transpirable soil water (FTSW) during soil drying cycle for glyphosate- resistant and susceptible Palmer amaranth (*Amaranthus palmeri* S. Wats.) accessions differing by the number of EPSPS gene copy number from a greenhouse experiment conducted at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center, Fayetteville, Ark., in 2021. A. plants with <10 EPSPS copy number; B. EPSPS copy number between 22 and 165.

ECONOMICS

Impact of Cultural and Management Practices on Soybean Yields and Profitability: An Evaluation of the Grow for the Green Participant Data

L.L. Nalley[1] *and J. Anderson*[1]

Abstract

Each year the Arkansas Soybean Promotion Board, Arkansas Soybean Association, and the University of Arkansas System Division of Agriculture unite to implement and promote the Grow for the Green (GFG) Soybean Yield Challenge contest. This study used soybean yields from GFG producers from 1999 to 2020 to estimate yield premiums compared to the Arkansas Soybean Research Verification Program (SRVP) for the same period. Results indicate that those producers who enrolled in the GFG program experienced a yield of 17.92 bu./ac higher than those producers who participated in the SRVP program, a yield enhancement of 30.4% (17.92/58.95). The SRVP maintains that, on average, they yield 10 bu./ac more than the state average, indicating that GFG producers yielded 36.6% more than the state average. While the cost of production details was not available for all GFG producers, it was estimated that their costs would have to increase by 33%–42% before their yield gains were offset by higher input costs. While the goal of any producer is not to maximize yield but rather to maximize profitability, our results show programs like GFG can be an important catalyst in motivating producers to think creatively about how to increase profitability.

Introduction

Each year the Grow for the Green (GFG) Soybean Yield Challenge recognizes and rewards Arkansas' top soybean producers. The Arkansas Soybean Promotion Board, Arkansas Soybean Association, and the University of Arkansas System Division of Agriculture unite to implement and promote this contest. Soybean checkoff funds are used to reward producers for helping increase soybean yield in Arkansas. Fields enrolled in the contest consist of 5 to 7 acres and must have been planted in soybean at least once in the previous 3 years. In this study, we compared yields from 173 GFG producers from 1999 to 2020 to the annual Arkansas Soybean Research Verification Program (SRVP) for the same period. Specifically, we set out to determine if the yields of GFG producers are statistically higher than the SRVP. Given that the SRVP yields an average 10 bu./ac higher than the state average yield, if GFG is found to have statistically higher yields, then yield-enhancing practices can be identified (Norton and Elkins, 2021).

Procedures

Using data (Table 1) from GFG participants from 1999–2020 and SRVP data from the same period, we regress production variables on yield. Importantly, management practices vary by location and year. Results from a single year or single site could be misleading due to the possibility of extreme weather events, disease, or pest pressure. Annual and location fixed effects are included in the regression model to account for differences in management and production practices across years and locations. Location fixed effects are included in the model to account for location-specific factors, including time-invariant factors such as altitude and soil texture. Potential yield trends over time are accounted for by including test plot-year fixed effects. Including these fixed effects, the regression models for yield for a given observation become:

$$Y_i = \alpha + \delta_1 CRD_i + \delta_2 Year + \delta_3 SeedTech_i + \delta_4 GFG_i + \beta_1 SeedingRate_i + \beta_2 PlantDate_i + \beta_3 HarvestDate_i + \varepsilon_i \quad \text{Eq. 1}$$

where $\delta_1 CRD_i$ is a dummy variable in which crop reporting district (*CRD*) observation *i* was produced. The location (*CRD*) captures agronomic differences across locations and location-specific events such as disease or pest pressure. Ideally, county-level dummies would be included, but this was not feasible given the lack of head-to-head (SRVP vs. GFG) yield data for a given county/year combination. The *Year* dummy captures weather events that can influence yields, such as drought or heat events. *SeedTech* is a dummy variable for which type of seed technology was used for observation *i*. These technologies included Roundup Ready®, Liberty Link®, Roundup Ready 2 Xtend®, Enlist®, and conventional. The *GFG* dummy captures if yield observation *i* was enrolled in the Grow for the Green program or not. *SeedingRate* accounts for the seeding rate density per acre of observation *i*. *PlantDate* and *HarvestDate* capture when observation *i* was both planted and harvested. Both variables are measured in their Julian calendar dates. These variables are important as GFG participants did not record the maturity group of their variety. Thus, by capturing planting and harvesting dates, we can account for the growing season's length and capture

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weather events that may happen earlier or later in the season. Further, a *GowingSeason* variable (*HarvestDate* minus *PlantingDate*) was used in alternative specifications of the model. Because of multicollinearity, all 3 variables could not be included in the same model.

It is important to note that not all observations were used in the regression: only those observations where we had a direct head-to-head comparison between SRVP and GFG. For instance, if there were a GFG observation in CRD 3 in 2000 but no SRVP observation in the same CRD in the same year, the former would be removed from the dataset. Thus, the regression only compares those years, location, and seed technology combinations where there was both an SRVP and a GFG comparison. Thus, observations for Xtend and Enlist seed technologies were removed because there were zero observations for SRVP and GFG; therefore, no head-to-head comparisons of these specific seed technologies could be made. Standard Errors were clustered by year.

Ideally, input values would have been included in the regression analysis. It stands to reason yield is a function of input use. That being said, most of the GFG observations lacked a complete list of inputs. Even complete input usage often had only the type of input used and not the timing or amount of application. For instance, it was common for producers to say, "I used Quadris® fungicide" or "I used Quadris when needed"; thus, it is difficult to estimate the amount used. This was also true for irrigation, where producers would state answers such as "pivot 13 times", "furrow 6 times", "weekly 8 times" "furrow 6 times". Given the ambiguity about actual amounts of water used (and the fuel/electricity needed to raise that water), inputs were not included in yield estimation, an obvious omitted-variable bias issue.

Results and Discussion

Table 2 presents the results from the preferred model. A total of 6 models were run using the combination of independent variables described in the methodology. The results presented in Table 2 were deemed the preferred model as it had the highest adjusted R^2. Regardless of specification, the GFG dummy was robustly significant (in terms of both direction and size of coefficient). The GFG variable ranged from 17.62 to 23.34 bu./ac, with the preferred model (Table 2) indicating a yield increase of 17.92 bu./ac ($P < 0.01$). This would indicate that those producers who enrolled in the GFG program experienced a yield of 17.92 bu./ac higher than those producers who participated in the SRVP program, a yield enhancement of 30.4% (17.92/58.95). The SRVP maintains that, on average, they yield 10 bu./ac more than the state average, indicating that GFG producers yielded 36.6% more than the state average.

Table 2 also indicates that planting ($P < 0.01$) and harvesting ($P < 0.10$) later can negatively affect yield, with a later planting date being more detrimental. Not surprisingly, seed technology matters with, on average, Liberty Link ($P < 0.10$), Roundup Ready ($P < 0.01$), and Roundup Ready Xtend ($P < 0.01$) yielding 2.96, 9.82, 11.09, and 9.24 bu./ac more, respectively, than conventional soybean varieties.

While these yield enhancements are impressive, they are difficult to compare holistically to non-GFG yields since input costs were not available. Table 3 shows how much costs would have to increase (in a % term) to maintain the estimated 2022 profitability put forth by the University of Arkansas System Division of Agriculture for the most prevalent seed technologies (Roundup Ready, Roundup Ready 2 Xtend, Liberty Link and conventional) and irrigation practices (furrow, flood, and pivot) assuming the 17.9 bu./ac yield increase (Table 2) associated with GFG participation. In other words, if yield increased 17.9 bu./ac, how much would costs have to increase per acre before GFG had equal profitability as non-GFG participants, assuming $12.10/bu. soybean? Revenue is assumed to increase by $216.84 (17.9 × 12.10) per acre across all scenarios. Profit per acre and cost of production by seed technology and irrigation type were obtained from the University of Arkansas System Division of Agriculture (Norton and Elkins, 2021). Thus, cost increases to equate GFG to non-GFG producers were calculated by dividing 216.84 (endogenously solved in the model) by the reported total cost of production per acre by Norton and Elkins (2021). Table 3 suggests that GFG producers would have had to experience cost increases of a minimum of 33.2% (for those producers using RRXtend and pivot irrigation) to a maximum of 41.69% (for those producers using conventional seed and flood irrigation) before GFG was not as profitable as a traditional production input and output estimates. While possible, it is unlikely that producers would be willing to increase costs by 33%–42% to participate in GFG. This would suggest, although anecdotally, that GFG spurred producers to think creatively about how to increase yields while likely increasing profits simultaneously. More complete farm-level data on input use would be required to quantify the impacts on the profitability of specific GFG practices accurately.

Practical Applications

While it is difficult to speak to profitability since exact input amounts were not recorded, it is obvious that those producers who enrolled in GFG experienced significantly higher yields than SRVP yields. These yield enhancements are even more impressive given that SRVP yields are, on average, 10 bu./ac higher than state average yields. This is likely due to thinking outside the box on how to produce soybeans spurred on by the GFG program. While the cost of production details was not available for GFG producers, it was estimated that their costs would have to increase by 33%–42% before their yield gains were completely offset by higher input costs. While the goal of any producer is not to maximize yield but rather to maximize profitability, programs like GFG can be an important catalyst in motivating producers to think creatively about how to increase profitability. The real impacts of GFG are likely manifested in changes in management practices in future growing seasons from the lessons learned by enrolling in the program. Given how risk-averse many agricultural producers are, programs like GFG can incentivize creative production practices which otherwise may have never been tried, helping to surface practices with significant commercial potential.

Acknowledgments

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Literature Cited

Norton, C. and C. Elkins. 2021. Soybean Research Verification Program Update for 21 May 2021. University of Arkansas System Division of Agriculture Cooperative Extension Service. Available at https://arkansascrops.uada.edu/posts/verification/srvp-may-twenty-one.aspx

University of Arkansas System Division of Agriculture. 2022. Crop Enterprise Budgets. Accessed 28 Oct. 2022. Available at: https://www.uaex.uada.edu/farm-ranch/economics-marketing/farm-planning/budgets/crop-budgets.aspx

Table 1. Summary Stats for the Soybean Research Verification Program (SRVP) and Grow for the Green (GFG) data.

Planting and Yield Characteristics						Soybean Seed Technology						
Trial	Yield (bu./ac)	Seeding Rate (#/ac)	Growing Season (days)	Planting Julian Date	Harvested Julian Date	Conv.	Roundup Ready®	Xtend®	Enlist®	Liberty Link™	Roundup Ready 2Xtend®	Dicamba
SRVP (mean)	58.95	154,742	146	136	282	8.67%	47.40%	15.03%	2.50%	26.03%	0.37%	0.00%
SRVP (stdev)	13.7	16,563	14	24	20							
GFG (mean)	83.45	151,290	152	118	270	0.55%	80.65%	0.20%	0.00%	4.35%	14.06%	0.28%
GFG (stdev)	12.35	22,218	18	18	21							

Table 2. Regression results from preferred model specification.

Variable	Estimate	Standard Error	t value	Pr(>|t|)	Significance
Intercept	86.12	8.08	10.66	0.00	***
CRD 3	7.72	6.88	1.12	0.26	
CRD 4	6.99	7.88	0.89	0.38	
CRD 5	1.19	6.00	0.20	0.84	
CRD 6	4.48	5.88	0.76	0.45	
CRD 9	6.37	5.88	1.08	0.28	
Year 07	3.27	1.73	1.89	0.06	*
Year 08	2.03	1.94	1.05	0.30	
Year 10	-1.12	1.89	-0.59	0.55	
Year 11	2.85	1.91	1.49	0.14	
Year 12	7.88	1.86	4.24	0.00	***
Year 13	12.51	1.80	6.95	0.00	***
Year 14	14.03	1.78	7.90	0.00	***
Year 15	13.34	1.89	7.07	0.00	***
Year 16	10.03	1.91	5.25	0.00	***
Year 17	10.44	2.03	5.14	0.00	***
Year 18	10.41	2.21	4.72	0.00	***
Year 19	11.72	2.65	4.42	0.00	***
Year 20	12.85	2.91	4.41	0.00	***
Tech LL	2.96	1.77	1.67	0.09	*
Tech RR	9.83	2.39	4.11	0.00	***
Tech RR2X	11.09	2.31	4.80	0.00	***
Tech Xtend	9.24	1.91	4.83	0.00	***
GFG	17.92	1.71	10.48	0.00	***
Date Planted	-0.26	0.04	-5.86	0.00	***
Date Harvested	-0.05	0.03	-1.71	0.09	*
R-squared	0.6877				
Adjusted R-squared	0.6724				

***, **, * Denotes significance at the 1, 5, and 10 percent levels, respectfully.

Standard Errors Clustered by Year.

CRD = Crop Reporting District; RR = Roundup Ready; RR2X = Roundup Ready 2 Extend; GFG = Grow for the Green.

Note: Some years, CRDs and seed technologies were not included in the regression results because there were no head-to-head comparisons for a given year, CRD, and seed technology between GFG and SRVP.

Table 3. Cost (2022 USD) increase per acre necessary to equate Grow for Green (GFG) yield enhancements to estimated profitability of non-GFG participants by seed technology and irrigation type.

Seed Technology and Irrigation Type	Cost per acre would have to increase by[a]	A % Cost increase of[b]	To maintain Profit per acre of[c]
	US$	%	US$
RR, Furrow Irrigated	216.84	40.34	188.46
RR, Flood Irrigated	216.84	41.27	200.64
RR, Pivot Irrigated	216.84	35.75	119.48
RRXtend, Flood Irrigated	216.84	38.47	162.66
RRXtend,Furrow Irrigated	216.84	38.38	161.08
RRXtend, Pivot Irrigated	216.84	33.20	72.93
LL, Flood Irrigated	216.84	39.86	181.34
LL, Furrow Irrigated	216.84	38.94	169.16
Conventional, Flood Irrigated	216.84	41.69	205.89
Conventional, Furrow Irrigated	216.84	40.74	193.7
Conventional, Pivot Irrigated	216.84	40.80	194.51

[a] Assuming a 17.9-bu. yield increase estimate from GFG (Table 2) at $12.10 per bushel.

[b] 216.84 as a percentage of estimated 2022 cost of production from each respective soybean seed technology and irrigation type (UADA, 2022).

[c] Estimated 2022 profitability per acre by seed technology and irrigation type.

RR = Roundup Ready®; RRXtend = Roundup Ready Extend®; LL = Liberty Link.®

ECONOMICS

Economic Analysis of the 2021 Arkansas Soybean Research Verification Program

C.R. Stark, Jr.[1] *and B. Deaton*[1]

Abstract

The 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 2021 season results provide additional economic relationship insights among seasonal, herbicide, and irrigation production systems as producers received record-high soybean market prices. Early-season production system fields had yields that exceeded full season by less than 1 bushel per acre and late season by 21 bushels. Early-season returns were almost $44 per acre higher net returns than the full season and $226 over late-season system fields. The Roundup Ready Extend® (RREx) herbicide production system fields had a 2 bushel per acre yield advantage over Roundup Ready Flex® (RRFL) and a 21 bushel per acre advantage over Enlist E3® system fields leading to an almost $19 per acre advantage in net returns across all program fields. Irrigated systems were far superior to non-irrigated in both yields and net returns. Total cost savings of $17 per acre associated with non-irrigated system fields could not overcome 16-bushel yield and associated $203 revenue disadvantages.

Introduction

The Arkansas 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 4 irrigated soybean fields. Records have been compiled each succeeding year from the fields of participating cooperators until over 500 individual fields now comprise the state data set. Among other goals, the program seeks to validate 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 regularly receives timely management guidance from state SRVP coordinators on a regular basis and from state extension specialists as needed.

Economic analysis has been a primary focus of the program from the start. The SRVP coordinators record input rates and production practices throughout the growing season, including official yield measures at harvest. A CES state extension economist compiles the data into the spreadsheet used for an annual cost of production budget development.

The profitability and production efficiency measures are calculated for each cooperator's field and grouped by the soybean production system.

Procedures

Nineteen cooperating soybean producers across Arkansas provided input quantities and production practices utilized in the 2021 growing season. A state average soybean market price was estimated by compiling daily forward booking and cash market prices for the 2021 crop. The collection period was 1 Jan. through 31 Oct. for the weekly soybean market report published on the Arkansas Row Crops Blog (Stark, 2022). Data was entered into the 2021 Arkansas soybean enterprise budgets for each respective production system (Watkins, 2021). 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 19 fields included in the 2021 Arkansas Soybean Research Verification Program report (Elkins et al., 2021) spanned 13 production systems based on seasonal, herbicide, and irrigation characteristics (Table 1). The system combination utilizing an early-season, Roundup Ready Xtend® (RRX) technology seed and furrow irrigation was most commonly used, appearing in 4 fields. Three fields used an early-season Roundup Ready Flex seed and furrow irrigation system. The remaining 6 combinations each occurred on only 2 or fewer fields. All economic comparisons were devel-

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oped from the soybean forward book and cash market prices for the 2021 crop reported by Stark in weekly and monthly summary market reports (Stark, 2022). The soybean forward book and cash market price for the 2021 crop averaged $12.77 per bushel for 1 Jan.–31 Oct. 2021. Market price multiplied by 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. Therefore, 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 and management are discussed.

Season Comparisons

Weather conditions for 2021 permitted a more normal planting distribution than 2020 and, thus, a good comparison across production system fields for the cooperating producers in the program. The 19 fields spanned 9 early-season, 6 full-season, and 4 late-season systems. Early-season and full-season plantings were comparable in yield, with just a 0.9 bu./ac advantage for early-season (Table 2). Revenue for the early-season fields was just $12/ac higher than the full-season. Return to land and management was almost $44 per acre higher on early-season fields. Late-season planting lowered yield by 20 bu./ac and returns to land and management by $210/ac from the full-season averages. These economic results are consistent with extension recommendations for seasonal planting choices in Arkansas.

Herbicide Comparisons

The Roundup Ready Xtend® (RRX) herbicide system was most frequently used in 7 of the 19 fields (Table 3). The Roundup Ready Flex® (RRF) system followed closely with 6 fields. Four fields used the Enlist® system. Yield comparisons by herbicide showed the RRX fields had a 2 bu./ac advantage over the RRF fields. RRF fields in 2021 were almost $12/ac less expensive in variable costs but $4/ac higher in fixed costs than the RRX systems. The lowest total cost per acre was $314/ac in both Roundup Ready Flex® (RRF) and Enlist® (E3), except for 1 Roundup Ready field. Returns to land and management gave a $19/ac advantage to Roundup Ready Xtend herbicide over Roundup Ready Flex® (RRF).

Irrigation Comparisons

Early spring precipitation in 2021 seemed to provide an advantage for the early-season fields that were planted. Recorded yields on those early-season fields were 3.4 bu./ac higher than full-season irrigated fields. The $31/ac total cost savings provided another advantage. Irrigation systems employed by growers in the 2021 program were predominantly furrow (14 fields). One field was entirely center pivot irrigated, and a second was split between center pivot and furrow. One was non-irrigated, and 2 used a flood system (Table 4). The 18 irrigated fields averaged 63.7 bu./ac compared to 47.9 bu./ac for the 1 non-irrigated field. Revenue was $185 higher per acre for irrigated fields, with only a $17/ac increase in total cost for irrigated over non-irrigated. Total variable costs were essentially the same for irrigated and non-irrigated fields. Total fixed costs differed by about $18, with irrigated fields at $81.19/ac and the non-irrigated field at $63.99. The combination of costs left irrigated fields at an average total cost of $319.22/ac compared to $301.90/ac for non-irrigated. Return to land and management averaged $185.02 higher per acre for irrigated fields over non-irrigated.

Overall Comparisons

The 2021 Arkansas Soybean Research Verification Program fields had a 62.9 bu./ac statewide average yield, 5.5 bushels more than 2020, and over 11 bushels above the Arkansas state average yield of 51 bu./ac. (USDA-NASS, 2021).

Revenue averaged $803.37 generated from this production and a historically high market price, an increase of over $278/acre compared to 2020. However, total Variable Costs averaged $238.02, a $20 decrease, and Total Fixed Costs averaged $80.29, more than $14 lower than 2020, for an average total cost per acre of $318.31, almost $22/ac lower. These revenue and cost averages left producers with an average per acre return to land and management of $485.06 across all production systems, an increase per acre of over $313 compared to 2020.

Practical Applications

The results of state research verification programs 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.

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Literature Cited

Elkins, C., C. Norton, J. Ross, and B. Stark. 2021. University of Arkansas System Division of Agriculture Soybean Research Verification Program Report. 2022. Accessed: 1 May 2022. Available at https://www.uaex.uada.edu/farm-ranch/crops-commercial-horticulture/verification/2020%20SRVP%20Final%20Report.pdf

Laughlin, D.H. and S.R. Spurlock. 2016. User's Guide for the Mississippi State Budget Generator. Version 6.0 for Windows. Accessed: 1 May 2022. Available at https://www.agecon.msstate.edu/whatwedo/budgets/generator/docs/userguide6.pdf

Stark, C.R., Jr. 2022. Arkansas Soybean Market Reports (various dates). Arkansas Row Crops Blog. Accessed 1 May 2022. Available at: http://www.arkansas-crops.com/

Stark, C.R., Jr., T. Griffin, and K. Bryant. 2011. Identifying Quantity Trends in Agricultural Chemical Use for Soybean Production Using State Research Verification Program Historical Data. Selected presentation at the Soil and Water Conservation Society 66th International Annual Conference, July 17-20, Washington, D.C.

Stark, C.R., Jr., T. Reaper, D. Beaty, and J. Ross. 2008. Arkansas Soybean Research Verification Program Production Cost Patterns. Poster presentation at 2008 Tri-State Soybean Forum, 3 Jan. 2008, Dumas, Arkansas.

USDA-NASS. 2021. United States Department of Agriculture, National Agricultural Statistics Service. 2021. QuickStats. Accessed: 30 April 2022. Available online http://quickstats.nass.usda.gov/

Watkins, B. 2021. Crop Enterprise Budgets for Arkansas Field Crops Planted in 2021. University of Arkansas System Division of Agriculture, Research and Extension, October, 2020. Accessed 1 May 2021. Available at: https://www.uaex.uada.edu/farm-ranch/economics-marketing/farm-planning/budgets/crop-budgets.aspx

Table 1. Production System Combinations of the nineteen fields participating in the 2021 Soybean Research Verification Program.

Production System	Early	Full	Full	Late	Late	Early	Full	Late	Late	Early	Late	Full	Early
Herbicide	RRX	RRX	RRX	RRF	RRF	RRF	RRF	LL	E3	E3	E3	E3	RR
Irrigation	Fur	Fur	FL	CP	Fur	Fur	Fur	Fur	Fur	Dry	CP	Fur	FL
Number of fields	4	1	2	1*	1*	3	2	1	1	1	1	1	1

Production Systems: Full = Full-Season; Late = Late-Season; Early = Early-Season
Herbicide: RRX = Roundup Ready Xtend®; RRF = Roundup Ready Flex®; LL = Liberty Link®; E3 = Enlist®; RR = Roundup Ready®.
Irrigation: Fur = 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: 2021 Arkansas Soybean Research Verification Program Report.

Table 2. Economic Results by Seasonal Production System for the 2021 Soybean Research Verification Program.

Production System	Early Season	Full Season	Late Season	All Fields
# Fields	9	6	4	19
Yield (bu./ac)	67.7	66.8	46.4	62.9
Revenue ($/ac)	864.39	852.61	592.21	803.37
Total Variable Costs ($/ac)	231.89	257.76	222.22	238.02
Total Fixed Costs ($/ac)	79.99	85.87	73.03	80.29
Total Costs ($/ac)	311.68	343.63	295.25	318.31
Returns to Land and Management ($/ac)	552.71	508.98	296.96	485.06

Source: 2021 Arkansas Soybean Research Verification Program Report.

Table 3. Economic Results by Herbicide System for the 2021 Soybean Research Verification Program.

Herbicide System	Roundup Ready Xtend®	Liberty Link®	Enlist® E3	Roundup Ready Flex®	Roundup Ready	All Fields
# Fields	7	1	4	6	1	19
Yield (bu./ac)	68.6	50.5	47.0	66.6	59.5	62.9
Revenue ($/ac)	876.39	644.89	599.77	850.48	759.82	803.37
Total Variable Costs ($/ac)	242.74	269.98	243.90	230.97	204.20	238.02
Total Fixed Costs ($/ac)	79.11	91.60	70.88	83.84	79.46	80.29
Total Costs ($/ac)	321.85	361.58	314.78	314.80	283.66	318.31
Returns to Land and Management ($/ac)	554.54	283.31	284.99	535.68	476.16	485.06

Source: 2021 Arkansas Soybean Research Verification Program Report.

Table 4. Economic Results by Irrigation System for the 2021 Soybean Research Verification Program.

Irrigation Production System	Irrigated	Non-Irrigated	All Fields
# Fields	18	1	19
Yield (bu./ac)	63.7	47.9	62.9
Revenue ($/ac)	814.02	611.70	803.37
Total Variable Costs ($/ac)	238.03	237.91	238.02
Total Fixed Costs ($/ac)	81.19	63.99	80.29
Total Costs ($/ac)	319.22	301.90	318.31
Returns to Land and Management ($/ac)	494.80	309.78	485.06

Source: 2021 Arkansas Soybean Research Verification Program Report.

Plant Sap Flow, Irrigation, Growing Degree Units, and Yield Relations in Different Maturity Group Soybeans with Various Planting Times

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Abstract

A study was initiated to measure plant transpiration using sap flow sensors, air, and canopy temperature, leaf area index, growing degree days, and yields across different planting dates for soybean [*Glycine max* (L.) Merr.]. On average, soybean transpires 15.3 in. of water in the season. Water use by the growth stage reveals that yields of earlier planted maturity group (MG) 5 soybeans were higher and transpired water more than MG 3 and 4 soybeans. In addition, canopy temperatures were 2–5 °F lower than the ambient air temperature in the R4 growth stage when the hourly sap flow is 10–12 g/h and 3–5 °F higher in the R7 growth stage when the hourly sap flow is 1–2 g/h.

Introduction

How soybean [*Glycine max* (L.) Merr.] transpiration, measured by sap flow, reacts to the environment is useful for improving irrigation recommendations. The sap flow and water demand of soybean plants vary with growth stages and weather/soil conditions (Payero and Irmak, 2013; Moreshet et al., 1990). Soil moisture, solar radiation, air temperatures, and vapor pressure deficit are related to sap flow in crops (Zhao et al., 2017; Ismanov et al., 2019). Ismanov et al. (2020) reported plant water use by growth stage and a relationship between yield and sap flow. Teague et al. (2019) conducted an experiment where irrigation was terminated at R4, R5, and R6, and the highest yield was observed in the R6 treatment. Most soybean farmers have different opinions on irrigation initiation and termination timings and still use calendar-based irrigation scheduling.

Procedures

Five different early to late relative maturity group (MG) Pioneer soybean varieties, (https://www.pioneer.com/) P31A06L, P38A49L, P40A03L, P47A76L, and P49A41L, were planted at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station in Marianna, Ark. to measure plant transpiration by growth stage. Soybean varieties are planted on 4 different planting dates in 2021: 23 April (early), 27 May (middle), 25 June (late), and 16 July (very late). Field preparation, fertilization, planting, and herbicide/pesticide treatments were fulfilled according to the University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations. Seeds were planted in the single-row scheme on 38-in. wide-row spacing seedbeds. The seeding rate was 139,000 seeds/ac.

Dynamax® Flow 32 1-K system (Flow32-1K Sap Flow System, Dynamax Inc., Houston, Texas https://dynamax.com/products/transpiration-sap-flow/flow32-1k-sap-flow-system) with SGA5-WS and SGB9-WS sensors used to measure transpiration by the plant sap flow method. The sap flow measurements began in June when the early planted soybeans reached R3 and the 27 May (middle) treatment reached the R1 growth stages. The sensors moved to the 25 June planted soybeans when the 23 April planted soybeans reached the R7–R8 growth stages. Watermark sensors (https://www.irrometer.com/) were installed at 6, 12, 18, and 30 inches depths to record the hourly soil moisture. WatchDog2900 ET weather station (http://www.specmeters.com) and Model E digital alfalfa reference ET-gage (http://www.etgage.com) were used to record the hourly evapotranspiration (ET) and other weather parameters, including solar radiation, air temperature, relative humidity, and wind speed in 10-minute intervals. A soybean canopy temperature measurement based on infrared temperature (IR) transmitters OS136A-1-MA and OS137A-1-MA (www.omega.com). Canopy temperature measurements were recorded every minute, and sap flow measurements every 10 minutes. Plant height was measured daily, and the leaf area index (LAI) and the number of nodes were measured once in every growth stage. Growing degree units (GDU) were calculated as follows:

$$\Sigma[(T_{max} - T_{min})/2-50]$$

where T_{max} and T_{min} are the maximum and minimum ambient air temperatures during the day.

Results and Discussion

Twenty percent of soybean plants of early planted soybeans emerged in 7 days with 98 cumulative GDU. Nine days after planting, a full stand was present with 135 GDU. For the

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middle season planting date, it only took 7 days and 134 GDU when a stand was established. The average soil temperature from planting to the emergence in these 2 planting times at a 2-in. depth were 67 ^{o}F and 76 ^{o}F, respectively. On the following 2 planting dates, the soil temperatures were 87 ^{o}F and 85 ^{o}F, respectively. The seeds emerged in 5 and 6 days with 160 and 170 GDU, respectively, in late and very late planting times.

The first reproductive stage with 4 nodes of soybean variety P31A06L was planted on 23 April and accumulated 727 GDU after 40 days. The same variety planted in the mid-season date reached the first reproductive stage 33 days after planting with 855 GDU. The soybean plant height across all the planting dates increases until the R5 growth stage. Then it was observed that plant height was impacted by how many GDUs were received. The plant heights at the beginning of the R5 growth stage were 31, 42, 39, and 32 inches with 1787, 2176, 2151, and 2078 GDUs, respectively, in early, middle, late, and very late soybeans planting date treatments (Table 1).

May and June's precipitation was recorded to be 5.1 and 6.1 inches, respectively. Alfalfa referenced that evapotranspiration was 4.9 and 5.4 inches in these months. Calendar-based irrigation began on 27 June. ET-based irrigation began when the watermark sensors achieved a soil moisture matric potential of over 60 centibars on 30 June, after which irrigation was scheduled by the alfalfa-referenced ET atmometer method. The calendar-based irrigation treatments were scheduled weekly unless significant rainfalls occurred. The calendar method generally resulted in 2–3 more irrigation events than the ET method. For the P31A06L soybean variety, the number of calendar and ET-based irrigation events was 7 and 4 in early, 6 and 4 in middle, 7 and 4 in late, and 5 and 4 in very late date planted soybeans, respectively (Table 2). The total irrigation applied was 8.4 ac-in./ac for ET and 14.7 ac-in./ac for the calendar method, resulting in the total water for the study for ET at 29 inches and 35.3 inches for the calendar method.

Sap flow measurements show that early planted soybean water use was 3.0, 2.6, and 2.2 inches during the R5 growth stage for the calendar-based, ET-based, and dryland-rainfed irrigation treatments, respectively. Dry conditions shorten the plant stages in all planting dates: R6 and R7 growth stages in dryland plots begin 5 to 7 days earlier than in irrigated plots. The maximum water use period in early planted soybeans continues until 23 July at the R6 growth stage.

Daily transpiration is a function of the LAI and the stem sap flow. At the R5 growth stage, the daily water transpiration from the soybean was 0.9 –1.3 g/cm^2. LAI in all varieties increases until the R5 growth stage, then becomes stable until the R6 stage. Then LAI rapidly decreases from the end of the R6.5 growth stage and coincides with reduced daily plant transpiration.

The plant transpiration rapidly decreases due to low temperature, solar radiation, and ET during rainy days, as shown in Fig. 1 on day 7/17. Transpiration is the highest immediately after irrigation and rainfall events. The sap flow differences are slight between the two irrigation plots, while the dry land plot plants' sap flow is less than this in an R6 growth stage and senesces earlier than other plots.

The daily cumulative transpiration averages for 2021 are shown in Table 3. The daily and cumulative transpiration averages of early, middle, and late planted treatments recorded between 2017 and 2021 are shown in Table 4. Transpiration rates in 2021 are slightly lower compared to 2017–2021 averages due to relatively lower ET and air temperature during the reproductive stages of early planted soybeans. The total transpiration of soybean plants in 2021 was 14.2–14.5 inches, and when combined with 2017 to 2020 measurements, total transpiration is 15.3–15.5 inches for early and mid-season planting dates.

Measurements show that the canopy temperature in the dryland plots was 5–10 °F higher than in the irrigated plots from the R5 growth stage. The sap flow, canopy, and ambient air temperatures are shown for 2 dates in Fig. 2 when the plant growth stages were R4 and R7. The canopy temperature is 2–5 °F lower than the air temperature, and the hourly sap flow is 10–12 g/h in the R4 growth stage. The canopy temperature is 3–5 °F higher than the ambient air temperature in the R7 growth stage with low (1–2 g/h) sap flow. Overall, the canopy temperature increases from the R6.5 growth stage when the sap-flow decreases.

The early planted P31A06L soybean variety yields 46, 44, and 38.3 bu./ac, respectively, in the calendar-and ET-based irrigation and dryland plots. The ET-based irrigation approach used 6 inches less irrigation water than the calendar treatment (Table 2). The calendar-base irrigated late-maturity soybean varieties P38A49L, P40A03L, P47A76L, and P49A41L yielded 53.2, 70, 61.9, and 54.2 bu./ac, respectively. The late maturity group of early planted soybeans yields appeared higher, likely from higher transpiration and GDUs. Aggregated three-year results (2019–2021) with different varieties, planting timings, and irrigation treatments show that soybean yield and GDU have a goodness of fit of 0.62 (R2), as shown in Fig. 3, indicating that other factors other than GDU contribute to yield potential. It should be noted that a good trend exists for the relationship between GDU and yield, albeit for 2 outlying data points.

Practical Applications

Different maturity groups of soybean varieties planted in early, middle, late, and very late planting dates with different irrigation treatments suggest that adequate GDU is necessary to maximize yield potential. However, at the end of the R5 growth stage, soybeans still need an additional 5.5 and 4.7 inches of water to finish, indicating that the late-season irrigations may be the most important ones to preserve yield potential. In addition, four years of data indicate that 15.3 in. of transpiration is needed during the growing season in the region for soybeans.

Dry conditions shorten plant development. During dryland plots' R6 and R7 growth stages, plants reached the next growth stage 5 to 7 days earlier than irrigated plots. The maximum water use period of soybeans continues until the R6 growth stage. The daily water evapotranspiration from the surface of soybean leaves changes from 0.9 to 1.3 g/cm^2 at R6. The LAI in all varieties increases until the R5 growth stage, becomes stable until the R6.5 stage, and then decreases. The yields of late maturity group varieties decreased from early to late planting timings that correspond to sap flow calculations, indicating that soybeans need both adequate water and solar radiation to achieve yield potential and that even with adequate water without enough, GDU's yield penalty will likely occur.

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Literature Cited

Ismanov, M., C.G. Henry, P.B. Francis., and L. Espinoza. 2019. Relations between sap flow, soil moisture, weather, and soybean plant parameters in high water demand and final growth stages. AS. Vol.10, No.3, March 2019. Accessed 8 July 2022. Available at: https://m.scirp.org/papers/91382

Ismanov, M., C.G. Henry, P.B. Francis, and L. Espinoza. 2020. Soybean Plant's Sap Flow And Crop Yields Relations. In: J. Ross (ed.) Arkansas Soybean Research Studies. 2020. University of Arkansas System Division of Agriculture Agricultural Experiment Station Research Series 680:185-189. Fayetteville.

Junhua, A., J. Fu, J. Tian, X. Yan, and H. Liao. 2010. Genetic variability for root morph-architecture traits and root growth dynamics as related to phosphorus efficiency in soybean. Functional Plant Biology. 37. 304-312. https://dx.doi.org/10.1071/ FP09215

Moreshet, S., M.G. Huck, J.D. Hesketh, and D.B. Peters. 1990. Relationships between Sap Flow and Hydraulic Conductivity in Soybean Plants. Agronomie, 10, 381-389. Accessed 8 July 2022. Available at: https://doi.org/10.1051/agro:19900504

Payero, J.O., and S. Irmak. 2013. Daily Energy Fluxes, Evapotranspiration and Crop Coefficient of Soybean. Agricultural Water Management, (2013):31–43. https://doi.org/10.1016/j.agwat.2013.06.018

Teague, T.G., N.R. Benson, A.J. Baker, and M.L. Reba. 2019. Irrigation Termination Timing and Interactions with Crop Protectants in Northeast Arkansas Soybeans. In: J. Ross (ed.) Arkansas Soybean Research Studies. 2019. University of Arkansas System Division of Agriculture Agricultural Experiment Station Research Series. 680:218-220. Fayetteville.

Zhao, C.Y., J. Hua, Q. Feng, F.Y. Teng, and D.L. Pei. 2017. Comparative Study of Daytime and Nighttime Sap Flow of *Populus euphratica*. Plant Growth Regulation, 82, 353–362. Accessed 8 July 2022. Available at: https://doi.org/10.1007/s10725-017-0263-6

Table 1. Soybean yields, irrigation and rainwater, and water use efficiency of the varieties with different irrigation treatments planted on different dates of 2021 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station in Marianna, Ark.

Stages		R1	R2	R3	R4	R5	R6	R6.5	R6.9	R7	R8
Early plant date	**Days**	40	48	56	65	78	89	104	113	117	128
	GDU	727	912	1156	1409	1787	2101	2577	2861	2981	3346
	ET	6.0	6.9	8.6	10.4	13.1	14.9	17.8	19.5	20.1	21.8
	SR	9.2	10.6	13.1	15.7	19.7	22.2	26.5	28.8	29.6	32.0
Middle plant date	**Days**	33	43	55	67	77	88	101	109	113	126
	GDU	855	1136	1483	1883	2176	2522	2933	3118	3229	3522
	ET	5.8	7.8	9.8	12.2	14.1	15.7	17.8	18.9	19.3	20.7
	SR	8.5	11.6	14.4	17.8	20.5	22.7	25.6	27.4	28.0	30.3
Late plant date	**Days**	32	40	48	60	70	80	88	94	99	108
	GDU	955	1210	1449	1831	2151	2391	2610	2718	2843	3053
	ET	6.1	7.6	9.1	10.9	12.5	13.9	14.7	15.4	15.9	16.8
	SR	8.7	10.9	13.1	15.6	17.8	20.0	21.2	22.4	23.1	24.6
Very late plant date	**Days**	31	39	47	61	72	82	90	98	102	107
	GDU	960	1213	1474	1832	2078	2318	2505	2614	2678	2712
	ET	5.6	6.8	8.1	10.0	11.2	12.1	12.9	13.5	13.9	14.1
	SR	8.0	9.5	11.3	14.3	16.1	17.6	19.0	20.2	20.9	21.3

GDU = Growing degree units, F°; ET = Evapotranspiration, inches; SR = Solar radiation, kW/m^2.

Table 2. Soybean yields, irrigation and rainwater, water use efficiency of the varieties with different irrigation treatments planted on different dates of 2021 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station in Marianna, Ark.

Plant date	Variety	Irr. trt.[a]	Yield	SD	Coef. var.	WUE	Rain	Irrigation		Total water
		#	bu./ac		%	bu./in.	in.	#	in.	in.
4/23	P31A06L	1	46.0	1.7	3.8	1.3	20.6	7	14.7	35.3
		2	44.0	3.0	6.8	1.5		4	8.4	29
		3	38.3	1.7	4.5	1.8		0	0	20.6
	P40A03L	1	70.0	1.3	1.9	1.9		8	16.8	37.4
		2	60.7	3.5	5.7	2.0		5	10.5	31.1
		3	42.7	13.5	31.5	2.0		0	0	20.6
	P49A41L	1	61.9	4.5	7.3	1.7		8	16.8	37.4
		2	62.0	5.9	9.5	2.0		5	10.5	31.1
		3	51.4	11.7	22.7	2.4		0	0	20.6
	P38A49L	1	53.2	4.4	8.3	1.4		8	16.8	37.4
	P47A76L	1	54.2	13.2	24.4	1.5		8	16.8	37.4
5/27	P31A06L	1	51.8	2.7	5.3	1.7	15.9	6	12.6	28.5
		2	42.8	4.6	10.6	1.6		4	8.4	24.3
		3	26.3	5.9	22.3	1.5		0	0	15.9
	P40A03L	1	50.0	3.7	7.5	1.6		7	14.7	30.6
		2	48.9	5.5	11.2	1.9		4	8.4	24.3
		3	33.9	4.2	12.4	1.9		0	0	15.9
	P49A41L	1	59.2	2.7	4.6	1.9		7	14.7	30.6
		2	58.8	3.3	5.6	2.3		4	8.4	24.3
		3	46.8	4.1	8.8	2.6		0	0	15.9
	P38A49L	1	61.6	1.5	2.4	1.9		7	14.7	30.6
	P47A76L	1	61.6	3.3	5.4	1.9		7	14.7	30.6
6/25	P31A06L	1	48.0	15.5	32.3	1.8	12	7	14.7	26.7
		2	47.4	14.0	29.4	2.3		4	8.4	20.4
		3	39.4	4.8	12.3	3.0		0	0	12
7/16	P31A06L	1	30.3	3.7	12.4	1.3	14	5	10.5	24.5
		2	25.0	3.1	12.2	1.1		4	8.4	22.4
		3	19.8	3.2	16.2	1.4		0	0	14
	P40A03L	1	35.0	6.1	17.4	1.3		6	12.6	26.6
		3	33.1	8.3	25.0	2.4		0	0	14
	P49A41L	1	39.0	3.0	7.6	1.5		6	12.6	26.6
		3	34.3	4.7	13.8	2.4		0	0	14

[a] Irrigation treatments (Irr. Trt.): 1 = Calendar-based, 2 = ET-based, 3 = Dry land treatments.
SD = Standard deviation; Coef. var. = Coefficient of variation; WUE = water use efficiency.

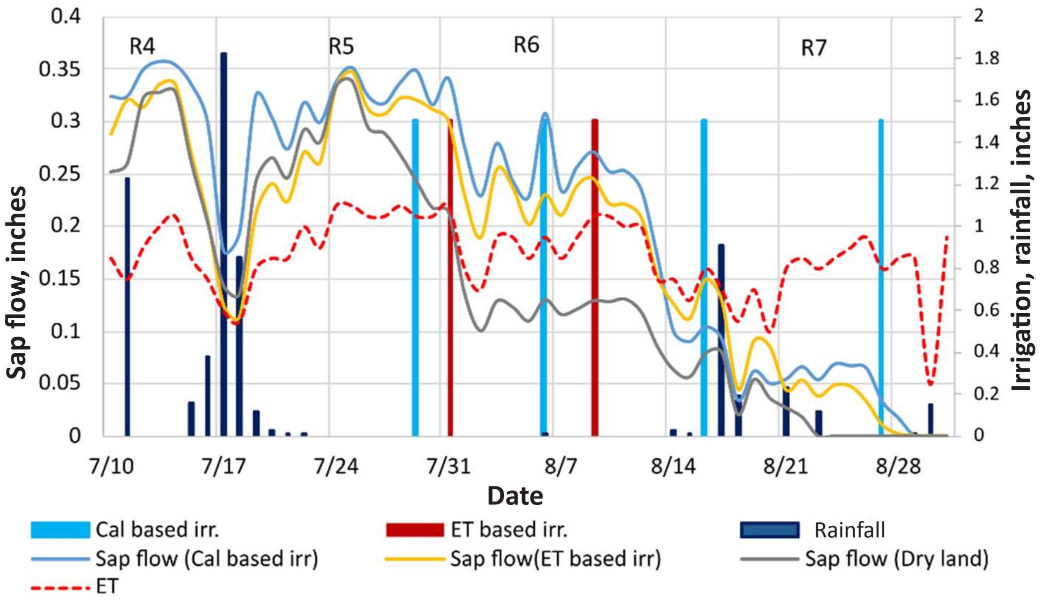

Fig. 1. Soybean plant sap flow in different irrigation treatment plots, evapotranspiration (ET), rainfall, and irrigation events during the R4–R7 growth stages.

Table 3. Averages of daily, different growth stages, and cumulative plant sap flow in inches of early maturity soybean variety planted in early, middle, and late time for 2021 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station in Marianna, Ark.

Growth	23 April				27 May				25 June			
stages	Days	Daily	Sum	Cum.	Days	Daily	Sum	Cum.	Days	Daily	Sum	Cum.
VE-VC	7	0.00	0.01	0.0	7	0.00	0.01	0.0	6	0.00	0.01	0.0
V1	5	0.00	0.02	0.0	4	0.00	0.02	0.0	4	0.00	0.02	0.0
V2	4	0.00	0.02	0.0	3	0.01	0.02	0.0	3	0.00	0.03	0.1
V3	6	0.01	0.06	0.1	4	0.01	0.05	0.1	4	0.03	0.07	0.1
V4	6	0.02	0.09	0.2	4	0.02	0.08	0.2	4	0.03	0.09	0.2
V5	5	0.05	0.24	0.4	5	0.02	0.10	0.3	4	0.06	0.30	0.5
R1	6	0.11	0.65	1.1	5	0.08	0.40	0.7	5	0.13	0.70	1.2
R2	7	0.13	0.90	2.0	9	0.21	1.90	2.6	9	0.24	0.85	2.1
R3	10	0.21	2.10	4.1	9	0.27	2.40	5.0	8	0.25	2.10	4.2
R4	10	0.23	2.30	6.4	10	0.26	2.60	7.6	9	0.22	1.98	6.1
R5	13	0.24	3.12	9.5	11	0.23	2.50	10.1	9	0.19	1.71	7.9
R6	11	0.22	2.42	11.9	12	0.21	2.50	12.6	8	0.19	1.50	9.4
R6.5	10	0.16	1.60	13.5	5	0.20	1.00	13.6	7	0.10	1.60	11.0
R6.9	5	0.07	0.37	13.9	5	0.10	0.50	14.1	4	0.08	0.37	11.3
R7	8	0.04	0.30	14.2	9	0.04	0.40	14.5	7	0.03	0.30	11.6
R8	8	0.00	0.00	14.2	8	0.00	0.00	14.5	7	0.00	0.00	11.6

Cum. = cumulative.

Table 4. Averages of daily, different growth stages, and cumulative plant sap flow in inches of early maturity soybean varieties planted in early, middle, and late time in 2017–2021 University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station in Marianna, Ark.

Growth	Early-time planting				Middle-time planting				Late-time planting			
stages	Days	Daily	Sum	Cum.	Days	Daily	Sum	Cum.	Days	Daily	Sum	Cum.
VE-VC	7	0	0.01	0.0	6	0.00	0.01	0.0	6	0	0.01	0.0
V1	4	0	0.02	0.0	4	0.01	0.02	0.0	3	0	0.01	0.0
V2	4	0	0.02	0.1	4	0.01	0.02	0.1	3	0	0.01	0.0
V3	5	0.01	0.05	0.1	5	0.01	0.06	0.1	4	0.01	0.04	0.1
V4	5	0.02	0.08	0.2	5	0.02	0.09	0.2	4	0.01	0.06	0.1
V5	5	0.03	0.16	0.3	5	0.03	0.13	0.3	4	0.02	0.09	0.2
R1	6	0.08	0.49	0.8	6	0.10	0.6	0.9	5	0.06	0.33	0.6
R2	9	0.19	1.71	2.5	9	0.24	2.12	3.1	8	0.19	1.91	2.5
R3	11	0.2	2.18	4.7	10	0.24	2.38	5.4	9	0.26	2.35	4.8
R4	10	0.23	2.41	7.1	10	0.28	2.79	8.2	7	0.24	1.72	6.5
R5	10	0.25	2.65	9.8	9	0.30	2.74	11.0	8	0.15	1.28	7.8
R6	9	0.24	2.25	12.0	8	0.26	2.06	13.0	7	0.19	1.39	9.2
R6.5	8	0.2	1.67	13.7	8	0.18	1.46	14.5	6	0.11	0.6	9.8
R6.9	5	0.14	0.68	14.4	3	0.18	0.54	15.0	3	0.06	0.22	10.0
R7	10	0.08	0.73	15.1	9	0.06	0.5	15.5	8	0.03	0.12	10.1
R8	8	0.03	0.22	15.3	8	0.00	0.02	15.5	7	0.01	0.03	10.2

Cum. = cumulative.

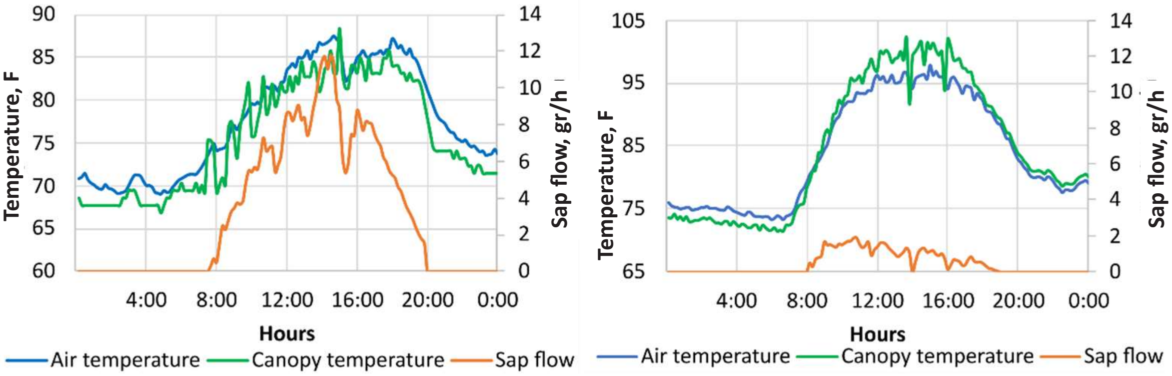

Fig. 2. The soybean plant sap flow, canopy, and ambient air temperature in 24 hours on 13 July (left) and 24 August (right).

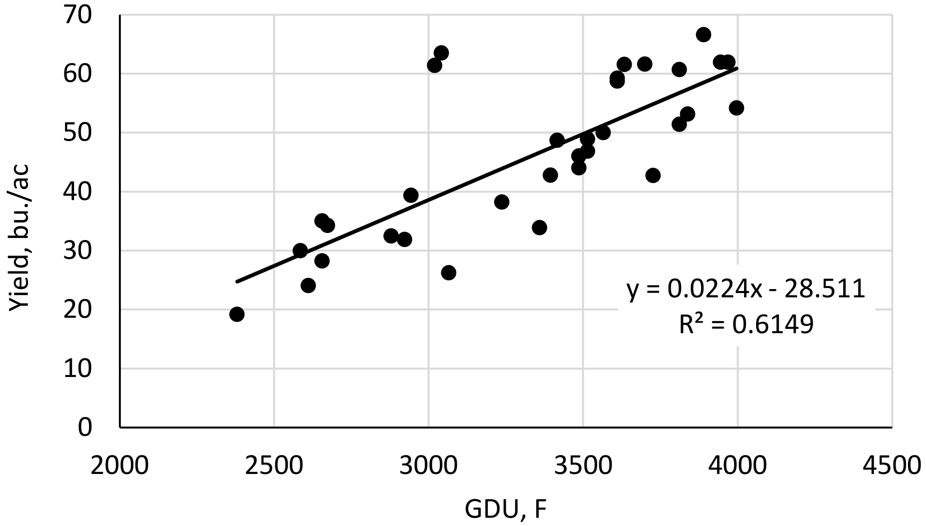

Fig. 3. Soybean yield and growing degree units (GDU) relation for all observed soybean varieties planted in different timings and irrigation treatments.

Results from Four Years of the Soybean Irrigation Yield Contest

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Abstract

The University of Arkansas System Division of Agriculture's Irrigation Yield Contest was conducted in 2018, 2019, 2020, and 2021. The contest was designed to promote better irrigation water use and record data on water use and efficiency for various crops. Unlike yield contests, where winners are decided by yield alone, the irrigation contest results are decided by a producer's highest calculated total water use efficiency (WUE). 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 using 8-in. and 10-in. portable mechanical flow meters. Rainfall totals were calculated using Farmlogs™. The contest average WUE of 2018–2021 for soybean was 3.24 bu./in. The winning WUE was 5.23 bu./in. for 2021, 4.34 bu./in. for 2020, 4.31 bu./in. for 2019, and 3.92 bu./in. for 2018. Participants are increasingly adopting irrigation water management (IWM) practices, such as computerized hole selection, surge irrigation, and soil moisture sensors. Soybean contest participants from 2018–2021 reported using, on average, 9.2 ac-in./ac of irrigation.

Introduction

According to data from 2015 reported by 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). However, one study of the aquifer found that 29% of the wells in the aquifer that were tested had dropped in water levels between 2009 and 2019 (ADANR 2020).

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 (CHS), surge irrigation, and soil moisture sensors (Spencer et al., 2019). Paired fields were set up, one using the IWM tools and one using conventional irrigation methods. It was found that implementing all 3 IWM tools reduced water use in the soybean fields by 21% while not reducing yields. The reduced water use also increased water use efficiency (WUE) by 36%. For the corn fields, 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 to encourage the use of water-saving methods by Arkansas producers. The competition's goals are to 1. promote water-reducing management practices by educating producers on the benefits of IWM tools; 2. provide feedback to participants on how they compared to other producers; 3. document the highest achievable water use efficiency in multiple crop types under irrigated production in Arkansas, and 4. recognize producers who achieved a high WUE.

Procedures

Rules for the irrigation yield contest were developed in 2018. The influence was from existing yield contests (ASA, 2014; NCGA, 2022; NWF, 2021; UCCE, 2018). The rules were designed to be as unobtrusive as possible to normal planting and harvesting operations. Fields must be at least 30 acres in size. A yield minimum of 60 bu./ac must be achieved to qualify.

A portable propeller-style mechanical flowmeter 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™ (Fargo, N.D.), 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.

The harvest operations were observed by a third-party observer, often an Extension Agent, Natural Resource Conservation Service employee, or a University of Arkansas System Division of Agriculture staff member. For the yield

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estimate, a minimum of 3 acres was harvested from the contest field.

The equation used for calculating WUE for the contest was:

$$WUE = Y / (Pe + IRR) \qquad \text{Eq. 1}$$

where WUE = water use efficiency in bushels per inch, Y = yield estimate from harvest in bu./ac., Pe = Effective precipitation in inches, and IRR = Irrigation application in ac-in./ac. Statistical analysis was performed using Microsoft Excel and JMP 15 (Cary, N.C.).

Results and Discussion

Detailed results are published on the contest website (Arkansas Irrigation Yield Contest) each year. Over the 4 years that the competition has been conducted, there have been 57 fields entered for soybean. The average WUE over the 4 years was 3.24 bu./in. By year, the average WUE was 3.53 bu./in. for 2021 with 14 contestants; 3.48 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 2021 than in the previous 3 years. The winning WUE for each year was: 5.23 bu./in. for 2021, 4.34 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. A best fit line was calculated by plotting WUE on one axis and yield on the other. The line calculated has a coefficient of determination of $R^2 = 0.3882$, where $R^2 < 0.95$ shows no relationship or correlation. 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. On the contest entry form, a similar survey was included to assess the usage of IWM tools among the participants. The results can then be compared to the average in use in the mid-South and Arkansas. In the 2015 survey, 40% reported using CHS, and more specifically, 66% of the Arkansas growers reported using CHS. However, 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, 40% of the participants for 2021 across all 3 categories included responses in their entry form. The IWM tool that was most widely adopted was CHS. The CHS average use among respondents was 89% across all 4 years, with 88% in 2018, 72% in 2019, 100% in 2020, and 95% in 2021. Soil moisture sensors were used by 58% of respondents from all 4 years, with 60% in 2018, 67% in 2019, 42% in 2020, and 65% in 2021. Surge valves were the least used IWM tool, with 29% of respondents from all 4 years saying they used surge valves. This included 44% from 2018, 28% from 2019, 16% from 2020, and 30% from 2021.

Practical Applications

The irrigation WUE of working farms is not a common metric available in the literature, and it is not a metric familiar to soybean farmers. However, the data from the Arkansas Irrigation Yield Contest provides direct feedback to irrigators about their performance in maintaining high yields and low irrigation water used. Direct feedback from Arkansas soybean farmers will give many a competitive advantage when water resources become scarce. In addition, 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 four years averaged 9.2 ac-in./ac applied and total water use of 24.8 inches for soybean.

Acknowledgments

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Literature Cited

ADANR. 2020. Arkansas Department of Agriculture Natural Resource Division. Arkansas Groundwater Protection and Management Report for 2019. Accessed 22 Feb. 2021. Available at: https://www.agriculture.arkansas.gov/wp-content/uploads/2020/06/27-2019_Report_Final_Draft.pdf

ASA. 2014. Arkansas Soybean Association. Grow for the Green Soybean Yield Challenge Rules and Entry Form. Accessed 14 Jan. 2021. Available at: https://www.arkansassoybean.com/2014_final_entry_form.pdf

Dieter, C.A., M.A. Maupin, R.R. Caldwell, M.A. Harris, T.I. Ivahnenko, J.K. Lovelace, N.L. Barber, and K.S. Linsey. 2018. Estimated use of water in the United States in 2015. U.S. Geological Survey Circular 1441, p. 65 Accessed 14 Jan. 2022. Available at: https://doi.org/10.3133/cir1441

Kresse, T.M., P.D. Hays, K.R. Merriman, J.A. Gillip, D.T. Fugitt, J.L. Spellman, A.M. Nottmeier, D.A. Westerman, J.M. Blackstock, and J.L. Battreal. 2014. Aquifers of Arkansas-protection, management, and hydrologic and geochemical characteristics of groundwater resources in Arkansas. U.S. Geological Survey Scientific Investigations Report 2014–5149. Accessed 22 Feb. 2022. Available at: http://dx.doi.org/10.3133/sir20145149

NCGA. 2022. National Corn Growers Association. National Corn Yield Contest. Accessed 24 June 2022. Available at: https://dt176nijwh14e.cloudfront.net/file/499/Entry%20and%20Harvest%20Rules%202022-2.pdf

NWF. 2021. National Wheat Foundation. National Wheat Yield Contest Rules. Accessed 24 June 2022.Available at: https://yieldcontest.wheatfoundation.org/Content/RulesPDF/NWYC%20Entry%20Harvest%20Rules.pdf

Spencer, G.D., L.J. Krutz, L.L Falconer, W.B. Henry, C.G. Henry, E.J. Larson, H.C. Pringle III, C.J. Bryant, and R.L. Atwill. 2019. Irrigation water management technologies for furrow-irrigated corn that decrease water use and improve yield and on-farm profitability. Crop Forage Turfgrass Mgmt., 5(1), 180100. Accessed 24 June 2022. Available at: https://doi.org/10.2134/cftm2018.12.0100

UCCE. 2018. University of California Cooperative Extension. UCCE Rice Yield Contest Entry and Harvest Rules. Accessed 14 Jan. 2022. Available at: https://ucanr.edu/sites/RiceTestSite/files/328524.pdf

USDA-NASS. 2017. United States Department of Agriculture National Agricultural Statistics Service. Quick Stats. Accessed 22 Feb. 2022. Available at: https://quickstats.nass.usda.gov/results/4754F465-950B-35AB-A192-B4699B526B66

Table 1. The 2018, 2019, 2020, and 2021 maximum, average, and minimum values for water and yield data points for soybeans 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.
2021	**Maximum**	5.23	101	21.4	19.0	32.0
	Average	3.53	84	14.5	9.9	24.5
	Minimum	2.45	72	10.4	5.1	18.9
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
4 Yr.	**Average**	3.15	76	15.9	8.9	24.8

Soybean Yield Components Among Nodes Are Influenced by Phosphorus Fertility

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Abstract

Soybean [*Glycine max* (L.) Merr.] is widely cultivated on arable soils with limited phosphorus (P) availability which can negatively impact plant yield potential. In this trial, the effects of P deficiency on soybean yield components and seed abortion among node sections were evaluated at two locations. Fertilizer-P rate trials were established in Arkansas at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) and in Louisiana at the Macon Ridge Research Station (MRRS). Pioneer 52A43L and 48A60X soybean were planted at RREC and MRRS, respectively. At soybean maturity, 6 plants/plot were collected to evaluate the number of pods and seeds, seed weight, and seed abortion among node sections (2 nodes and 2 internodes/node section, numbered from top to bottom). The maturity group (MG) 4 soybean plants had an average of 21 nodes, with the greatest number of pods and seeds occurring at the intermediate node sections (i.e., 4, 5, 6, and 7), representing 53% of the plant's seed weight. The MG 5 soybean had an average of 16 nodes, with a greater number of pods and seeds in the uppermost node sections (i.e., 1, 2, and 3) and at node section 7 (where branches were frequently observed), representing 72% of the plant's seed weight. Regardless of MG, the no-P control consistently had fewer pods and seeds across node sections than fertilized treatments, resulting in lower seed weight. The mean seed weight of the 0, 40, and 80 lb P_2O_5/ac treatments was 15, 17, and 23 g/plant, respectively, at RREC and 16, 20, and 21 g/plant at MRRS, respectively. Seed abortion followed a similar trend as soybean yield components, with the highest yielding node sections having the greatest (1.3–2.1%) seed abortion indicating potential competition for P among forming seeds. Sub-optimal P availability affected soybean growth and yield components, highlighting the importance of adequate P fertilization to maximize soybean yield.

Introduction

Soybean [*Glycine max* (L.) Merr.] is a major row crop worldwide because of its nutritional value for human and animal consumption (Esper Neto et al., 2021). It is also of great importance for the economies of the mid-Southern United States. Soybean yield potential is related to several production factors, such as cultivar, environmental conditions, and soil physical, chemical, and biological properties. When the soil has a limited capacity to supply enough nutrients to satisfy the plants' demand for adequate growth, fertilization is necessary. Among the nutrients with low availability in the soil, special attention is given to phosphorus (P) due to its complex and dynamic nature in the soil system, high adsorption capacity to the soil mineral phase, and importance in plant metabolism.

A recent summary of Arkansas soil-test results shows that 41% of the acres cropped to soybean have soil-test P < 25 ppm and 14% of the acres test <16 ppm (DeLong et al., 2021), where yield responses to fertilization may occur. Phosphorus is required in relatively large amounts for proper soybean yield. Harvested soybean seed removes the equivalent of 0.7 lb P_2O_5 per bushel (Esper Neto et al., 2021) and accounts for the removal of about 70% of the plants' aboveground P content at maturity. Failure to replace the nutrient removal by the harvested grain with adequate fertilizer rates contributes to soil nutrient depletion and eventual nutrient deficiencies that will limit crop yield and soil productivity in the long term (Mozaffari et al., 2020).

Compared with potassium (K) deficiency, soybean is relatively tolerant to P deficiency, and the published literature has limited information describing the effect of P deficiency on soybean growth and yield. A better understanding of how low soil-P availability influences soybean growth and yield components among nodes is important for developing more efficient fertilization practices and improving methods for monitoring plant P nutrition, yield potential, and seed quality. Our objective was to evaluate the effects of P fertility on soybean yield components and seed abortion among node sections.

Procedures

The research was performed in 2021 in a long-term trial established in 2007 at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC), near Stuttgart, Ark., and in a trial established in 2021 on a P-deficient site located at the Louisiana State Uni-

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versity AgCenter's Macon Ridge Research Station (MRRS), near Winnsboro, La. The soils are mapped as a Dewitt silt loam at the RREC and a Gigger-Gilbert silt loam at MRRS (NRCS USDA, 2022).

The long-term experiment at the RREC is a randomized complete block design with 6 blocks that contain 5 fertilizer-P rates (0, 40, 80, 120, and 160 lb P_2O_5/ac/year) applied as triple superphosphate (TSP; 0-46-0) annually. The research area contains adjacent and duplicate trials that allow rice (*Oryza sativa* L.) and soybean to be grown yearly. Individual plots measure 15-ft wide and 25-ft long, which allows 2 passes with a small plot (8-row) drill with 7.5-in. row spacings. The research area has been managed with no-tillage since the beginning of the trial, is flood irrigated, and rotated with rice. The same P-fertilizer treatments have been applied annually to each plot since the trial was initiated, with applications made to the soil surface as early as February (preplant) to as late as immediately following crop planting. Ample rates of fertilizer-K are applied uniformly to the trial area to ensure that only P is potentially limiting crop growth. The mean Mehlich-3 P concentration (0 to 4-in. depth) among the 5 annual fertilizer-P rates ranges from 12 to 108 ppm (Table 1).

The experiment located at MRRS was a randomized complete block design with 4 blocks. Each experimental plot was 35-ft long x 13.33-ft wide and contained 4 rows. Fertilizer-P rates (0, 40, 80, 120, and 160 lb P_2O_5/ac as TSP) were broadcast on the top of the seedbed on the same day as soybean planting. Based on initial soil-test results, before setting up the trial, the entire area received 2 tons/ac of lime (87% calcium carbonate equivalent (CCE); applied in fall 2020 and incorporated with tillage) and was fertilized with 80 lb K_2O/ac (muriate of potash; 0-0-60), 20 lb sulfur (S)/ac (gypsum; 16% S), and 10 lb zinc (Zn)/ac (zinc sulfate; 20% Zn and 5% S) at planting to ensure adequate amounts of these nutrients for plant development, according to the Louisiana State University guidelines for soybean production. The site was furrow irrigated (40-in. bed spacing), corn (*Zea mays* L.) was the previous crop, and the mean Mehlich-3 P was 15 ppm in the 0–4 in. depth (Table 1). Selected soil chemical properties for both the RREC and MRRS trials are presented in Table 1.

Pioneer 48A60X and 52A43L (Pioneer Hi-Bred International, Johnston, Iowa) soybean were planted on 27 April and 21 May at the MRRS and RREC, respectively. The annual soil-test results and prior-year crop yield results (up to and including 2020) were used to select 3 annual fertilizer-P rates that produce different growth and yield. These rates represent Deficient (0 lb P_2O_5/ac/year), Low (40 lb P_2O_5/ac/year), and Optimal (80 lb P_2O_5/ac/year) P availability for crop yield production to assess soybean yield components among node sections. At maturity (R8), 6 whole, mature plants were collected (cut at the soil surface) from an interior row of each plot to evaluate selected soybean yield components as affected by main-stem and branch node locations and P fertility levels. Thereafter, the 4 most uniform plants/plot were selected, and their nodes were numbered from the topmost node (node 1) to the bottom node. Selected plants were dissected from top to bottom, and tissues from each plot were composited by node section, each consisting of 2 nodes and 2 internodes. Tissues from each dissected node section were separated into the following categories: 1. stem and branch internodes, 2. pods, and 3. seeds. These categories were used to evaluate selected yield components' responses among nodes to P fertility, including the number of pods, number of seeds, and seed weight. Branches were separated into the same plant components described for the main stem. The yield components (number of pods, number of seeds, and seed weight) were added to the associated main stem node section where the branch was located.

Soybean pods were examined, and the number of filled and unfilled seed cavities was recorded to evaluate the distribution of the total percentage of seed abortion among node sections [(total number of unfilled cavities per node section/ total number of cavities per plant) × 100]. Soybean seeds were counted and weighed to evaluate the total seed weight from each node section after discarding the aborted and/or malformed seeds.

Data for the maturity group (MG) 4 (MRRS) and 5 (RREC) cultivars were analyzed separately due to different growth habits (e.g., number of branches and number of nodes). Each fertility study was conducted as a factorial with 3 fertilizer-P rates and 8 (RREC 3 × 8 factorial) or 11 (MRRS 3 × 11 factorial) node sections. At each site, plots were arranged in a randomized complete block design with 4 replications (only 4 of the 6 replicates were sampled at RREC). Soybean seed weight, selected yield components, and seed abortion data were subjected to analysis of variance (ANOVA) using the GLIMMIX procedure in SAS v. 9.4 (SAS Institute, Cary, N.C.). When the F test was significant ($P < 0.05$), the means were compared using Fisher's protected least significant difference at the 0.05 probability level. The correlation (Pearson linear correlation coefficient) between soybean pod number and seed abortion was also evaluated using the CORR procedure in SAS.

Results and Discussion

The overall number of nodes/plant varied among soybean MG. However, it was relatively consistent among fertilizer-P rates (average of 16 nodes for the MG 5 soybean grown at the RREC and 21 nodes for the MG 4 soybean plants at MRRS), resulting in 8 and 11 node sections, respectively, where soybean yield components and seed abortion were evaluated. We observed while conducting the trials that plants growing in the no-P control were visibly shorter than plants from the 40 and 80-lb P_2O_5/ac rate treatments. Soybean plants grown in the unfertilized treatment at RREC also had smaller leaves, resulting in a lower canopy coverage at the R1 development stage (data not shown), indicating that the sub-optimal P availability limited plant growth and development.

Soybean pod number, seed number, and seed weight were significantly ($P < 0.05$) affected by fertilizer-P rate and node section at both locations (Table 2). The MG 5 soybean receiving 80 lb P_2O_5/ac at the RREC increased the number of pods, seeds, and seed weight by about 33%, 33%, and 30%, respectively, compared to the control and 40 lb P_2O_5/ac treatments, which did not differ from each other (Table 3). Likewise, regardless of rate, fertilized treatments at the MRRS increased the number of pods, seeds, and seed weight of soybean plants by 19%, 19%, and 23%, respectively, in relation to the control. Although not statistically compared, the distribution of yield components among node sections varied between soybean MG. The MG 5 soybean had the greatest number of pods, seeds, and seed weight at node section 7, where branches were frequently observed (especially for the 40 and 80 lb P_2O_5/ac treatments), followed by the uppermost node sections 2, 3, and 1 (Table 3). On the other hand, the MG 4 soybean had the greatest number of pods, seeds, and seed weight at the intermediate node sections (node sections 5, 6, 4, and 7). These node sections (1, 2, 3, and 7 for the MG 5 cultivar, and 4, 5, 6, and 7 for the MG 4 cultivar) were responsible for 72% and 53% of the plants' total seed weight, respectively. Regardless of the MG, the no-P control consistently had fewer pods and seeds across node sections than P-fertilized treatments, resulting in a lower mean seed weight node/section. The plant's total seed weight was significantly different at RREC ($P < 0.05$), while a numerical difference ($P = 0.0808$) was also observed among fertilizer-P rates at MRRS (Table 3).

There was a significant P_2O_5 rate × node section interaction ($P < 0.05$) for seed abortion in the RREC trial (Table 2). The MG 5 soybean at RREC had the greatest relative seed abortion (1.3%–2.1%) in node sections 7 and 2 for the 80 lb P_2O_5/ac treatment, node section 4 for the no-P control, and node section 2 for the 40 lb P_2O_5/ac treatment (Table 4). For the MG 4 soybean at MRRS, only the main effect of node section was significant ($P < 0.05$) for seed abortion, with the greatest abortion (1.15%–1.56%) being observed in node sections 5, 3, 4, and 7 (Tables 2 and 4). Overall, the total seed abortion/plant was about 6.3% for MG 5 at RREC and 11.0% for MG 4 at MRRS. There was a positive correlation between pod number ($r = 0.79$ and 0.57) and seed abortion ($n = 96$ and 132) with $P < 0.001$ for RREC and MRRS, respectively, as the greatest seed abortion was observed in the node sections that showed the highest pod and seed number. This behavior is probably related to the plant's inability to fill all seed cavities as a result of competition for P and other nutrients among developing seeds in these sections with an increased number of pods. Sub-optimal P availability compromised adequate plant growth and development, evidenced by the reduced plant height, yield components, and seed weight in soybean growing in the no-P control treatment. These results suggest that an adequate P-fertilizer management program maximizes soybean production and profitability.

Practical Applications

Preliminary results from this research show that P availability significantly affects soybean growth and yield components among node sections. Specifically, we identified that sub-optimal P supply (via soil or fertilization) reduces plant height and the number of pods, seeds, and seed weight per plant. In addition, the soybean yield components and seed abortion followed a similar pattern across node sections, with the uppermost node sections plus node section 7 (where branches were frequently present) in the MG 5 cultivar and the middle portion of the MG 4 cultivar presenting the highest values. This trend is comparable to the results reported by Parvej et al. (2016) for soybean yield responses to K nutrition in determinate and indeterminate cultivars, indicating that both P and K are major nutrients that may influence soybean yield potential. While the information from the first year of these trials is informative, additional site-year observations need to be performed to create a robust data set and provide more conclusive information regarding soybean yield components and grain yield response to different levels of P availability.

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Literature Cited

DeLong, R.E., N.A. Slaton, C.G. Herron, and D. Lafex. 2021. Arkansas soil-test summary for samples collected in 2019. In: N.A. Slaton (ed.). W.E. Sabbe Arkansas Soil Fertility Studies 2020. Arkansas Agricultural Experiment Station Research Series 675:5-22. Fayetteville.

Esper Neto, M., L.M. Lara, S.M. Oliveira, R.F. Santos, A.L. Braccini, T.T. Inoue, and M.A. Batista. 2021. Nutrient removal by grain in modern soybean varieties. Front. Plant Sci. 12:615019.

Mozaffari, M., C.E. Wilson Jr., Z.M. Hays, J.M. Hedge, M.G. Mann, K.M. Perkins, R.A. Wimberley, and A.M. Sayger. 2020. Corn grain yield response to soil-applied phosphorus and potassium in Arkansas. In: N.A. Slaton (ed.). W.E. Sabbe Arkansas Soil Fertility Studies 2019. Arkansas Agricultural Experiment Station Research Series 666:51–55. Fayetteville.

NRCS USDA. 2022. Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Accessed 4 April 2022. Available at: http://websoilsurvey.sc.egov.usda.gov/

Parvej, M.R., N.A. Slaton, L.C. Purcell, and T.L. Roberts. 2016. Soybean yield components and seed potassium concentration responses among nodes to potassium fertility. Agron. J. 108:854-863.

Schulte, E.E., and B.G. Hopkins. 1996. Estimation of soil organic matter by weight loss-on-ignition. In Magdoff F.R. et al. (Eds.), Soil organic matter: Analysis and interpretation. Pp. 21–31. Madison, Wisc.:SSSA.

Sikora, F.J., and D.E. Kissel. 2014. Soil pH. In Sikora F.J. and K.P. Moore (Eds.), Soil test methods from the southeastern United States. Southern Cooperative Service. Bulletin 419:48-53. Accessed 30 March 2022. Available at:[http://aesl.ces.uga.edu/sera6/PUB/MethodsManual-FinalSERA6.pdf](http://aesl.ces.uga.edu/sera6/PUB/MethodsManualFinalSERA6.pdf)

Zhang, H., D.H. Hardy, R. Mylavarapu, and J.J. Wang. 2014. Mehlich-3. In Sikora F.J. and K.P. Moore (Eds.), Soil test methods from the southeastern United States. Southern Cooperative Service Bulletin 419:101-110. University of Georgia. Accessed 30 March 2022. Available at:http://aesl.ces.uga.edu/sera6/PUB/MethodsManualFinalSERA6.pdf

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Table 1. Soil chemical properties in the 0- to 4-in. depth at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., and the Louisiana State University's Macon Ridge Research Station (MRRS), Winnsboro, La., prior to fertilizer-P treatment application in 2021.

	P_2O_5			Mehlich-3 extractable nutrients[§]										
Location	**rate**	**SOM[†]**	**pH[‡]**	**P[¶]**	**K**	**Ca**	**Mg**	**S**	**Na**	**Fe**	**Mn**	**Zn**	**Cu**	**B**
	lb/ac	%	-	-----	-----	-----	-----	-----	ppm	-----	-----	-----	-----	-----
RREC	0	2.2	5.4	12 e	91	843	115	9	23	508	97	6.5	1.1	0.2
	40		5.4	25 d	93	882	111	8	22	553	84	7.1	0.8	0.2
	80		5.4	56 c	99	903	112	8	21	616	71	7.2	0.7	0.2
	120		5.4	75 b	82	877	105	7	22	608	70	6.4	0.6	0.2
	160		5.6	108 a	93	1094	120	7	24	606	66	8.2	0.6	0.2
	P-value			<0.0001										
	CV (%)			12.0										
MRRS[#]	–	2.1	4.7[††]	15	72	1087	236	21	76	187	114	1.3	1.0	0.3

[†] SOM = soil organic matter (Schulte and Hopkins, 1996).

[‡] Sikora and Kissel (2014).

[§] Zhang et al. (2014).

[¶] Variable Mehlich-3 soil-test P within the RREC trial is an effect of long-term fertilizer-P rates application. Mean soil-test P followed by different lowercase letters are statistically different at the 0.05 probability level.

[#] Soil-test values prior to fertilizer-P treatment application and trial set up in 2021.

[††] Lime (2 ton/ac with 87% calcium carbonate equivalent (CCE)) was applied and incorporated with tillage before setting up the trial to increase soil pH to adequate levels for soybean growth.

Table 2. Analysis of variance (ANOVA) *P*-values for soybean seed number, seed weight, and seed abortion as affected by fertilizer-P rate, node section, and their interactions at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., and Louisiana State University's Macon Ridge Research Station (MRRS), Winnsboro, La, in 2021.

		Degrees of	*P*-value			
Site	**Source of Variation**	**Freedom**	**Pod Number**	**Seed Number**	**Seed Weight**	**Seed Abortion**
RREC	P_2O_5 rate	2	0.0003 *(0.0003)*[†]	0.0003 *(0.0002)*	0.0012 *(0.0010)*	0.1042 *(0.1214)*
	Node Section	7	<0.0001	<0.0001	<0.0001	<0.0001
	P_2O_5 rate × Node Section	14	0.1051	0.2536	0.2572	0.0314
MRRS	P_2O_5 rate	2	0.0008 *(0.0539)*	0.0007 *(0.0567)*	<0.0001 *(0.0808)*	0.8635 *(0.7979)*
	Node Section	10	<0.0001	<0.0001	<0.0001	<0.0001
	P_2O_5 rate × Node Section	20	0.4645	0.6683	0.8160	0.1814

[†] *P*-value in parenthesis corresponds to the main effect of P_2O_5 rate for the total (sum across node sections) number of pods, seeds, seed weight, and seed abortion/plant.

Table 3. Soybean pod number, seed number, and seed weight as affected by fertilizer-P rate and node section at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark., and Louisiana State University's Macon Ridge Research Station (MRRS), Winnsboro, La., in 2021.

	Pod Number				Seed Number				Seed Weight			
Node	P_2O_5 rate (lb/ac)				P_2O_5 rate (lb/ac)				P_2O_5 rate (lb/ac)			
Sec.[†]	0	40	80	Avg[‡]	0	40	80	Avg	0	40	80	Avg
#	#								g			
	RREC											
1	9.3	9.9	10.0	9.7 bc[§]	21.6	22.7	23.1	22.5 bc	3.01	2.94	3.14	3.0 a
2	10.3	12.4	13.6	12.1 ab	23.8	27.7	31.1	27.5 ab	3.20	3.56	3.79	3.5 a
3	8.5	11.6	10.8	10.3 bc	20.2	25.6	25.0	23.6 bc	2.74	3.21	3.07	3.0 a
4	8.4	6.9	8.2	7.8 cd	16.8	13.9	18.9	16.5 cd	2.03	1.61	2.27	2.0 b
5	2.8	4.5	9.6	5.6 de	6.3	9.6	19.8	11.9 de	0.77	1.22	2.28	1.4 b
6	3.9	2.9	4.1	3.6 e	8.1	5.8	10.1	8.0 e	1.10	0.61	1.10	0.9 c
7	8.4	15.2	20.4	14.7 a	18.3	32.3	42.7	31.1 a	2.28	3.75	5.02	3.7 a
8	0.5	0.0	9.6	3.4 e	1.2	0.0	19.8	7.0 e	0.15	0.00	2.35	0.8 c
Avg	6.5 B	7.9 B	10.8 A		14.5 B	17.2 B	23.8 A		1.9 B	2.1 B	2.9 A	
CV (%)		50.9					49.1				47.1	
Total[¶]	52 C	63 B	86 A		116 B	137 B	190 A		15 B	17 B	23 A	
CV (%)		8.8					10.1			10.0		
	MRRS											
1	2.9	4.3	4.4	3.9 e	7.0	9.7	9.7	8.8 e	0.74	1.14	1.12	1.00 f
2	3.0	4.1	3.7	3.6 e	7.3	9.4	8.3	8.3 e	0.82	1.07	1.10	1.00 f
3	5.4	6.6	6.1	6.0 d	11.9	14.8	13.3	13.3 d	1.37	1.74	1.66	1.59 de
4	7.3	9.2	8.1	8.2 abc	17.2	21.6	19.1	19.3 ab	1.99	2.67	2.38	2.35 ab
5	9.0	9.6	9.4	9.3 a	21.4	22.5	22.9	22.3 a	2.51	2.73	2.97	2.73 a
6	8.4	9.4	9.4	9.1 ab	19.4	22.2	22.3	21.3 ab	2.35	2.81	2.88	2.68 a
7	7.4	8.3	8.3	8.0 bc	16.8	18.6	19.9	18.5 bc	2.16	2.40	2.61	2.39 ab
8	6.3	6.9	6.4	6.5 d	14.9	16.9	16.1	16.0 cd	1.90	2.10	2.18	2.06 bc
9	6.1	6.9	7.7	6.9 cd	13.4	16.1	17.6	15.7 cd	1.62	1.89	2.31	1.94 cd
10	2.1	4.2	7.6	4.6 e	3.9	9.3	15.8	9.6 e	0.53	1.08	2.03	1.21 ef
11	0.8	2.5	0.8	1.4 f	2.0	4.4	1.7	2.7 f	0.05	0.38	0.17	0.20 g
Avg	5.3 B	6.5 A	6.5 A		12.3 B	15.0 A	15.1 A		1.46 B	1.82 A	1.95 A	
CV (%)	27.3						27.2				30.3	
Total[¶]	59 B	72 A	72 A		135	166	167		16	20	21	
CV (%)		11.3					11.3				14.9	

[†] Node sections (2 nodes and 2 internodes) are numbered from the top to the bottom of the plant.

[‡] Average.

[§] Uppercase and lowercase letters compare the main effects of fertilizer-P rate and soybean node section, respectively, at the 0.05 probability level.

[¶] Total (sum of across node sections) number of pods and seeds, and seed weight/plant for each fertilizer-P rate.

Table 4. Soybean seed abortion as affected by fertilizer-P rate and node section at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) near Stuttgart, Ark. and Louisiana State University's Macon Ridge Research Station (MRRS), Winnsboro, La., in 2021.

	P_2O_5 rate (lb/ac)			
Node Section[†]	**0**	**40**	**80**	**Average**
#	**Seed Abortion[‡] (%)**			
	RREC			
1	1.06 BCDE[§]	0.88 BCDEFG	0.74 BCDEFGH	0.89
2	1.25 BC	1.30 ABC	1.50 AB	1.35
3	0.69 BCDEFGH	1.23 BC	1.07 BCDE	1.00
4	1.38 AB	0.76 BCDEFGH	0.28 EFGH	0.81
5	0.20 FGH	0.23 EFGH	0.96 BCDEF	0.46
6	0.16 FGH	0.16 FGH	0.37 DEFGH	0.23
7	0.50 CDEFG	1.18 BCD	2.10 A	1.26
8	0.04 GH	0.00 H	0.84 BCDEFGH	0.29
Average	0.66	0.82	0.98	
CV (%)		76.1		
Total[¶]	5.3	5.7	7.9	
CV (%)		26.6		
	MRRS			
1	0.83	1.01	1.23	1.03 cde
2	0.75	0.95	0.89	0.86 de
3	1.61	1.74	1.15	1.50 ab
4	1.55	1.22	1.43	1.40 abc
5	2.13	1.52	1.04	1.56 a
6	1.18	0.85	1.26	1.10 bcde
7	1.25	1.25	0.94	1.15 abcd
8	0.78	0.85	0.39	0.67 e
9	0.66	0.84	0.88	0.80 de
10	0.50	0.53	1.34	0.79 de
11	0.00	0.37	0.08	0.15 f
Average	1.02	1.01	0.97	
CV (%)		53.5		
Total[¶]	11.3	11.1	10.6	
CV (%)		17.0		

[†] Node sections (2 nodes and 2 internodes) are numbered from the top to the bottom of the plant.

[‡] Percentage of seed abortion among node sections = [(total number of unfilled cavities per node section/total number of cavities per plant) × 100].

[§] Uppercase and lowercase letters compare the interaction between fertilizer-P rate and soybean node section and the main effect of node section, respectively, at the 0.05 probability level.

[¶] Total (sum of across node sections) seed abortion/plant for each fertilizer-P rate.

SOIL FERTILITY

Understanding Spatial Variability of Soybean Leaf Potassium to Establish a Sampling Protocol

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Abstract

The method to collect a representative sample can be used to accurately diagnose in-season soybean [*Glycine max* (L.) Merr.] potassium (K) deficiencies rely on the spatial variability of trifoliolate tissue-K concentrations within a field. Five commercial soybean fields were sampled at a 1-acre grid resolution throughout reproductive growth to quantify the trifoliolate tissue-K concentration. The objectives of this study were to identify the potential field variability in soybean leaf tissue-K concentrations in typical Arkansas soybean production systems and develop a sampling protocol for in-season tissue monitoring. No spatial dependencies were found in all fields and sample times, indicating that leaf samples should be collected according to the producer's preferred management strategy instead of specific grid size. One composite sample consisting of at least 18 of the upper-most fully expanded trifoliolate leaves from throughout the delineated management zone is needed to capture the average leaf tissue-K concentration. This sampling protocol, coupled with the newly developed dynamic critical tissue-K concentration curve, will allow producers to effectively monitor soybean for potential hidden hunger and verify K deficiency symptoms in season.

Introduction

Potassium (K) is often the most yield-limiting nutrient for soybean [*Glycine max* (L.) Merr.] grown on silt loam and sandy loam soils in Arkansas. Previous work in Arkansas has measured as much as 40% yield loss due to K deficiency (Popp et al., 2020). Diagnosis of this deficiency can be challenging as the classic visual deficiency symptoms may not always be apparent, and yield loss may occur prior to the onset of symptomology or without obvious visual deficiency symptoms. This phenomenon, known as hidden hunger, necessitates tissue testing for accurate diagnosis and preventative management. Slaton et al. (2021) defined critical concentrations for leaf tissue-K throughout reproductive growth, allowing for an accurate K deficiency diagnosis before permanent yield damage has occurred. The potential yield loss from severe K deficiency can be fully recovered with fertilizer-K applications up to 20 days after R1 or first flower (Slaton et al., 2020). This window of opportunity extends to 44 days after R1 when the deficiency is moderate or exists as hidden hunger (Slaton et al., 2020). Following these 44 days, yield loss is permanent because the deficient plant has already begun seed fill and the yield loss is unrecoverable. Therefore, a timely and accurate K deficiency diagnosis is needed to execute optimized K fertilization strategies. However, the reliability of the diagnosis depends entirely on the reliability of the sample, and creating a sampling protocol for in-season leaf tissue-K testing could help Arkansas producers minimize soybean yield loss from K deficiency.

Characterizing in-field variability in plant demand for K within a production field is necessary to optimize fertilizer application and maximize profits. Spatial variability of soil physical, chemical, and biological characteristics has been widely documented, likely from differences in soil genesis, localized environments, management history, and human or experimental error (Mallarino, 1996; Flowers et al., 2005; Yang et al., 2009). Therefore, a monoculture crop grown at the field scale is expected to vary within the field, which has been confirmed using remote and proximal sensing technology and yield maps. Many factors can contribute to differences in yield, including water stress, soil pH, nutrient availability, and pest pressures. These biotic and abiotic factors may also contribute towards variability of nutrient uptake and, therefore, leaf-K concentrations.

The objectives of this research involved 1. characterizing the spatial dependencies in production field trifoliate leaf tissue-K concentrations using a semivariogram and 2. determining how many trifoliolate leaves must be included in 1 composite sample to converge within the 95% confidence interval of the field average. The successful completion of this research will provide a reliable sampling method of trifoliolate soybean leaves for the proper diagnosis of K deficiencies and in-season K management.

Procedures

Data was collected in 5 commercial soybean fields in Arkansas, Lonoke, and Faulkner Counties. All fields were

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selected to represent typical spatial variability in Arkansas soybean production fields with silt loam soils. Each field was sampled at a 1-acre grid resolution to capture the in-field variability of tissue-K concentrations on silt loam soils. Producers managed fields to best represent Arkansas soybean production across various management practices that followed the current University of Arkansas System Division of Agriculture's Cooperative Extension Service guidelines (Ross et al., 2000). Planting dates, cultivars, maturity groups, field size, and crop rotations varied between locations (Table 1). Crop growth was tracked using SoyStage (Purcell et al., 2021) until R1 and assessed in the field thereafter.

Trifoliolate leaf samples were collected using grid sampling at R2, or full flower, in 2020 and 2021 and expanded to include an additional sampling at R4, or full pod, in 2021. The sampling resolution was 1 sample per acre. Trifoliolate leaf samples were gathered from 12 plants within a 39-in. radius of each sampling location using the method described by Flowers et al. (2005). Only the upper-most fully expanded trifoliolate was taken from each plant. Tissue samples were dried at 60 °C, ground using a Wiley Mill (Troemner, Thorofare, New Jersey) to pass through a 1-mm sieve, mixed, digested with 1 mol/L HNO_3, and analyzed using inductively coupled plasma atomic emission spectroscopy to determine elemental concentrations (Jones and Case, 1990). Each field's specific critical leaf-K concentration at each sampling time was determined based on the exact number of days after R1 that sampling occurred using the dynamic critical tissue-K concentration curve, assuming a 95% relative grain yield goal (Slaton et al., 2021). Any tissue-K concentration below the sampling date-specific critical concentration was considered deficient, and any concentration above the critical concentration to be sufficient. The collected data were summarized by field and sampling time (Table 1).

Semivariograms were computed to describe the spatial dependencies between tissue-K measurements for each location and sampling time. A semivariogram is a plot that quantifies the variability between two spatial measurements depending on the distance between the two sampling locations. The relationship between sample location and tissue-K concentration is modeled, expecting samples closer together to have more closely related values and samples farther apart to have a wider range of tissue-K concentrations. The more similar the data, the smaller the variability found between measurement pairs. In the field, the amount of variability between treatment pairs (assuming no spatial trends) only increases to a site-specific distance threshold, referred to as the range. Any points collected below the range or closer together than the distance threshold are spatially dependent. While 2 points are spatially independent if collected above the distance threshold or farther apart than the range. It is important to note that the range may not be represented on a semivariogram if the sampling resolution is too coarse for its identification. In this study, the range was quantified using appropriate mathematical models and defined as the area represented by the different samples in each field and sampling time.

The individual data points collected in each field were used to determine the number of sample locations needed to compile one composite sample representative of the area. Within each field, 35 individual samples were taken at each sample time. Multiple sample sizes were considered, from only 1 sample location to all 35 sample locations. For each sample size, samples were randomly selected to represent the field. When multiple samples were selected for larger sample sizes, the individual measurements were averaged to create 1 "composite" sample. This process of randomly selecting samples to converge 1 composite sample was repeated 10 times for every sample size possibility, ranging from 1 to 35 sample locations. The upper and lower boundaries of the results were considered in comparison to the 95% confidence interval of the field mean when all 35 samples were considered.

Data analysis was conducted in R (R Core Team, 2021) using packages sp (Pebesma and Bivand, 2005; Bivand et al., 2013), rgdal (Bivand et al., 2021), gstat (Pebesma, 2004; Graler et al., 2016), geodist (Padgham and Sumner, 2021), tidyverse (Wickham et al., 2019), and raster (Hijmans, 2022).

Results and Discussion

The trifoliolate leaf tissue-K concentrations varied from 1.68% to 1.99% K at R2 and from 1.29% to 1.89% K at R4 (Table 1). The difference in tissue-K concentrations measured within a field at 1 sample time ranged from 0.25% to 0.92% K (Table 1). Overall, each field measured either equal levels of variability between sampling times or increased variability at the R2 growth stage (Table 1). This variability is likely due to the translocation of K from the leaves into the pods during reproductive growth, decreasing the quantity and variability in the leaf-K while simultaneously increasing the quantity and potential variability of K in the pods, although this was not measured. Similarly, the percent of each field that measured deficient increased from the R2 sample time to the R4 sample time, except for the Arkansas County East (Arkansas E) field, which received a corrective fertilizer application between samplings (Table 1). This exemplifies the importance of the sample time, understanding that the dynamic critical concentration considers the mobility of K in the crop but is limited to the current nutrient status. Crop K uptake continues at high rates throughout soybean reproductive stages (Bender et al., 2015), allowing the possibility that the crop may run out of available K after the R2 tissue sample was collected, providing a false sense of yield potential. Therefore, monitoring should continue throughout the reproductive stages to ensure no yield limitations.

No spatial dependencies between tissue-K concentration measurements were found across all fields and sampling times at the one-acre resolution (Fig. 1). If spatial dependencies did occur in the selected fields, then they occurred at a finer scale than the 1 sample per acre spatial resolution. While spatial dependencies may be present at a finer resolution, it would be an impractical sampling protocol to recommend and therefore was not considered. Some fields, such as

Arkansas County West (Arkansas W), showed consistently lower semivariance values across distances, representing less field variability of leaf tissue-K concentrations (Fig. 1). Other fields, such as Faulkner County, have large variations in the semivariance of leaf tissue-K, yet still do not have an apparent trend of dependence (Fig. 1). Overall, the lack of spatial relationships found in all semivariograms indicates in-season soybean tissue sampling does not need to be conducted based on a specific sampling resolution but instead should be done to best fit the field management strategy.

Within a management zone, trifoliolate leaves should be taken from multiple points across the area to create a composite sample. If leaves were only taken from 1 point within that area, it might not represent the entire area's K status. The more leaf sample points within an area, the closer to the field means the composite sample concentration will become. Analysis of the grid samples showed that leaf samples must be taken from at least 18 points within a management zone to measure within the 95% confidence interval of the true field average (Fig. 2). All fields and sampling times agreed with these findings, indicating that at least 18 points sampled within the area (equally distributed spatially) to create a composite sample to represent the average K concentration of the area.

Practical Applications

In-season soybean tissue sampling does not need to be conducted on a grid-sampling approach similar to what might be employed for soil sampling. Instead, soybean leaf collection should be done to fit the producers' preferred management strategy best. A producer should sample at the resolution which matches their management strategy, understanding that more, smaller zones will better capture the potential field variability. However, there is no need to break a field into multiple management zones if the producer intends to treat the entire field the same or does not have the capability or desire to treat individual sections of the field differently. Within each management zone, a composite sample of at least 18 trifoliolate leaves from throughout the designated area is needed to produce a sample that adequately captures the tissue-K concentration variability of the area. The dynamic critical concentration curve should be used to interpret the tissue sample results. If the observed field tissue-K concentration is below the critical concentration, the deficiency can be corrected with an in-season application of K fertilizer.

Acknowledgments

Sincere appreciation is extended to the producers and County Extension Agents involved in this study for their continued help and cooperation, without which this project could not have happened. The authors would also like to thank the Soybean Checkoff Program administered by the Arkansas Soybean Promotion Board for their funding of this research and the University of Arkansas System Division of Agriculture.

Literature Cited

Bender, R.R., J.W. Haegele, and F.E. Below. 2015. Nutrient Uptake, Partitioning, and Remobilization in Modern Soybean Varieties. Agron. J. 107(2), 563-573. Accessed 4 May 2022. Available at: https://doi.org/10.2134/agronj14.0435

Bivand, R., T., Keitt, and B. Rowlingson. 2021. rgdal: Bindings for the 'Geospatial' Data Abstraction Library. R package version 1.5-28. Accessed 4 May 2022. Available at: https://CRAN.R-project.org/package=rgdal

Bivand, R.S., E. Pebesma, and V. Gomez-Rubio. 2013. Applied spatial data analysis with R, Second edition. Springer, NY. Accessed 4 May 2022. Available at: https://asdar-book.org/

Flowers, M., R. Weisz, and J.G. White. 2005. Yield-based management zones and grid sampling strategies: Describing soil test and nutrient variability. Agron. J., 97(3), 968–982. Accessed 4 May 2022. Available at: https://doi.org/10.2134/agronj2004.0224

Gräler, B., E. Pebesma, and G. Heuvelink. 2016. Spatio-Temporal Interpolation using gstat. The R Journal 8(1), 204-218.

Hijmans, R.J., 2022. raster: Geographic Data Analysis and Modeling. R package version 3.5-15. Accessed 4 May 2022. Available at: https://CRAN.R-project.org/package=raster

Jones, J.B., and V.W. Case. 1990. Sampling, handling, and analyzing plant tissue samples. In: R.L. Westerman, editor, Soil testing and plant analysis. 3rd ed. SSSA Book Ser. 3. SSSA, Madison, Wisc. p. 389–428.

Mallarino, A.P. 1996. Spatial Variability Patterns of Phosphorus and Potassium in No-Tilled Soils for Two Sampling Scales. Soil Sci. Soc. Am. J., 60(5), 1473–1481. Accessed 4 May 2022. Available at: https://doi.org/10.2136/sssaj1996.03615995006000050027x

Padgham, M., and M.D. Sumner. 2021. geodist: Fast, Dependency-Free Geodesic Distance Calculations. R package version 0.0.7. Accessed 4 May 2022. Available at: https://CRAN.R-project.org/package=geodist

Pebesma, E.J., 2004. Multivariable geostatistics in S: the gstat package. Computers & Geosciences, 30: 683-691.

Pebesma, E.J., and R.S. Bivand, 2005. Classes and methods for spatial data in R. R News 5 (2), Accessed 4 May 2022. Available at: https://cran.r-project.org/doc/Rnews/

Popp, M.P., N.A. Slaton, and T.L. Roberts. 2020. Profit-Maximizing Potassium Fertilizer Recommendations for Soybean. Agron. J., 1–31. Accessed 4 May 2022. Available at: https://doi.org/10.1002/agj2.20424

Purcell, L.C., C. Dos Santos, and M. Salmeron. 2021. Soybean Development Stage Predictions. University of Arkansas System Division of Agriculture, FSA2194-PD-05-21N.

Ross, W.J. 2000. Soybean Production Handbook. University of Arkansas System Division of Agriculture, MP 197. Accessed 4 May 2022. Available at: https://www.uaex.uada.edu/publications/mp-197.aspx

Slaton, N. A., T.L. Roberts, W.J. Ross, and T.L. Richmond, 2020. Irrigated soybean response to granular fertilizer potassium application timing. Agron. J., Accessed 4 May 2022. Available at: https://doi.org/10.1002/agj2.20342

Slaton, N.A., G.L. Drescher, M.D. Parvej, and T.L. Roberts 2021. Dynamic Critical Potassium Concentrations in Soybean Leaves and Petioles for Monitoring Potassium Nutrition. Agron. J. Accessed 4 May 2022. Available at: https://doi.org/10.1002/agj2.20819

Wickham, H., M. Averick, J. Bryan, W. Chang, L. D. McGowan, R. François, G. Grolemund, A. Hayes, L. Henry, J. Hester, M. Kuhn, T.L. Pedersen, E. Miller, S.M. Bache, K. Müller, J. Ooms, D. Robinson, D.P. Seidel, V. Spinu, K. Takahashi, D. Vaughan, C. Wilke, K. Woo, and H. Yutani. 2019. Welcome to the tidyverse. J. Open Source Software, 4(43), 1686, Accessed 4 May 2022. Available at: https://doi.org/10.21105/joss.01686

Yang, Y., J. Zhu, X. Tong, and D. Wang. 2009. The spatial pattern characteristics of soil nutrients at the field scale. IFIP International Federation for Information Processing, 293, 125–134. Accessed 4 May 2022. Available at: https://doi.org/10.1007/978-1-4419-0209-2_14

Table 1. Field trifoliolate K concentration status and variability measured at each growth stage and site year.

Site Year	Growth Stage	Critical K Concentration	Field Sufficient	Field Deficient	Field Average	Field Median	Field Range
			---------------%	--------------			
Faulkner	R2	1.92	14	86	1.77	1.76	0.92
Lonoke	R2	1.93	62	38	1.99	1.98	0.60
	R4	1.41	11	89	1.29	1.28	0.60
Arkansas S	R2	1.89	82	18	1.96	1.96	0.42
	R4	1.61	65	35	1.66	1.65	0.42
Arkansas E	R2	1.80	23	77	1.68	1.62	0.46
	R4	1.47	100	0	1.89	1.87	0.32
Arkansas W	R2	1.89	80	20	1.99	1.98	0.48
	R4	1.63	8	92	1.56	1.57	0.25

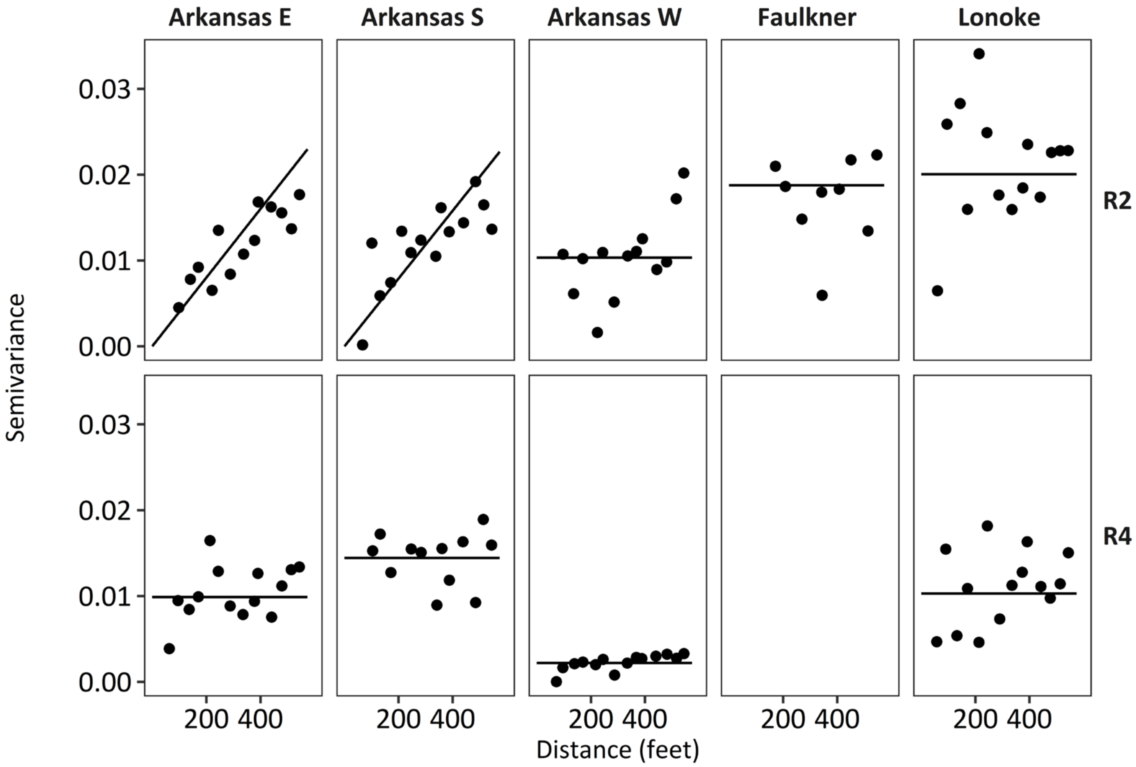

Fig. 1. Semivariograms for all fields at the R2 (full flower) and R4 (full pod) sampling times.

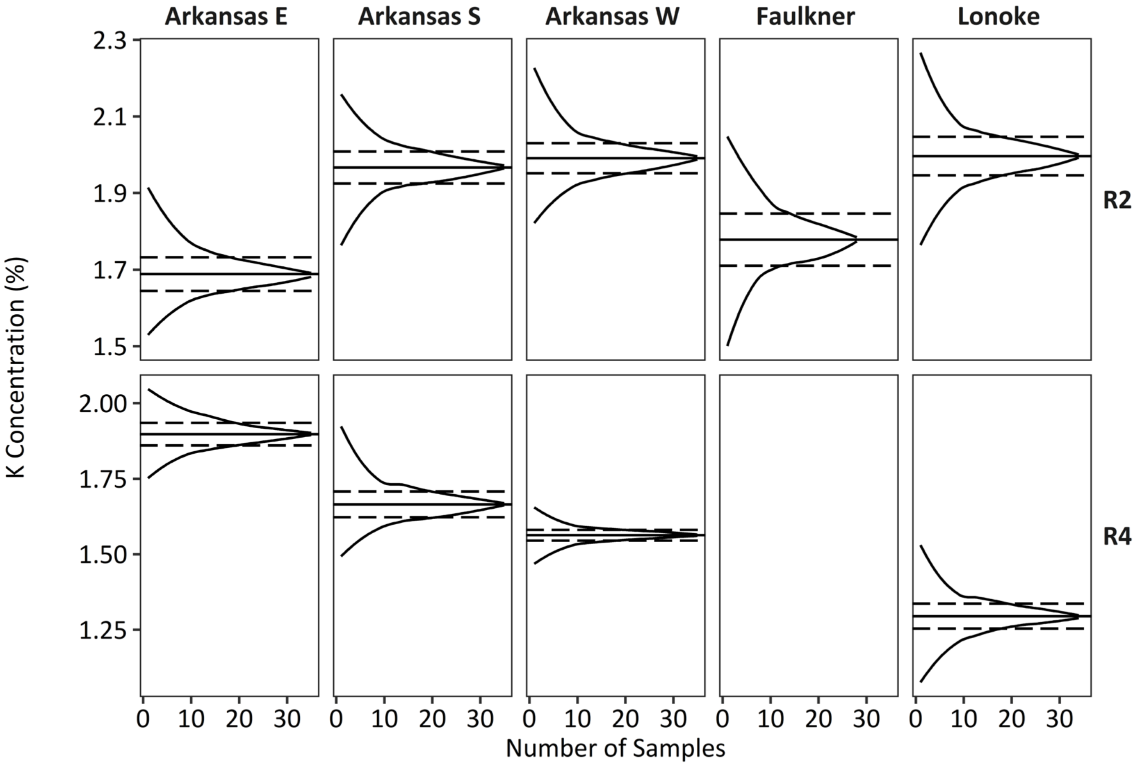

Fig. 2. Leaf composite sample size analysis for all 5 fields at both R2 (full flower) and R4 (full pod) sampling times. Solid lines represent the upper and lower limits of the average measured values. Dashed lines represent the 95% confidence interval for each site year.

Corrective In-Season Potassium Application Rates to Arkansas Soybean

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Abstract

Recent advancements for in-season potassium (K) management in soybean [*Glycine max* (L.) Merr.] allows the diagnosis of deficiencies at any point during reproductive growth. However, the rate of fertilizer-K necessary to correct the various levels of deficiency defined by trifoliolate leaf tissue-K concentrations to achieve maximum yield remains unknown, especially as the season progresses. Therefore, our primary objectives were to correlate the trifoliolate leaf-K concentrations with soybean relative grain yield and to calibrate K-fertilizer rates with leaf-K concentrations to create rate recommendations to achieve 95% relative grain yield based on the leaf tissue-K concentrations and days after R1 (DAR1). Treatments included multiple rates of granular muriate of potash at 15 DAR1, 30 DAR1, and 45 DAR1. The research was conducted in 2021 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station near Marianna, Ark., on silt loam soil. The results indicate that maximal yield can be recovered from a deficient crop at 15 DAR1, a positive yield response can be recovered from a deficient crop at 30 DAR1, and little yield response was observed when fertilizer-K was applied at 45 DAR1. Therefore, in-season applications are effective at maintaining yield if applied during early reproductive growth. However, a delay in application timing may jeopardize yield potential to the degree that correcting it is no longer profitable, especially when the K deficiency is severe. Calibrated K rates based on tissue-K concentrations for a given growth stage will enable producers to correct deficiencies in-season with the appropriate fertilizer rate to maximize yield and profit.

Introduction

Potassium (K) deficiency is one of the most important yield-limiting factors in Arkansas soybean [*Glycine max* (L.) Merr.] production and can be difficult to identify due to the lack of visual symptoms, known as hidden hunger. To prevent yield loss, proactive tissue sampling of the uppermost fully expanded trifoliolate leaf (no petiole) should occur prior to any signs of K deficiency, as unrecoverable yield loss has often occurred by the time a plant shows visible K deficiency symptoms. Slaton et al. (2021) recently established a dynamic tissue-K critical concentration curve to correctly diagnose in-season K deficiencies in soybean at any time during reproductive growth. If a deficiency is confirmed, a timely application of fertilizer-K is required to recover the potential yield loss. More specifically, Slaton et al. (2020) found there to be a window of opportunity in relation to the R1 growth stage, or first flower, for restoration of yield potential assuming adequate soil moisture for plant uptake of K. When soil test K levels are "very low" or visible potash deficiencies are observed, maximum soybean yield can be recovered up to 20 days after the R1 growth stage with a timely potash fertilizer application that is incorporated via irrigation or rainfall. When soil test K levels are "low to medium" or plants are experiencing hidden hunger (yield loss with no visual K deficiency symptoms present), maximum soybean yield can be recovered up to 45 days after the R1 growth stage with a timely potash fertilizer application that is incorporated into the soil. The yield response of K-deficient soybean to potash fertilization diminishes as fertilization is delayed beyond these critical periods. While proper soil testing and preplant fertilization is the best way to avoid in-season deficiencies, once diagnosed, these deficiencies can be corrected to produce a maximal to near-maximal yield when managed properly. This research aims to determine the fertilizer rate needed to correct in-season K deficiencies during reproductive growth stages and maximize soybean yield potential.

Procedures

Field trials were conducted in 2021 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station near Marianna, Ark., on Convent silt loam soil. One composite soil sample consisting of an average of 8 subsamples was taken from each replicate just prior to planting from the 0- to 4-in depth. The soil was oven-dried, ground, and mixed prior to analysis for pH (1:2 v/v soil/water mixture) and Mehlich-3 extractable nutrients (Helmke and Sparks, 1996). Experiments were designed as a randomized complete block design with 4 replications of each treatment.

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Individual plots were 12.6-ft wide and 30-ft long with 38-in. row spacings. One treatment of 160 lb K_2O/ac was applied as muriate of potash (0-0-60) at preplant and incorporated. All other treatments were applied in-season at either 15, 30, or 45 days after R1 (DAR1) at rates of 0, 40, 80, 120, and 160 lb K_2O/ac as muriate of potash following no preplant K fertilizer. These in-season applications were broadcasted across the plot, and the field was irrigated within 24 hours. Forty lb P_2O_5/ac was applied and incorporated prior to planting to ensure that P was not limiting. The Delta Grow 47E80 (Delta Grow Seed Co., England, Ark.) variety was planted at a seeding rate of approximately 130,000 seed/ac on 17 June 2021. General crop management and furrow irrigation followed the current University of Arkansas System Division of Agriculture's Cooperative Extension Service's production recommendations for stand establishment and pest control in soybean (Ross, 2000).

At each scheduled in-season fertilizer application time, a composite sample of 12 trifoliolate leaves was taken from the uppermost fully expanded trifoliate leaves within the middle 2 rows of each plot scheduled to receive treatment at that specific time (i.e., 15 DAR1). A sample was also taken from the untreated control and the preplant treatment of 160 lb K_2O/ac. The leaves were dried, ground, and digested with concentrated HNO_3 and 30% H_2O_2 (Jones and Case, 1990) and analyzed by ICP-AES to determine K concentration. At maturity, the middle 2 rows were harvested, and the seed yields were adjusted to 13% moisture for statistical analysis. Relative grain yield was calculated by comparing the measured yield from each replicate to the highest yielding treatment average and correlated to the trifoliolate-K concentrations measured at 15, 30, and 45 DAR1 using Pearson's correlation coefficient. The relative grain yield was also analyzed by K fertilizer application rate applied at 15, 30, and 45 DAR1 as a randomized complete block design using a mixed effect model. Means separation was conducted using Tukey's honestly significant difference test. All analysis was completed in R version 4.0.2 (R Core Team, 2021) using packages tidyverse (Wickham et al., 2019), ggpubr (Kassambara, 2020), lmerTest (Kuznetsova et al., 2017), and emmeans (Lenth, 2022) and yield responses were interpreted as significant at $P < 0.05$.

Results and Discussion

A strong correlation between trifoliolate leaf-K concentration and relative grain yield was confirmed at all three sampling times with correlation coefficients of 0.96, 0.95, and 0.97 at 15, 30, and 45 DAR1, respectively. A positive correlation confirms that a soybean relative grain yield increase was observed as the trifoliolate leaf-K concentration increased for each sampling time. These correlations can also be used to predict the expected yield loss at any level of trifoliolate leaf-K without an in-season corrective fertilizer-K application. Quantifying the degree of K deficiency experienced is required to calibrate a rate recommendation. The rate will change with varying degrees of deficiency and the crop development or growth stage when the deficiency is identified.

At 15 DAR1, the average trifoliolate-K concentration measured 1.34% K, which confirms the crop would be deficient in K compared to the critical concentration of 1.89% and 1.34% K to achieve 95% and 85% relative grain yield, respectively (Slaton et al., 2021). Therefore, crop yield is expected to be limited to approximately 85% relative grain yield at 15 DAR1 according to the critical concentration without a corrective application of fertilizer-K. At 30 DAR1, the average trifoliolate-K concentration was 1.09% K compared to the critical K concentrations of 1.72%, 1.23%, and 0.91% K for 95%, 85%, and 75% relative grain yield goals, respectively (Slaton et al., 2021). Therefore, the expected yield at 30 DAR1, if no corrective application of fertilizer-K is applied, would fall between 75% and 85% relative grain yield. At 45 DAR1, the average trifoliolate-K concentration was 0.70% K. When compared to the critical concentrations of 1.47%, 1.05%, and 0.77% K for 95%, 85%, and 75% relative grain yield goals, respectively, it is apparent that as much as 25% yield loss would be occurring. The field was consistently deficient and would be expected to respond positively to a fertilizer-K application considering the dynamic critical concentrations. However, no visual deficiency symptoms were apparent in the field at any time during the growing season, confirming the deficiency was hidden hunger. The tissue-K results, which indicated a large yield loss would occur (>25%) coupled with the lack of visual K deficiency symptoms, are concerning and suggests that more soybean fields in Arkansas may be suffering from hidden hunger and yield loss than previously thought.

Across all application times, the treatments which received no fertilizer-K yielded numerically lowest, while the preplant application yielded numerically higher than all in-season corrective applications (Table 1). For example, where no fertilizer-K was applied for the duration of the season, the relative grain yield was 79.6% compared to the highest-yielding treatment of 52.8 bu./ac, which received 160 lb K_2O/ac applied at preplant. This yield reduction indicates that as much as 20% of soybean yield could be lost without fertilization. However, the degree of yield difference between the preplant treatment and all others differed among application times. Therefore, the suggested fertilizer-K rate recommendation was determined as the lowest fertilizer-K rate, which reached maximal yield at each application time of 15 ($P < 0.0001$), 30 ($P < 0.0001$), and 45 ($P < 0.0001$) DAR1 treatments, each run as a separate mixed effect model and considered independently.

At 15 DAR1, all in-season applications yielded significantly higher than the untreated control (Table 1). When considering the preplant application of 160 lb K_2O/ac to be the maximal yield goal, or 98% relative grain yield, the in-season applications of 40, 80, 120, and 160 lb K_2O/ac at 15 DAR1, which yielded similarly, confirm the ability to correct the deficiency and reach 88%, 96%, 91%, and 93% relative grain yield, respectively (Table 1). The lowest rate which reached the 95% relative grain yield goal at 15 DAR1 was

80 lb K_2O/ac and is the K rate recommendation that will be included when creating a calibration curve. These results are both agronomically and economically promising. The ability to achieve 96% relative grain yield with an in-season application of 80 lb K_2O/ac on a very low soil test K soil with no preplant fertilizer-K was previously unthinkable.

Later in-season fertilizer-K applications at 30 DAR1 resulted in reduced yield response as the crop progressed, even with the increasing level of deficiency measured in the trifoliolate leaves (Table 1). At 30 DAR1, none of the in-season applications resulted in a significant yield increase compared to the untreated control (Table 1). However, a numerical yield increase was measured across all in-season application rates at 30 DAR1, ranging from a 6.3% to an 8.4% increase in relative grain yield (Table 1). Additionally, none of the fertilizer-K rates applied at 30 DAR1 reached the calibration curve's 95% relative grain yield goal. Therefore, the results indicate that 30 DAR1 was too late in the season to expect a full yield response. This loss agrees with Slaton et al. (2020) findings for very low soil test K fields, with permanent yield loss expected beyond 20 DAR1 if a severe deficiency remains uncorrected.

Similarly, at 45 DAR1, none of the in-season applications resulted in a significant yield response compared to the untreated control (Table 1). The highest yielding fertilizer-K rate applied at 45 DAR1 was 160 lb K_2O /ac and only reached 82% relative grain yield. No in-season treatment at 45 DAR1 reached the 95% relative grain yield goal for the calibration curve, and therefore no rate can be calibrated to correct a severe deficiency at this time. These results confirm that any severe deficiency found in fields in the very low soil test K category where no preplant K was applied can reach a point where an in-season application is no longer beneficial or profitable. Severely deficient fields (>15%) anticipated yield loss and remain uncorrected beyond 20 DAR1 will exhibit a diminishing yield response to fertilizer-K as the crop matures. These results indicate that early diagnosis of hidden hunger or confirmation of K deficiency is necessary to achieve a maximal or near-maximal yield response (Slaton et al., 2020).

Practical Applications

Using a recently developed dynamic critical concentration curve (Slaton et al., 2021), in-season deficiencies can be accurately diagnosed during the reproductive growth stages. However, once a deficiency is confirmed, it remains unclear how much fertilizer-K is needed to recover lost yield potential and reach maximal yield. The preliminary results of this trial indicate an in-season application rate of 80 lb K_2O/ac may be needed and applied early in the reproductive stages (15 DAR1) to a deficient soybean crop (1.34% trifoliolate K) to recover maximal yield potential. However, timely applications are critical to achieving significant yield responses, and the likelihood of these significant yield responses decreases with increased DAR1. Continued research will include various levels of soil test K to manipulate a wide range of trifoliolate leaf-K concentrations and, ultimately, crop deficiency levels. These various levels of deficiency will contribute to a more robust calibration curve that can provide rate recommendations for soybean at any level of deficiency, from severe to sufficient.

Acknowledgments

Sincere appreciation is extended to the Agricultural Experiment Station staff for their continued help and cooperation, without which this project could not have happened. The authors would also like to thank the Soybean Checkoff Program administered by the Arkansas Soybean Promotion Board for their funding of this research and the University of Arkansas System Division of Agriculture.

Literature Cited

Helmke, P.A. and D.L. Sparks. 1996. Lithium, sodium, potassium, rubidium, and cesium. p. 551–574. In D.L. Sparks (ed.) Methods of soil analysis. Part 3. SSSA Book Ser. 5. SSSA, Madison, WI.

Jones, J. B. and V.W. Case. 1990. Sampling, handling, and analyzing plant tissue samples. In R. L. Westerman (Ed.), Soil testing and plant analysis. 3rd ed., pp. 389–428. SSSA.

Kassambara, A 2020. ggpubr: 'ggplot2' Based Publication Ready Plots. R package version 0.4.0. Accessed 4 May 2022. Available at: https://CRAN.R-project.org/package=ggpubr

Kuznetsova A., P.B. Brockhoff, and R.H.B. Christensen. 2017. "lmerTest Package: Tests in Linear Mixed Effects Models." J. Stat. Software, 82(13), 1-26. Accessed 4 May 2022. Available at: https://doi.org/10.18637/jss.v082.i13

Lenth, R.V. 2022. emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.7.3. Accessed 4 May 2022. Available at: https://CRAN.R-project.org/package=emmeans

Ross, W.J., 2000. Soybean Production Handbook. University of Arkansas System Division of Agriculture, MP 197. Accessed 4 May 2022. Available at: https://www.uaex.uada.edu/publications/mp-197.aspx

Slaton, N.A., Roberts, T.L., and R. Parvej. 2021. Dynamic critical potassium concentrations in soybean leaves and petioles for monitoring potassium nutrition. Agron. J., Accessed 4 May 2022. Available at: https://doi.org/10.1002/agj2.20819

Slaton, N.A., T.L. Roberts, W.J. Ross, and T.L. Richmond. 2020. Irrigated soybean response to granular fertilizer potassium application timing. Agron. J., Accessed 4 May 2022. Available at: https://doi.org/10.1002/agj2.20342

Wickham, H., M. Averick, J. Bryan, W. Chang, L. D. McGowan, R. François, G. Grolemund, A. Hayes, L. Henry, J. Hester, M. Kuhn, T.L. Pedersen, E. Miller, S.M. Bache, K. Müller, J. Ooms, D. Robinson, D.P. Seidel, V. Spinu, K. Takahashi, D. Vaughan, C. Wilke, K. Woo, and H. Yutani. 2019. Welcome to the tidyverse. J. Open Source Software, 4(43), 1686. Accessed 4 May 2022. Available at: https://doi.org/10.21105/joss.01686

Table 1. The effect of fertilizer-K rates on relative grain yield (%) across application time in days after first flower (DAR1). The high preplant rate represents the maximum relative grain yield achieved when following traditional soil test recommendations. Each in-season application time was compared to the preplant treatment but not to other in-season application times.

Treatment time	Fertilizer-K Rate	15 DAR1	30 DAR1	45 DAR1
		-------------------% relative yield--------------------		
Preplant [†]	160 lb K_2O ac	98.5 a [‡]	98.5 a	98.5 a
Preplant and In-season [§]	0 lb K_2O ac	79.6 b	79.6 b	79.6 b
In-season	40 lb K_2O ac	88.2 ab	86.9 ab	77.2 b
In-season	80 lb K_2O ac	96.9 a	86.4 ab	77.3 b
In-season	120 lb K_2O ac	92.4 a	88.0 ab	79.3 b
In-season	160 lb K_2O ac	94.6 a	85.9 b	82.7 b

[†] The preplant treatment of 160 lb K_2O/ac yielded an average of 48.6 bu./ac.

[‡] Means followed by the same letter are not statistically significant at $P = 0.05$.

[§] The untreated control yielded an average of 38.6 bu./ac.

APPENDIX

2021-2022 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	3 of 3	35,000
T. Butts		A Team Approach to Weed Management	3 of 3	233,162
M. Daniels		The Arkansas Discovery Farm Program	1 of 3	23,071
B. Deaton		Economic Analysis of Soybean Production and Marketing Practices	1 of 3	7,113
J. Edwards		Breeding New and Improved Soybean Cultivars with High Yield and Local Adaptation	3 of 3	199,724
J. Edwards		Fast Tracking MG4 and Early MG5 Cultivars with Southern Root Knot Nematode Resistance	2 of 3	50,324
J. Edwards		Soybean Germplasm Enhancement Using Genetic Diversity	3 of 3	175,191
J. Edwards		Utilization of Winter Nursery for Soybean Line Development through Back-crossing	1 of 3	39,409
T. Faske	T. Spurlock and K. Korth	Comprehensive Disease Screening of Soybean Varieties in Arkansas	2 of 3	128,000
T. Faske	A. Rojas	Integrated Management of Soybean Nematodes in Arkansas	3 of 3	67,670
T. Faske	A. Rojas	Monitoring and Management of Fungicide-Resistant Soybean Diseases in Arkansas	1 of 3	48,424
C. Henry		Promoting Irrigation Water Management for Soybeans	3 of 3	148,500
C. Henry		The Arkansas Irrigation Yield Contest (Year 5)	Year 5	10,000
B. Kegley		The Effect of Soybean Products in Ruminant Diets on Inflammatory Response, Health, Growth, and Economics	1 of 3	50,120
M. Kidd		Assessment of Broiler Dietary Least Cost Protein Supply Via Soybean Genotype Amino Acid Selection	1 of 3	46,023
J. Norsworthy		Screening for Soybean Tolerance to Metribuzin	1 of 3	14,535
A. Poncet	L. Espinoza and C. Henry	Monitoring Water Stress to Improve Irrigation Scheduling in Furrow-Irrigated Fields	2 of 3	64,000
T. Roberts		Fertilization of Soybean	3 of 3	68,239
T. Roberts		Influence of Cover Crops and Soil Health on Soybean	3 of 3	61,816

Continued

2020-2021 Soybean Research Proposals, continued.

Principal Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
T. Roberts	J. Ross and J. Carlin	Field-based Determination of Chloride Tolerance in Soybean	3 of 3	47,495
J. Robinson		Arkansas Future Ag Leaders Tour	1 of 3	5,000
J. Robinson		Soybean Science Challenge	3 of 3	90,773
J. Ross		Arkansas Soybean College	1 of 3	15,042
J. Ross		Improving Technology Transfer for Profitable and Sustainable Soybean Production	3 of 3	49,419
J. Ross	B. Thrash	Investigating Emerging Production Recommendations for Sustainable Soybean Production	3 of 3	247,950
J. Ross		Soybean Research Verification Program	3 of 3	199,087
J. Ross	A. Poncet, and Greenway Equipment	On Farm Variable Soybean Seeding Rate Study	2 of 3	74,911
T. Spurlock	N. Bateman and A. Rojas	Determining Factors Associated with Poor Grain Quality in Soybean and Management Options	1 of 3	67,000
T. Spurlock	A. Rojas	Understanding Taproot Decline; A Soybean Disease of Increasing Importance in Arkansas	3 of 3	37,000
T. Spurlock		Determining the Value of Fungicide Applications on Regional, Whole-Farm, Field Level, and Within-Field Scales	1 of 3	32,800
B. Thrash		Refining Insect Thresholds in Arkansas Soybean	1 of 3	70,701
B. Thrash		Impact of Water Quality on Insects	2 of 3	20,000
B. Watkins		Soybean Enterprise Budgets	3 of 3	10,000
			Total:	**2,437,499**

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