Arkansas Soybean Research Studies 2022

Jeremy Ross, Editor

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Cover photo: Potassium response trials in 2023 at the Northeast Rice Research and Extension Center outside of Jonesboro, Arkansas. Depicted is severe potassium deficiency in R4 soybeans, seen as marginal chlorosis of the leaves in the upper and middle canopy. This is a result of the very low potassium soils and dry weather experienced in July. (U of A System Division of Agriculture photo by Carrie Ortel).

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

Arkansas Agricultural Experiment Station (AAES), University of Arkansas System Division of Agriculture, Fayetteville. Deacue Fields, Vice President for Agriculture; Jean-François Meullenet, AAES Director and Senior Associate Vice-President for Agriculture–Research. WWW/CC2023.

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Preface

The 2022 Arkansas Soybean Research Studies includes research reports on topics pertaining to soybean across several disciplines from breeding to post-harvest processing. Research reports contained in this publication may represent preliminary or only data from a single year or limited results; therefore, these results should not be used as a basis for long-term recommendations.

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

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

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

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

Acknowledgments

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The Arkansas Soybean Promotion Board

Introduction

Arkansas is the leading soybean-producing state in the mid-southern United States. Arkansas ranked 11th in soybean production in 2022 when compared to the other soybean-producing states in the U.S. The state represented 3.04% of the total U.S. soybean production and 3.64% of the total acres planted in soybean in 2022. The 2022 state soybean average yield was 52.0 bushels per acre, tying the previous state yield record of 52 bushels per acre set in 2021. The top five soybean-producing counties in 2022 were Mississippi, Crittenden, Phillips, Poinsett, and Arkansas (Table 1). These five counties accounted for over 35.7% of the soybean production in Arkansas in 2022.

Weather events during the early portion of the 2022 growing season were wetter compared to those during 2021. Frequent rain events hampered preplant tillage and delayed planting for some portions of the state. Soybean planting during 2022 was delayed compared to the previous year and behind the 5-year average for planting progress until mid-March. Weather conditions improved by mid-March, and planting progress met and surpassed the 5-year average for planting progress for the remainder of the planting season. According to the 5 June 2022 USDA-NASS Arkansas Crop Progress and Condition Report (USDA-NASS, 2022), 86% of the soybean acreage had been planted as of the first of June compared to 85% and 79% for the 2021 and the 5-year average planting progress, respectively. With higher commodity prices, Arkansas soybean producers planted 3.18 million acres in 2022. This was an increase in acreage compared to 2021, and back to over 3 million acre planted for the last two years. The most significant event to occur in Arkansas during the 2022 growing season was the abnormally hot and dry conditions during June and July.

Overall, disease and insect issues were at typical levels in 2022. The exception was in the southern part of the state where Redbanded stinkbug were detected in fields earlier than in past few years and their numbers remained high throughout harvest. 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 2022 growing season was the sixth year where the use of dicamba was labeled for over-the-top applications on dicamba-tolerant soybean. Even with restriction on applications, complaints were filed with the Arkansas State Plant Board for non-dicamba soybean fields showing dicamba symptomology.

Table 1. Arkansas soybean acreage, yield, and production by county, 2021–2022.[a]

	Acres Planted		Acres Harvested		Yield		Production	
	2021	2022	2021	2022	2021	2022	2021	2022
County	------------acres----------		-----------acres-----------		----bu./ac----		----------------bu.---------------	
Arkansas	168,500	171,500	167,400	171,000	59.4	56.0	9,948,000	9,576,000
Ashley	45,800	52,800	45,400	52,600	63.7	59.7	2,892,000	3,140,000
Benton	600	*	600	*	41.2	*	24,700	*
Chicot	164,000	171,000	163,000	170,800	55.2	54.1	8,997,000	9,240,000
Clay	105,000	112,500	104,400	111,800	44.0	54.7	4,590,000	6,110,000
Conway	14,600	16,300	14,500	15,900	32.9	31.8	477,000	506,000
Craighead	*	96,800	*	95,600	*	46.5	*	4,445,000
Crittenden	212,500	218,500	211,500	217,500	52.3	53.2	11,056,000	11,571,000
Cross	152,000	162,500	151,200	162,000	53.3	51.9	8,059,000	8,408,000
Desha	162,000	158,500	152,600	158,100	52.1	58.8	7,956,000	9,296,000
Drew	28,300	29,300	27,600	29,200	58.6	61.9	1,618,000	1,807,000
Faulkner	7,400	6,900	7,340	6,620	33.2	39.9	244,000	264,000
Greene	*	74,200	*	73,400	*	52.0	*	3,817,000
Independence	*	23,700	*	22,700	*	42.9	*	974,000
Jackson	106,000	111,000	105,100	109,000	46.8	38.4	4,919,000	4,181,000
Jefferson	94,300	106,000	91,100	105,400	57.0	57.6	5,195,000	6,071,000
Lawrence	*	67,400	*	65,900	*	48.7	*	3,209,000
Lee	110,500	132,500	109,500	131,700	53.5	57.7	5,853,000	7,599,000
Lincoln	65,200	65,300	64,700	65,100	53.2	60.8	3,443,000	3,958,000
Little River	*	12,900	*	10,500	*	31.2	*	328,000
Logan	5,700	*	5,550	*	35.3	*	196,000	*
Lonoke	92,300	89,200	91,400	88,500	47.5	49.6	4,342,000	4,390,000
Mississippi	*	279,000	*	278,000	*	59.4	*	16,505,000
Monroe	83,200	90,300	81,500	89,700	45.1	44.2	3,675,000	3,966,000
Phillips	197,000	202,000	194,500	201,000	58.8	55.4	11,427,000	11,135,000
Poinsett	185,500	197,500	183,800	197,000	54.2	49.2	9,962,000	9,692,000
Pope	*	8,100	*	8,080	*	43.8	*	354,000
Prairie	102,000	100,500	101,100	99,800	55.5	50.6	5,611,000	5,050,000
Pulaski	17,900	18,700	16,300	17,200	38.8	35.4	633,000	609,000
Saint Francis	139,500	148,500	138,400	147,900	51.9	52.0	7,183,000	7,691,000
White	32,000	31,200	31,800	30,400	45.8	36.4	1,456,000	1,107,000
Woodruff	117,000	122,000	116,000	119,300	48.4	40.1	5,614,000	4,784,000
Yell	6,700	7,000	6,570	6,680	38.2	34.4	251,000	230,000
Other Counties	624,500	96,400	617,140	91,620	49.2	41.3	30,378,300	3,787,000
State Totals	3,040,000	3,180,000	3,000,000	3,140,000	52.0	52.0	156,000,000	163,280,000

[a] Data obtained from USDA-NASS, 2023.

* Included in "Other Counties."

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2022 Soybean Research Verification Program

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Abstract

The 2022 Soybean Research Verification Program (SRVP) was conducted on 17 commercial soybean fields across the state. Counties participating in the program included Arkansas, Ashley, Chicot, Conway, Desha, Drew, Greene, Independence, Lawrence, Lee, Lonoke, Mississippi, Monroe, Poinsett, St. Francis, White, and Woodruff for a total of 1,079 acres. Grain yield in the 2022 SRVP averaged 65.5 bu./ac, ranging from 37.3 to 88.0 bu./ac. The 2022 SRVP average yield was 13.5 bu./ac, greater than the estimated Arkansas state average of 52 bu./ac. The highest-yielding field was in Desha County, with a grain yield of 88 bu./ac. The lowest yielding field was in Independence County and produced 37.3 bu./ac.

Introduction

In 1983, the University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) established an interdisciplinary soybean educational program that stresses management intensity and integrated pest management to maximize net returns. The purpose of the Soybean Research Verification Program (SRVP) is to verify the profitability of the University of Arkansas System Division of Agriculture's 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 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 695 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 is mainly attributed to intensive cultural and integrated pest management.

Procedures

The SRVP fields and cooperators are selected prior to the beginning of the growing season. Cooperators agree to pay production expenses, provide expense data, and implement CES production recommendations in a timely manner, from planting to harvest. A designated County Extension Agent 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 of CES specialists and Division of Agriculture researchers with soybean responsibility assists with decision-making, recommendation development, and program direction. Field inspections by committee members are utilized to assist in fine-tuning recommendations.

In 2022, the following counties participated in the SRVP: Arkansas, Ashley, Chicot, Conway, Desha, Drew, Greene, Independence, Lawrence, Lee, Lonoke, Mississippi, Monroe, Poinsett, St. Francis, White, and Woodruff. The 17 SRVP fields totaled 1,079 acres. Five Roundup Ready 2 Xtend® varieties (Armor 46-D09, Asgrow AG43X0, Asgrow AG46X6, Dyna-Gro 48XY56, and Pioneer P48A60X.), 8 Roundup Ready 2 XtendFlex® varieties (Asgrow AG48XF2, Becks 4443XF, Becks 4885XF, Becks 5005XF, Mission 4690XF, Northrup King NK42T5XF, Northrup King NK48-H3XFS and Progeny 4604XF), and 3 Enlist E3® varieties (Delta Grow DG47E20, Local Seed ZS4691E3S and Progeny P4775E3S), were planted. Cooperative Extension Service 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 stand density, weed populations, disease infestation levels, insect populations, rainfall amounts, irrigation amounts, and dates for specific growth stages (Tables 1 and 2).

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Results and Discussion

Yield

The average 2022 SRVP grain yield was 65.5 bu./ac, ranging from 37.3 to 88.0 bu./ac (Table 2). The SRVP average yield was 13.5 bu./ac higher than the estimated 2022 state average yield of 52 bu./ac (USDA, 2023). 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, 88.0 bu./ac, was planted with Asgrow AG48XF2 in Desha County.

Planting and Emer7gence

Planting was initiated in Ashley County on 10 April and concluded on 15 June in Woodruff County, with an average planting date of 8 May. The average seeding rate across all SRVP fields was 138,000 seeds/ac, ranging from 120,000 to 155,000 seeds/ac. The average emergence date was 16 May, beginning 18 April and continuing to 20 June. On average, across all SRVP fields, 8 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 and 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 enrolled in the University of Arkansas Irrigation Scheduler Program or used moisture sensors to determine irrigation timing based on soil moisture deficit. All irrigated fields utilized computerized hole selection programs such as PHAUCET or Pipeplanner to maximize irrigation efficiency. Fifteen of the 17 SRVP fields were furrow irrigated, 1 was pivot irrigated, and 1 was non-irrigated.

Practical Applications

Data from the 2022 SRVP reflected higher soybean yields and maintained above-average returns in the 2022 growing season. Analysis of this data showed that the average yield was higher in the SRVP than the state average, and the cost of production was equal to or less than the CES estimated soybean production budgeted costs (Watkins, 2022).

Acknowledgments

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

Literature Cited

Watkins, B. 2022. University of Arkansas System Division of Agriculture Cooperative Extension Service Enterprise Crop Budgets. Accessed: 27 February 2023. 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: 27 February 2022. Available at www.nass.usda.gov/AgCensus

Table 1. Agronomic Information for 2022 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 P48A60X	44	Corn	FSI	126K	115K
Ashley	Asgrow AG43X0	79	Corn	ESI	140K	116K
Chicot	Asgrow AG46X6	80	Soybean	FSI	140K	113K
Conway	Local Seed ZS4694ES3	69	Soybean	FSI	160K	102K
Desha	Asgrow AG48XF2	25	Corn	FSI	132K	121K
Drew	Armor 46D-09	100	Corn	FSI	155K	138K
Greene	NK48-H3XFS	75	Corn	FSI	140K	88K
Independence	NK S46E3S	55	Soybean	FSNI	140K	117K
Lawrence	Becks 4443XF	40	Rice	LSI	150K	102K
Lee	Mission 4690XF	36	Corn	FSI	140K	119K
Lonoke	Asgrow AG46X6	75	Corn	FSI	140K	120K
Mississippi	Becks 5005XF	32	Soybean	FSI	148K	101K
Monroe	Progeny 4604XF	60	Corn	FSI	125K	95K
Poinsett	Becks 4885XF	74	Corn	FSI	120K	116K
St. Francis	Dyna-Gro 48XT56	90	Corn	FSI	130K	87K
White	NK 42T5XF	60	Rice	FSI	120K	93K
Woodruff	Armor 47E03	85	Rice	LSI	140K	133K
Average		**63.5**			**138K**	**110K**

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

[b] Production Systems; ESI = Early-season Irrigated; FSI = Full-season Irrigated; FSNI = Full=season Non-irrigated; LSI = Late-season Irrigated.

Table 2. Planting, Emergence, and Harvest Dates and Adjusted Soybean Grain Yield for 2022 Soybean Research Verification Program Fields.

County	Planting date	Emergence date	Harvest date	Yield adj. to 13% moisture[a]
				(bu./ac)
Arkansas	4/30	5/8	9/27	85.9
Ashley	4/10	4/18	9/27	60.2
Chicot	4/27	5/4	10/1	72.4
Conway	5/11	5/17	10/4	53.3
Desha	4/28	5/7	9/19	88
Drew	4/23	5/1	9/16	75.7
Greene	5/16	5/26	10/19	64.6
Independence	4/28	5/8	10/6	37.3
Lawrence	6/7	6/14	10/20	51.8
Lee	4/30	5/8	9/27	68.8
Lonoke	5/13	5/19	10/5	68.1
Mississippi	5/18	5/26	10/27	57.8
Monroe	4/29	5/7	10/9	68.8
Poinsett	5/12	5/18	9/30	67.3
St. Francis	5/17	5/23	10/13	74.5
White	5/15	5/23	9/30	69.5
Woodruff	6/15	6/20	10/14	49.2
Average	**5/8**	**5/16**	**10/4**	**65.5**

[a] 2022 Arkansas state soybean average yield was 52.0 bu./ac (USDA, 2023).

Table 3. Soil Test Results, Fertilizer Applied and Soil Classification for 2022 Soybean Research Verification Fields.

County	Soil Test Results			Pre-plant applied	
	pH	P	K	fertilizer N-P-K	Soil Classification
		-------ppm-------		lb/ac	
Arkansas	5.7	15	80	0-64-140	Ethel, Dewitt silt loam
Ashley	6.1	42	58	0-0-160	Henry, Calhoun silt loam
Chicot	7.2	34	92	0-30-90	Sharkey clay
Conway	6.0	46	138	0-0-0	Gallion silt loam
Desha	6.9	87	188	0-0-60	McGehee, Rilla silt loam, Portland clay
Drew	6.3	43	234	0-0-0	Portland clay, Rilla, Herbert silt loam
Greene	6.1	27	95	0-0-60	Hillemann silt loam
Independence	7.7	26	110	0-0-0	Sturkie silt loam and Wideman loamy fine sand
Lawrence	7.6	8	240	0-40-0	Jackport silty clay
Lee	6.3	37	137	0-0-90	Marvell fine sandy loam, Henry silt loam
Lonoke	6.0	34	30	0-50-120	Calhoun, Calloway silt loam
Mississippi	6.2	79	157	0-0-0	Dundee silt loam
Monroe	6.8	23	116	0-23-90	Foley-Calhoun-Bonn complex,
Poinsett	6.8	46	110	0-0-70	Mhoon silt loam
St. Francis	7.2	15	124	2 ton poultry litter	Calloway and Henry silt loam
White	6.5	57	55	0-0-100	Calhoun silt loam
Woodruff	6.3	18	129	0-0-60	Dundee and Amagon silt loam

Table 4. Herbicide Rates and Timing for 2022 Soybean Research Verification Program Fields.

	Herbicide (rates/ac)	
County	**Burndown/Pre-emergence**	**Post-emergence**
Arkansas	Burndown; 1 qt Cornerstone® Pre-emerge; 1 pt Mocassin® + 6 oz Metribuzin	1st; 40 oz Cornerstone + 1 pt Mocassin 2nd; 30 oz Mad Dog® 5.4 Harvest aid; 1 pt paraquat + 1% NIS
Ashley	Burndown; 25.6 oz RoundUp PowerMax® + 1 pt 2,4-D Pre-emerge; 1 pt Charger Basic®	1st; 22 oz RoundUp PowerMax + 3.25 oz Zidua SC 2nd; 12.8 oz Engenia® 3rd; 22 oz RoundUp PowerMax 4th; 12.8 oz Engenia
Chicot	Burndown; 26 oz RoundUp PowerMax + 1 qt 2,4-D Pre-emerge; 3.2 oz Anthem Max® + 25.6 oz Roundup PowerMax + 1 pt Select®	1st; 22 oz XtendiMax® 2nd; 1 qt Cornerstone + 1 pt Charger Basic Harvest aid; 1 pt paraquat
Conway	Pre-emerge; 40 oz paraquat +.33 lb metribuzin + 2 oz Valor®	22 oz Roundup PowerMax + 2 pt Enlist One + 3.25 oz Anthem Maxx®
Desha	Burndown; 22 oz RoundUp PowerMax + 1.5 pt 2,4-D Pre-emerge; 1 pt paraquat + 1 qt Boundary®	1 qt Prefix + 1 qt Cornerstone
Drew	Pre-emerge; 1 pt paraquat + 1 pt Charger Basic + 8 oz metribuzin	56.5 oz Tavium®
Greene	Burndown; 1 qt glyphosate	1st; 36 oz Liberty® + 1.25 pt *S*-metolachlor 2nd; 32 oz Liberty + 1 qt glyphosate 3rd; 1 qt glyphosate
Independence	Pre-emerge; 2 oz Valor®	2 pt Enlist One®
Lawrence	Pre-emerge; 1 qt glyphosate + 1.25 pt *S*-metolachlor	1st; 1 qt glyphosate 2nd, 1 qt glyphosate 3rd; 8 oz clethodim
Lee	Burndown; 1 qt Cornerstone + 8 oz dicamba + 1 oz First Shot® Pre-emerge; 8 oz Trivence®	36 oz Liberty + 22 oz RoundUp PowerMax + 12.8 oz Outlook®
Lonoke	Pre-emerge; 1 pt Dual Magnum II	1 qt Cornerstone + 3.25 oz Zidua® SC
Mississippi		1st; 22 oz XtendiMax 2nd; 1 qt glyphosate
Monroe	Burndown; 22 oz RoundUp PowerMax + 8 oz dicamba + 1 oz First Shot Pre-emerge; 24 oz Devour + 3.2 oz Zidua SC + 8 oz Derive®	36 oz Liberty + 1.2 pt Charger Basic
Poinsett	Pre-emerge; 21 oz Gramoxone + 3 oz Fierce®	1st; 1 qt glyphosate + 12 oz Outlook 2nd; 1 qt Liberty
St. Francis	Pre-emerge; 40 oz paraquat + 3 oz Fierce	1st: 22 oz XtendiMax 2nd; 1 qt glyphosate
White		1st; 22 oz Roundup Powermax + 1 qt Liberty + 1pt *S*-metolachlor 2nd; 22 oz Roundup Powermax
Woodruff	Pre-emerge; 1.25 pt *S*-metolachlor	1 qt glyphosate + 2 pt Enlist One + 1 pt *S*-metolachlor

Table 5. Fungicide and Insecticide Applications for 2022 Soybean Research Verification Program Fields.

County	Aerial Web Blight	Frogeye Leaf Spot	Bollworms/Defoliators	Stink Bugs
Arkansas	--	--	--	--
Ashley	--	--	--	5.12 oz/ac Tundra® + 0.5 lb/ac acephate
Chicot	--	--	--	5.12 oz/ac Brigade® + 0.5 lb/ac acephate
Conway	--	--	--	--
Desha	--	--	--	--
Drew	--	--	--	--
Greene	--	--	--	--
Independence	--	--	--	--
Lawrence	--	--	--	--
Lee	--	--	5 oz/ac Intrepid Edge®	5.12 oz/ac bifenthrin
Lonoke	--	--	--	--
Mississippi	--	--	--	--
Monroe	--	--	--	--
Poinsett	--	--	--	--
St. Francis	--	--	--	--
White	--	--	4 oz/ac Intrepid Edge	3.2 oz/acre Lambda Cyhalothrin
Woodruff	--	--	1.2 oz/ac Vantacor	--

Classification of Soybean Chloride Sensitivity Using Leaf Chloride Concentration of Field-Grown Soybean: 2022 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 plant population with multiple genes that influence Cl uptake. A field-based Cl monitoring program has been developed 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 158 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 Vegetable Research Station location of the 2022 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 39, 24, 40, 39, and 20 varieties, respectively. The detailed rating system provides producers with more information regarding the relative Cl tolerance of available soybean varieties.

Introduction

Historically, soybean [*Glycine max* (L.) Merr.] varieties have been categorized as chloride (Cl) includers, excluders, or a 'mixed' population. Cox (2017) showed that this 3-class categorization and the method of assigning the trait leads to inaccurate categorization of some varieties, and a more robust system is needed to describe accurately soybean tolerance to Cl. Abel (1969) concluded that a single gene-controlled the Cl inclusion attribute of soybean contributed to the over-simplification of the Cl trait rating. Zeng et al. (2017) recently suggested that multiple genes may control Cl uptake by soybean, adding complexity to an already poorly understood phenomenon. Research by Cox (2017) supports this hypothesis and highlights the varying levels of Cl inclusion and exclusion across a wide range of soybean varieties. Individual plants of some commercial varieties are mixed populations, with some plants being strong includers with high Cl concentrations, some being strong excluders with very low Cl concentrations, and some plants having intermediate Cl concentrations. The large range of Cl concentrations in individual plants suggests that there may be multiple genes that regulate Cl uptake. Traditional methods of assessing the Cl sensitivity of soybean varieties involve short greenhouse trials (completed before reproductive growth begins) with a limited number of plants (5–10), which limits the scope and applicability of the results. Our research objective was to examine 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 in the Arkansas Soybean Variety Performance trials were sampled at the University of Arkansas System Division of Agriculture's Vegetable Research Station (VRS) in 2022. The trial included late-3, early-4, late-4, and 5 maturity group categories ranging from 3.5 to 5.9. Soybean were planted on 31 May 2022 in a field having soil mapped as a Dardanelle silt loam following corn (*Zea mays* L.) in the rotation. Soybean was flat planted in rows spaced 36-in. apart, with each plot having 2 rows. Plots were irrigated via overhead sprinklers on a lateral move 10 times with approximately 0.75 in. application based on an irrigation scheduling program and managed using the University of Arkansas System Division of Agriculture's Cooperative Extension guidelines for irrigated soybean. Based on 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. Varieties were arranged as a randomized complete block design with 3 replications. Additional details of this trial and yield data are available from the variety testing website (https://aaes.uada.edu/variety-testing/). Varieties with known chloride tolerance (strong includer, strong excluder, and mixed) were included in each maturity group and herbicide grouping block to

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serve as a 'check' to provide a baseline response for relative comparison amongst varieties and locations within the field.

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 Liu (1998) outlined.

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

The mean leaflet-Cl concentrations ranged from 10 to 288 ppm Cl across the 158 varieties sampled (Tables 1–3). The standard deviation increased linearly as the mean Cl concentration increased, suggesting greater variability in variety Cl concentrations for mixed and includer varieties. The range and magnitude of Cl concentrations observed in this study during 2022 were lower than previous reports from samples collected at the University of Arkansas System Division of Agriculture's Rohwer Research Station (RRS). It was apparent that the Cl concentrations in the soil and water at the VSS were significantly lower than at the RRS, but the separation of cultivars was still completed. The late-3 and early-4 tests had the second most total varieties with 42 entries combined. Within this group, 11 varieties were identified as strong excluders in category 1 (Table 1). Half of the total varieties for this maturity group class (late-3 and early-4) were classified as a 3 or 4. These Cl classifications within the late 3 and early 4 categories are similar to the 2021 data that indicated a majority of the varieties in the late-3 and early-4 maturity group were shifting towards more of a "mixed" population rather than an includer (Roberts et al., 2021). However, the options for strong excluders available for producers who need Cl excluder varieties in the late-3 and early-4 maturity group range are increasing. 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 that had a rating of 3 or lower.

The late-4 varieties had the most overall entries, with 86 and mean Cl concentrations ranging from 10–142 ppm. Within this maturity group range, 23 varieties were identified as being strong excluders, which all fell within a range of Cl concentrations (Table 2; 10–43 ppm Cl). Fourteen varieties fell within ranking 2 as moderate excluders. Fourteen varieties fell within category 3 or mixed trait varieties. The moderate and strong includers were similar to the strong excluder category, with 37 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 various herbicide-tolerant traits and agronomic characteristics.

For the maturity group 5 class, there were a total of 32 entries, and the mean Cl concentration ranged from 66–196 ppm across this group of varieties. Within the late-4 class of varieties, a few varieties (5) were identified as strong excluders (Table 3), much lower than data reported in 2021 but similar to results from 2020 and previous seasons. The trend of fewer strong excluders in this category is concerning as this has historically been an issue with maturity group 5 varieties.

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 from year to year. The overall Cl concentrations presented in 2022 are much lower than the values reported for 2021, 2020, and 2019. The trial location in 2022 was at a different experiment station than in previous years. 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 various herbicide tolerance and agronomic characteristics. When a producer searches for a variety with specific traits and a high level of Cl tolerance, this new ranking system allows for more discernable differences in Cl tolerance amongst varieties traditionally 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 another 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 farming with irrigation water high in Cl concentration.

Acknowledgments

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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.

Cox, D.D. 2017. Characterization of the relationships between soybean yield, trifoliolate leaf chloride concentration, and cultivar chloride inclusion/exclusion rating. Masters 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. In: Y.P. Kalra, editor, Handbook of reference methods for plant analysis. CRC Press, Boca Raton, Fla. P. 111-113.

Roberts, T.L., A. Smartt, L. Martin, C. Scott, S. Williamson, J. Carlin, R.D. Bond, and R.B. Morgan. 2022. Classification of Soybean Chloride Sensitivity using Leaf Chloride Concentration of Field-Grown Soybean. *In*: J.R. Ross (ed.) Arkansas Soybean Research Studies 2021. Arkansas Agricultural Experiment Station Research Series 689. 25-30. Fayetteville.

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 Vegetable Research Station Soybean Variety Performance trial in 2022. A rating of 1 means a strong excluder and a rating of 5 means a strong includer.

Variety[a]	Mean	Rating[b]	Variety[a]	Mean	Rating[b]
	ppm			ppm	
Pioneer P44A21X	75	1	Progeny P4505RXS	139	3
Dyna S45ES10	84	1	Local LS4415XF	142	3
Pioneer P45A79E	96	1	Dyna S40XF21S	146	3
Pioneer P44A91E	99	1	Armor 44-D49	146	3
Dyna S43XS70	100	1	Innv. MEX44122XF	151	3
Pioneer P40A90LX	103	1	Pioneer P42A84E	158	3
Pioneer P40A36E	104	1	Integra 74383N	162	3
Osage (Check)	107	1	Axis 4112XFS	165	3
DG 44XF41	108	1	Progeny P4202XFS	182	4
NK45-P9XF	109	1	Progeny P4444RXS	183	4
DG 45E33	110	1	Integra 74142NS	186	4
Pioneer P45A40LX	118	2	NK44-J4XFS	197	4
Armor 45-F02	121	2	NK43-Y9XFS	198	4
Progeny P4431000	121	2	Progeny P4521XFS	202	4
NK43-V8XF	123	2	NK45-V9E3	210	4
DM45F23	125	2	R18C-11737	216	4
Eagle Seed 4.1	132	3	Dyna S45XF02	217	4
Local LS4526XF	135	3	NK44-Q5E3S	246	5
Dyna S41ES80	136	3	NK42-T5XF	259	5
R19C-1012	138	3	Progeny P4200RXS	283	5
AG45XF3	138	3	Axis 4522XF	288	5

[a] Abbreviation key: AG = Asgrow; DG = Delta Grow; DM = DONMARIO; Dyna = Dyna Gro; Innv. = Innvictis; R = University of Arkansas System Division of Agriculture.

[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 for "Late Group 4" varieties (4.5–4.9) as determined from field-grown plants at the Vegetable Research Station Soybean Variety Performance trial in 2022. A rating of 1 means a strong excluder and a rating of 5 means a strong includer.

Variety[a]	Mean	Rating[b]	Variety[a]	Mean	Rating[b]
	ppm			ppm	
NK49-T6E3S	10	1	DG 48XF33/STS	53	3
Progeny P4821RX	12	1	Axis 4813XFS	53	3
NK47-Z1XF	14	1	Progeny P4798XF	53	3
Integra 54660NS	15	1	Progeny P4932000	55	3
Osage (Check)	16	1	AG47XF3	57	3
DG 48E59	17	1	AG49XF3	58	3
Progeny P4775E3S	23	1	R18-5798	60	3
USG 7461XFS	23	1	Progeny P4844XFS	61	3
Local LS4795XS	24	1	Local IS4918E3	61	3
Armor 48-D25	25	1	AG48XF2	61	3
Dyna S48XF61S	26	1	Armor 49-F37	61	3
Local LS4727XF	28	1	Local LS4925XF	62	3
Integra 74893NS	31	1	Dyna S46XS60	62	3
DG 48E49/STS	32	1	R18C-13665	62	3
Local LS4826XFS	33	1	NK48-H3XFS	63	4
DG 46X65/STS	38	1	Progeny P4604XFS	64	4
S16-7922C	39	1	DG 49E80	66	4
Local LS4806XS	40	1	Innv. MEX49992XF	66	4
Progeny P4691XFS	41	1	USG 7463XFS	66	4
Innv. MEX46332XF	42	1	R18-14502	66	4
Dyna S46ES91	42	1	AG47XF2	67	4
DG 46E10	43	1	Axis 4613XF	67	4
AG46XF3	43	1	S17-2193C	68	4
USG 7481XF	46	2	Integra 74621NS	69	4
DG 46XF18	46	2	Dyna S46XF31S	69	4
DG 49XF29/STS	47	2	Eagle Seed 4.8	70	4
DG 48X45	47	2	Pioneer P46A20LX	73	4
USG 7493ETS	48	2	Local LS4606XFS	74	4
Integra 74731NS	48	2	DM48F53	75	4
DG 47E20/STS	49	2	Progeny P4951XFS	76	4
Local IS4737E3	49	2	R19C-3148	78	4
R18C-144	50	2	Progeny P4732XF	80	4
Pioneer P47A64X	50	2	Dyna S49XF82S	82	4
Pioneer P48A14E	50	2	Dyna S49EN12	83	4
R18-14753	50	2	R19C-3152	85	4
Armor 46-F13	51	2	UA46i20c (Check)	86	4
AG48XF3	53	2	R19C-13253	86	4

Table 2. Cont. Mean leaflet chloride (Cl) concentrations and preliminary rating for "Late Group 4" varieties (4.5–4.9) as determined from field-grown plants at the Vegetable Research Station Soybean Variety Performance trial in 2022. A rating of 1 means a strong excluder and a rating of 5 means a strong includer.

Variety[a]	Mean	Rating[b]	Variety[a]	Mean	Rating[b]
	ppm			ppm	
S16-13165C	93	5	Progeny P4806XFS	104	5
Armor 48-F22	94	5	Armor 46-F96	106	5
Integra 54891NS	96	5	Dyna S47XF52	108	5
DG 48E60	99	5	R19C-3159	116	5
R19C-3151	99	5	R19C-3191	117	5
Paloma PL2E472	101	5	DG 47E35/STS	120	5
Axis 4641XFS	104	5	R18-14147	142	5

[a] Abbreviation key: AG = Asgrow; DG = Delta Grow; DM = DONMARIO; Dyna = Dyna Gro; Innv. = Innvictis; 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 leaflet chloride (Cl) concentrations and preliminary rating for maturity group 5.0 to 5.9 varieties as determined from field-grown plants at the Vegetable Research Station Soybean Variety Performance trial in 2022. A rating of 1 means a strong excluder and a rating of 5 means a strong includer.

Variety[a]	Mean	Rating[b]	Variety[a]	Mean	Rating[b]
	ppm			ppm	
Dyna S54XF62	66	1	Progeny P5150XFS	127	3
DG 53E30	69	1	Local LS5029XF	128	3
R18-13337	78	1	R19C-3182	129	3
Local IS5143E3	81	1	DG 52XF22/STS	135	3
Osage (Check)	82	1	Progeny P5056XFS	139	3
DG 54XF20	85	2	R19C-3169	140	3
Progeny P5554RX	88	2	R19C-3194	141	3
Integra 75003NS	94	2	Local LS5614XF	148	4
AG53XF2	97	2	DG 52E80	150	4
R18-14272	99	2	R19C-3144	156	4
Paloma PL2E502	108	3	Local IS5102E3	163	4
S16-14801C	109	3	Local ZS5429E3	163	4
Progeny P5016RXS	111	3	R18-3332	164	4
R18-14286	113	3	Progeny P5521000	164	4
R17-283F	123	3	Progeny P5045E3S	174	5
R19C-3085	126	3	Armor 51-F88	196	5

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

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

Soybean Science Challenge: Growing Soybean Education

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 and is aligned with the Next Generation Science Standards (NGSS), which engages junior high and high-school students in active learning and the co-creation of knowledge through support of classroom-based lessons and applied student research. The SSC educates and engages junior high and high school science students and teachers in "real-world" Arkansas-specific soybean science education through original NGSS-aligned curriculum in 7E and 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. Even as in-person instruction returned to a new normal post-pandemic, the educational landscape looked different in 2022. The nature of the existing design and methodology of the SSC facilitated the launching of online Next Generation Science Standards (NGSS) Aligned Gathering Reasoning and Communicating (GRC)-3D and 7E lesson plans for teachers. An additional online course was added that included NGSS-aligned mini-lesson videos for the science classroom and additional virtual field trips to the list on the Soybean Science Challenge website. The Soybean Science Challenge was active in science fairs across the state, judging regional and state participants. In addition, the SSC is in its third year of the junior-level award at regional science fairs. Through the SSC, teachers now have access to many educational instructions that bring real-world agricultural critical thinking into the classroom and homes of students. The SSC has learned that Arkansas teachers and students benefit from these additional resources, and teachers and students from other states also benefit.

Introduction

The Soybean Science Challenge (SSC) has been active and growing since its inception in 2014. The SSC has always used a high-tech approach through online classes, virtual field trips, virtual mentoring, and communication through emails and Zoom.© It has also balanced this with "person-to-person" interactions at teacher workshops, conventions, and science fairs. The goal of the SSC is to support a higher level of student learning and research regarding the importance of soybean production and agricultural sustainability in Arkansas. For this to happen, the SSC has worked tirelessly at developing relationships with Arkansas teachers by supplying them with cutting-edge educational tools and the knowledge they need through online teacher in-service and face-to-face workshops. The SSC has also worked with students through mentorship and online courses.

Procedures

The Soybean Science Challenge is, foremost, an instructional tool for teachers and a real-life critical thinking program for students (Ballard and Wilson, 2016). One of the flagships of this program is the SSC Cash Awards given out to soybean-related science fair projects at the regional science fairs, the FFA Agriscience Fair, and the State Science Fair. For students to enter the SSC Award competition at these fairs, students must submit for judging a project that is either soybean-based or an agriculturally sustainable project and have passed the 6-module SSC online course. 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 requiring more exploration than at the local high school.

To determine the outcomes and impact of SSC, the number of students enrolled in the SSC online course and the fairs over the last year, plus the usage of resources, was tabulated and noted in Tables 1 and 1A. These outcomes include Spring of 2023, based on the funding cycle. The Community Garden and online course numbers are reported to date at the time of article submission.

Results and Discussion

A series of key factors contribute to the evidence of real learning-based results in the Soybean Science Challenge Program. For 2022–2023, the SSC Pre-test, student learning, and knowledge averaged 34%. However, the post-test

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average was 91%, a marked increase in student knowledge of soybeans attributed to online course completion. Another factor is the number of students taking and completing the course. The number of students completing the online course in 2022–2023 was 109. The increase in pre and post-test scores strongly indicates that the course successfully teaches students about soybeans.

Along with the online course, the SSC student research awards presented at Arkansas regional and state science fairs played a major role in increasing student knowledge about the sustainability and impact of the Arkansas soybean industry. Despite a return to normal in-person activities post-pandemic, fairs saw a decrease in entries. Even so, each fair had at least 1 or more entries in the SSC. Despite low enrollment issues and challenges, SSC had 13 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 2 regional SSC winners who received 'Best of Fair' or second place overall and were awarded a spot in the International Science and Engineering Fair (ISEF). This placing continues to demonstrate an increase in the quality and rigor of projects competing for the SSC award in soybean and agricultural sustainability. It suggests that the SSC is a successful program for junior high and high school students by providing student information and education to reach a higher level of research.

Through this program, the Arkansas Soybean Promotion Board (ASPB) invested $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 about soybeans in Arkansas and the importance of ASPB's goal of supporting effective youth education emphasizing agriculture. A total of 35 individual or team projects were judged, with 17 student awards presented on behalf of the ASPB.

The SSC has also chosen this year to continue to focus on helping teachers bring critical thinking into the classroom through agriculture. In 2016, science teachers throughout the state had to start phasing in the new Arkansas State Science Standards (based on the NGSS) into their classrooms. These new science standards included lessons written in the new GRC-3D format. To this end, the SSC now has 11 different soybean or agriculturally-based lessons written in the standard 7E Format and the new GRC-3D Format for teacher use. The SSC also has 14 different Virtual Field Trips (VFT) with NGSS-aligned manuals for teachers. All are in paper form and online at the Soybean Science Challenge 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 NGSS-aligned subjects and bringing an agricultural bend to everyday science concepts to the Soybean Science Challenge website.

To see the success of the SSC, one only needs to look at the numbers. The SSC had 35 entries in this year's science fairs. At least two regional winners received the ISEF Finalist position, showing the increased quality and caliber of projects judged. The numbers show that the SSC is impacting, 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. The SSC team has been told by several teachers, especially junior high teachers, what a difference the SSC has made to their students and the impact the SSC has had on their classrooms. Students are excited to research soybean projects and want to win! The SSC team has even been emailed and called by parents and told how much the SSC has influenced their child's decision regarding future careers in agriculture. These stories cannot be quantified, but they demonstrate some of the impact the SSC has in the classroom and the home. It shows people noticed our presence 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. It helps teachers teach through real-world critical thinking lessons, mini-lessons, and virtual field trips. The success of this project shows that high school and junior high school students are up to the task of handling real-world, real-time problems that require critical thinking while being exposed to the world of agriculture in ways they never expected to see. Students now understand that agriculture is a STEM field that requires highly educated youth to take the reins of the future from our current professionals. They continue to learn that agriculture is more than farming; it is a technical career that offers them the opportunity to make a difference worldwide. The SSC's goal has been successful in helping youth to discover the world of agriculture.

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Literature Cited

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

Table 1. 2023 Soybean Science Challenge Regional and State Science Fair Winners.

Science and Engineering Fair	Winner(s) Name and High School	Project Title
Arkansas State Science & Engineering Fair Conway – University of Central Arkansas, March 31.	First Place: Alyssa Thomas and Drew Johnson, ASMSA Second Place: Rini Eluvathinga, Little Rock Central High School Honorable Mention: Justus Osbon, Fayetteville Christian School	*1st: Examination of Variability of Fall Armyworm Infestations in Arkansas and the Potential for Biopesticide Treatment of Soybeans.* *2nd: Effects of Biochar and SAPs on Water Holding Capacity of Soil* *Honorable: How Much Smoke Until You Choke?*
Arkansas School for Mathematics, Science, and the Arts: Hot Springs – Sciences and the Arts Science Fair, February 24.	Charis Xiong and Amanda Navarro, ASMSA	*Development of a Novel AI Soybean Root-Knot Nematode Stress Assessment Model in Soybean Plants (Field and Homegrown)*
Central Arkansas Regional Science & Engineering Fair Little Rock – University of Arkansas-Little Rock, March 3.	Senior Level: Siddharth Snidharan, Little Rock Central High School Junior Level: Sanjay Iyer, Forest Heights STEM Academy	*Senior: Deciphering the Radio-protective Effects of the Soy Isoflavone Genistein in Lung Cells* *Junior: PEST (Pest Evaluating Soybean Tool): A Novel Machine Learning Method to Detect Soybean Pests*
Northwest Arkansas Regional Science & Engineering Fair Fayetteville – University of Arkansas-Fayetteville, March 10.	Senior Level: Jack Snell and Mason Collins, Alma High School Junior Level: Keila and Michelle Ortiz Salinas, Springdale JR High School	*Senior: Diagnosing Bacterial Blight with Darknet* *Junior: How do Magnets Affect the Germination Rate of a Soybean Plant?*
Southeast Arkansas Regional Science Fair Monticello. University of Arkansas at Monticello	Senior Level: Sydney Fuller, Stuttgart High School Junior Level: Layne Smith, Dumas Middle School	*Senior: Effects of Growing Environment on Plants and Productivity* *Junior: Soils and Soybeans*
Northeast Arkansas Regional Science Fair Jonesboro – Arkansas State University, March 11.	Senior Level: Sydney Wolf, The Academies at Jonesboro High School Junior Level: Levi Foster, Salem High School	*Senior: How do Planting Configuration and Irrigation Method Affect Soybean Growth?* *Junior: Comparing the Growth of Soybeans Using Different Types of Water*
Southwest Arkansas Regional Science Fair Magnolia – Southern Arkansas University, March 31.	Senior Level: Ka'Lee Hanson, Emerson High School Junior Level: Aiden Watson, Emerson High School	*Senior: Different Types of Soybeans in Hydroponics* *Junior: The Effect of Oil Spills on Soybean Plant Growth*
State FFA Agriscience Fair Hot Springs – April 25.	Senior Level: Hannah and Hadleigh Baker, Mountain Home High School Junior Level: Holland Stacks, Taylor High School	*Senior:* Improving Turkey Production Through Assessment of Various Feed Proteins *Junior:* Winter Forage

Table 2. Year-to-date Soybean Science Challenge Online Courses Enrollment: 1 April 2022–22 February 2023.

Student Enrollment	Current Student Course Completion	Average Student Pre-Test Score	Average Student Post-Test Score	Teacher In-Service Enrollment	Teacher Resources # logged in
119	109	34	91	12	2

Table 3. Soybean Science Challenge Products, Audience, Activities and Impact 2022–2023.

Product	Target Audience	Activities and Impact
Soybean Science Challenge student online course	6–12th grade	**119** Students enrolled; **109** completed
Soybean Science Challenge Online Course – Teacher In-Service (7 hours)	Science Teachers	**12** Teachers enrolled; **12** completed
Soybean Science Challenge Online Course – Teacher Resources	Science Teachers	**2** Users
Partnering with 7 regional science fairs, the FFA Agriscience Fair and the Arkansas State Science Fair, **2022-2023** Attended and judged nine Arkansas science fairs, **2022-2023**	Science Teachers/Students Science Fairs	**40** articles published or posted in newspapers or on websites. **17** individual/team student winning projects with **34** student/teacher awards, totaling **$7000 for the 2023 fairs.**
Free Resources for Teachers and Soybean Science Challenge Awards Flyer	Science Teachers/Students	Released multiple times to ARSTEM List Serve, AR Educational Cooperatives, personal emails; mailed to over **2500** Science and AG Teachers each year for 2022–2023.
6-one-hour workshops at Pinnacle West High School, September 2022	6–12 grade Science teacher and students	**Over 150 students** attended the SSC presentation focusing on soybean nutrition, growth, and DYI Feed.
Farm Bureau Meeting, December 2022	Farm Bureau Participants	Handed out SSC materials to **over 100 participants,** such as promotional items, lesson plans, and resource information.
Virtual Science Fair In-Service Workshop, September 2022	6–12 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.
Arkansas Grown School Garden of the Year Ceremony, Oct. 12	6–12 grade teachers and students, and local legislators from the State Capitol	Attended this ceremony at Pinnacle West High School as SSC soybeans are grown in this award-winning school garden.
Accessibility for 2022	All accessible participants	All VFTs, lessons, mini lessons, and online courses were rewritten to make them accessible to those who need this.

Continued

Table 3. Continued.

Soybean Science Challenge Seed Store announcement	Junior High and High School Students/Teachers	SCIENCE List Serve, AR Educational Cooperatives, personal emails; soywhatsup website, CES web page; workshops; teacher conferences; emailed to over **2500** Arkansas Science and AG Teachers.
Soybean Science Challenge Brochure	6–12th Grade High School Students/ Teachers	SCIENCE List Serve; AR Educational Cooperatives; personal emails; soywhatsup website, CES web page; conferences, and teacher workshops
Soybean Science Challenge Lesson Plans, Mini Lessons, and online courses	6–12th Grade High School Students/ Teachers **Over 2500 teachers**	SCIENCE List Serve; AR Educational Cooperatives; personal emails; soywhatsup website, CES web page; conferences; teacher workshops, emails.
Soy Science Scholars Booklet	ASPB; CES schools	Mailed to ASPB and CES. Booklet mailed to students, teachers, and administration of all winning participants' schools, plus handed out at conferences.
Soy What's Up? Flier on resources found on the CES Soybean Science Challenge webpage – Soywhatsup	Science Teachers/Students	Arkansas Educational Cooperatives; personal emails; soywhatsup website, CES web page; workshops, mailed to **over 2500** Arkansas Science and AG Teachers and teachers across the nation.
Media Coverage of Soybean Science Challenge Events	Science Research, Agriculture Educators, and General Public	**40** articles in newspapers, magazines, and other publications, including YouTube.
2016–2017 Arkansas High School Science Project Development Guide	Science Teachers/Students	Several handed out to teachers and students; posted on soywhatsup website, CES webpage.
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, SCIENCE List Serve, Arkansas Educational Cooperatives and individual science teacher/student emails.
Soybean Science Challenge Community Gardens	Science teachers, students, County AG Agents, Master Gardeners, and Community Garden Participants	**60 gardens** across the state and USA as of 4/01/2023. Advertising through Constant Contact, email, and on the soywhatsup website, reaching over 2,500 contacts.

EDUCATION

Arkansas Future Ag Leaders Tour

J.C. Robinson[1]

Abstract

The Arkansas Future Ag Leaders tour is a 5-day professional development opportunity for undergraduate juniors and seniors enrolled in colleges of agriculture or pursuing agriculture-related majors across the state of Arkansas. Agriculture and agriculture-related professions are the largest employers in the state. This 1-week experience enhances students' leadership and employability skills, provides firsthand networking opportunities with potential employers, and highlights the vast resources, services, and careers available through Arkansas' agriculture industry. The call for applications goes out to all colleges with agriculture-related academic departments. Institutions with agriculture departments will be guaranteed a set number of seats if they designate participants by a specified date. Following the initial application deadline, the remaining unfilled seats will be open to any interested applicants, regardless of institutional affiliation.

Introduction

Agriculture is Arkansas' largest industry, adding around $16 billion to the state's economy in 2020—Arkansas's 23 agricultural products ranked in the top 25 in the United States. According to the U.S. Bureau of Labor Statistics (BLS), employment opportunities between 2020 and 2025 will remain strong for new college graduates with interest and expertise in food, agriculture, renewable natural resources, and the environment. The BLS forecasts an overall increase in the U.S. labor force between 2018 and 2028 due primarily to openings from retirements and job growth. It is expected that employment opportunities in occupations related to food, agriculture, renewable natural resources, and the environment will grow 2.6% between 2020 and 2025 for college graduates with a bachelor's or higher degree.

As new graduates enter the workforce, there is a training gap between technical skills and knowledge and soft skills employers desire. Among the career readiness competencies identified by the National Association of Colleges and Employers (NACE), graduates who are successful in transitioning into the workplace possess professionalism. The NACE defines professionalism as demonstrating personal accountability and effective work habits, e.g., punctuality, working productively with others, time workload management, and understanding the impact of non-verbal communication on professional work image. Ability to demonstrate integrity and ethical behavior, act responsibly with the interests of the larger community in mind, and the ability to learn from mistakes.

Procedures

The goals of the tour included increasing the participant's employability in agricultural careers; acquainting participants with the vast resources, market segments, and services available through Arkansas' number one industry; providing participants with a "bird's eye view" of current employment opportunities in the Arkansas agriculture industry, and increasing the student's options and opportunities by networking with future employers.

The participants engage in leadership and team-building activities to get to know each other and the coordinators. The participants also participate in professional development activities related to networking, key tips for snagging the job of their dreams, and career advancement strategies. Each day, participants travel across the state to pre-arranged tour sites to visit facilities and network with professionals. The tour allows students to experience firsthand the diversity of opportunities within Arkansas' agriculture industry. Growers, producers, processors, manufacturers, educators, and research facilities will host students across Arkansas.

During the week of 16–20 May 2022, 22 Arkansas college juniors and seniors participated in the Arkansas Future Ag Leaders Tour. Students enrolled at six (6) Arkansas institutions participated, including the following institutions:

- Arkansas Tech University
- University of Arkansas – Fayetteville
- Southern Arkansas University
- University of Arkansas – Monticello
- Arkansas State University – Jonesboro
- Harding University

Majors of the tour participants included:

- Agriculture Business
- Agronomy
- Agriculture Education
- Engineering
- Agriculture Leadership
- Animal Science
- Plant Science and Animal Science
- Marketing

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The 5-day professional development opportunity included professionalism skills and team building to kick off the week on Monday, 16 May. On Tuesday, 17 May, participants loaded up on a tour bus to travel across the state and visit or hear from representatives from many areas of the agriculture industry, including:

- JBS Foods
- Anheuser-Busch
- Cooperative Extension Service
- Woodruff County Electric Coop
- Farm Credit
- Delta Dirt Distillery
- OK Foods
- Kingwood Forestry Services, Inc
- Tyson Discovery Center
- Riceland
- Farm Bureau
- Dabbs Farm, Stuttgart
- Peco Foods
- Jake Appleberry Farm, Tillar
- Greenway Equipment
- Bayou Meto Water District
- Five Oaks
- Arkansas Department of Agriculture
- NRCS
- The Cotton Board

Results and Discussion

Each participant was surveyed after the tour. Participants' written responses were related to increased knowledge of the agriculture industry, the value of networking, expanding their understanding of agriculture career opportunities, and improved professionalism skills (Table 1). Respondents also responded when asked what they will use on the job; responses specifically mentioned new knowledge gained, new professional skills, networking experiences, and new connections (Table 2).

Based on previous tours in 2019 and 2022, the following evaluation results demonstrate:

- 86% of participants reported that participating in the tour changed or expanded their career options.
- 100% of participants made new networking connections.
- 93% of participants agreed that their knowledge of agricultural job opportunities in Arkansas increased a lot or a great deal.
- Two tour participants applied for positions with an employer they met on the tour before the tour ended.

When participants were asked what they learned on the tour, responses were related to increased knowledge of the agriculture industry, the value of networking, expanding their understanding of agriculture career opportunities, and improved professionalism skills (Table 1). Respondents also responded when asked what they will use on the job; responses specifically mentioned new knowledge gained, new professional skills, networking experiences, and new connections (Table 2).

Practical Applications

The Arkansas Future Ag Leaders Tour gives a broad view of the agriculture industry in Arkansas and just a few of the many employment opportunities available. As the aging workforce retires, many vacancies are waiting to be filled. The Ag Leaders Tour introduces college students to employers and career opportunities they may not have been aware of or reinforces preexisting career goals. As participants travel around the state, they are also introduced to different communities where they may want to live. However, they were not familiar with it before they participated in the tour. To keep native Arkansans working in their home state, the Ag Leaders Tour attempts to help participants understand the vast opportunities and support systems already in place for careers in agriculture. The Ag Leaders Tour also prepares participants with professional and soft skills often overlooked by educators and assumed to exist by employers. For many participants, the Ag Leaders Tour is the first opportunity to network with other agriculture professionals their age outside of their home institution, beginning lifelong friendships and working relationships. Lastly, participants in the Ag Leaders Tour discuss issues and policies impacting Arkansas farmers and the agriculture industry. This awareness helps them be better prepared to support and contribute to the success of Arkansas agriculture.

Acknowledgments

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Literature Cited

APLU. 2009. Association of Public and Land-Grant Universities. Human capacity development: The road to global competitiveness and leadership in food, agriculture, natural resources, and related sciences. Accessed 5 July 2023. Available at: https://www.aplu.org/wp-content/uploads/human-capacity-development-the-road-to-global-competitiveness-and-leadership-in-food-agriculture-natural-resources-and-related-sciences.pdf

NACE. 2023. National Association of Colleges and Employers. What is Career Readiness? Accessed 5 July 2023. Available at: https://www.naceweb.org/career-readiness/competencies/career-readiness-defined/

Table 1. Responses to participant evaluation question: What did you learn?

Increased Knowledge of the Ag Industry	The Value of Networking	Expanded Understanding of Ag Career Opportunities	Professionalism
The diversity of Arkansas agriculture operations	How to network	I learned that there are many diverse ag jobs and that a lot of them will accept multiple or various degrees	How I am a leader in a group
The ag industry is huge!	Networking, more than one job opportunity	I learned that there are way more ag jobs in Arkansas than I thought	The three Cs are very important to me
I learned how broad the ag industry is	What networking actually is	Ag careers are about passion for agriculture and helping people	I learned how to properly set up a resume
Which industries in agriculture there are in Arkansas	Networking is everything	Don't let your degree define you!	
More about each sector of Ag (crop science, soils, and opportunities)	Who you know, not what you know	Apply for internships/jobs! Even if you do not meet all of the qualifications	
The great diversity of ag jobs; new jobs that I did that went with ag business	Networking is important and a good tool to use is LinkedIn	I'm not limited to my degree	
I learned where I do not want to work	How to network with future employers	I don't have to be defined by my degree; I can be in multiple fields	
I learned what employers want and the various job opportunities Arkansas has	Use connections I've made to be more successful	Not to limit myself to my degree. There were a lot of options that were available to me when I knew I was coming here.	
The Cooperation Extension Service cares about the well-being of college students and future Ag Leaders of Arkansas	Networking opportunities		
	I learned how to network		
	How to make personal connections with potential employers		
	How to network, among other skills to be used in the workforce		
	Who you know, not what you know		

Table 2. Participant responses to the evaluation question: What will you use on the job?

New Knowledge	New Professional Skills	Networking Skills
Educational resources	Hiring skills, networking, and communication	I will use my new networks to get my name across my agency
Professional development	To effectively communicate with others	Connecting with a team like this one
The knowledge I have received from the many speakers	I will project myself with more confidence	The connections I made on this trip; networking
Personal development skills at its best	Using teamwork skills along with future co-workers	I will use skills from this week to continue networking to find or advance in a job
Professionalism	Interview skills	Using my connections that I got through previous networking
I will use my new knowledge on networking and building a resume	I will use this to lead others and grow or carry this knowledge to others	Networking
Agriculture is extensive: many careers in ag, many different degrees can be used	Positive ways and productive feedback to managers at my current job	I will use our newly acquired networking skills to get the interview
Use knowledge to pursue upcoming opportunities in Arkansas agriculture	Communicate better	I will use my improved networking skills
Keeping an open mind to not limit yourself	Listen better	Networking skills
		Networking; making connections anywhere and everywhere

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 aims to develop high-yielding, disease-resistant, well-adapted conventional and non-conventional maturity group (MG) 4 and 5 soybean cultivars. In the initial stage of the breeding pipeline, parents with desirable agronomic and economically important traits are identified. Next, elite lines from the Arkansas breeding program are crossed with diverse materials from southern and northern breeding programs or plant introduction from the Soybean Germplasm Collection. New breeding populations are advanced for 4 consecutive generations until plant homozygosity is reached. Then, single plants are selected, planted individually as progeny rows, and evaluated for overall yield potential and plant architecture. Selected progeny rows are advanced to yield trial evaluations for 2 consecutive years across Arkansas and other mid-South states. Lastly, selected lines with excellent yield performance, broad adaptability, and a robust disease package are evaluated in a final stage in the Arkansas Variety Testing Program, the USDA soybean uniform trials, and other southern states' official variety testing programs before being proposed for release.

Introduction

The University of Arkansas System Division of Agriculture's Soybean Breeding Program has been working towards the development and release of new conventional and herbicide-tolerant soybean cultivars for Arkansas growers. Developed cultivars are widely adapted to Arkansas' environments, are tolerant to disease and abiotic stressors, and have enhanced seed composition. 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 public checks in the United States Department of Agriculture (USDA) Uniform Soybean Trials. Here, we summarize the work towards developing and commercializing new high-yielding maturity groups (MG) 4 and 5 soybean varieties.

Procedures

The main objective of the Soybean Breeding Program at the University of Arkansas System Division of Agriculture is to provide high-yielding, well-adapted MG 4 and 5 elite soybean cultivars for Arkansas farmers. The first step of our breeding pipeline is to identify and cross materials with key agronomics and economically important traits to increase the genetic diversity of our breeding lines. To do so, materials from different U.S. southern and northern breeding programs and plant introductions available in the Soybean Germplasm Collection are selected and crossed with elite Ark. lines. After initial hybridizations, developed F_1 populations are submitted to the generation advancement stage in off-season nurseries, in which materials are quickly advanced for 4 (F_4) generations to allow genetic recombination and reach homozygosity. Off-season nurseries are highly valuable to soybean breeding programs since they can conduct as many as 3 growing seasons in a year. During the last generation advancement, single plants (F_4) are selected and planted as progeny rows ($F_{4:5}$) and evaluated for plant adaptation and overall agronomic traits. Selected rows are tested during 2 consecutive years of multi-location yield trials. In 2022, 128 new crosses were made, 253 populations from F_1 to $F_{4:5}$ generations were evaluated and advanced, and over 16,000 progeny rows were planted, of which 889 were selected for preliminary yield trials.

Additionally, 4,000 progeny rows were planted in an off-season nursery in Chile to expedite the breeding process. From the progeny rows, 620 were selected for preliminary yield trials. Preliminary yield trials were grown in 3 Arkansas locations in replicated tests. Intermediate and Advanced yield trials were grown in 6 Arkansas locations with 2 replications each. High-yielding lines selected from advanced yield trials were evaluated in our pre-commercial test, the USDA Southern Uniform Tests, and the Arkansas Official Variety Test. Simultaneously, breeder seed was produced in Stuttgart, Ark., and foundation seed was provided for seed production. Additionally, all pre-commercial lines were screened for disease resistance to soybean cyst nematode, root-knot nema-

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tode, stem canker, frogeye leaf spot, and drought and flood-tolerance in either greenhouse or field conditions.

Results and Discussion

Conventional breeding line R18-14502 was evaluated in the 2022 USDA Uniform Test IV, yielding 57.1 bu./ac (90.5 of check mean; 63.1 bu./ac). It has been proposed as a new indeterminate conventional MG 4 release. Line R18-3332 was evaluated in the 2022 USDA Uniform Test V and yielded 49.2 bu./ac (89.3% of check mean; 55.1 bu./ac).

Two promising breeding lines (R18C-11151 and R19-39444) were also evaluated for yield performance in the 2022 Uniform Preliminary MG IV late Soybean Tests. Line R18C-11151 yielded 51.2 bu./ac (80.9% of check mean; 63.3 bu./ac). Line R19-39444 yielded 59.0.2 bu./ac (92.8% of check mean; 63.3 bu./ac). Five breeding lines, R18-10491, R18-10519, R18-10919, R18C-11127, and R18C-11272, were evaluated in the 2022 USDA Preliminary Uniform Test V early and yielded 50.4, 48.6, 47.9, 48.7, and 51.3 bu./ac, respectively (88.9, 85.7, 84.5, 85.9, and 90.4% of the check mean, respectively; 56.7 bu./ac). Lines R18-11770, R18-11839, and R18-67F were also evaluated in the 2022 USDA Preliminary Uniform Test V late, yielding 60.8, 61.7, and 60.7 bu/ac, respectively (90.74, 92.08, and 90.59% of the check mean, respectively; 67 bu./ac).

In addition, during the 2022 season, we evaluated 1,122 conventional breeding lines for yield performance in multi-location trials in Arkansas (Table 1), with approximately 88% of entries being MG 4 and 12% MG 5. In the pre-commercial trials, 43 conventional lines were evaluated. In total, 16,396 progeny rows were grown in Kibler, Ark., and 889 lines (5.4%) were selected based on overall yield potential and agronomic traits for yield trial evaluation in 2023. Finally, 7,837 single plants were pulled from F_3-F_4 breeding populations and will continue generation advancement (Table 1).

Practical Applications

We aim to supply Arkansas soybean growers with high-yielding, broadly adapted soybean cultivars at a lower cost. The continued release of public cultivars, including Ozark, Osage, UA5612, UA5213C, UA5014C, UA5414RR, UA5715GT, UA54i19GT, and UA46i20C offers low-cost, high-yielding cultivars for Arkansas farmers. These public cultivars provide germplasm sources 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 'U.A. 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 'U.A. 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, 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 'U.A. 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 the University of Arkansas System Division of Agriculture's Soybean Breeding and Genetics Program tests in 2022.

Testing stage	Number of Entries
USDA Uniform/Preliminary Tests	12
AR Variety Testing Program	24
Arkansas Advanced Lines	70
Arkansas Intermediate Lines	292
Arkansas Preliminary Lines	746
Progeny Rows	16,396
Single plants	7,837
Breeding Populations (F_1 – F_4 generation)	253
New Crosses	128

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 and exchanges exotic germplasm with diverse genes and traits. It introduces these value-added genetic traits into Arkansas cultivars and breeding lines to develop and release elite varieties and germplasm with high yield, disease resistance, and broad adaptability. In 2022, 5 pre-commercial maturity group (MG) 4 lines R19-39444, R18-14147, R18-5798, R19-35367, and R18C-144, and 2 pre-commercial MG 5 lines R18-13337 and R18-13309 derived from diverse exotic germplasm were evaluated for yield, maturity, and other agronomic traits in multi-state regional trials. Line R18-14147 was selected to be released as a high-yielding MG 4 germplasm for Arkansas soybean production. Line R19-39444 was selected for further evaluation in the 2023 regional trial and Arkansas pre-commercial yield trial and may be proposed for release in spring 2024, pending satisfactory yield performance. A total of 12 advanced, 63 intermediate, and 25 preliminary lines with diverse exotic pedigrees were evaluated for yield and agronomic traits in multiple Arkansas locations. In addition, more than 4,000 progeny rows with exotic pedigrees were evaluated for agronomic traits and uniformity at the University of Arkansas System Division of Agriculture's Vegetable Research Station in Kibler, Ark., and more than 300 lines were selected for 2023 preliminary yield tests. Multiple diverse F_1 to F_4 breeding populations were advanced in Arkansas and off-season nurseries, and 9 new crosses between Arkansas elite varieties/lines and diverse exotic germplasm were made at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark. in the summer of 2022. All these breeding efforts effectively enhance the genetic diversity of Arkansas varieties and breeding lines and benefit the development of elite Arkansas soybean cultivars.

Introduction

Soybean cultivars and germplasms have a narrow genetic base with many diverse genetic traits lost during long-term domestication and intense breeding activities. The high-yielding commercial cultivars are often sensitive to diseases, pests, and abiotic stressors, and seeds have lower nutritional values and quality (Carter et al., 1993). Gizlice et al. (1994) reported that 90% of the total ancestry of commercial soybean cultivars in the United States derived from only 26 ancestors. Introducing diverse exotic germplasm into public and private breeding programs is important to develop variety and germplasm with elite traits and genes. A highly active soybean germplasm exchange system is implemented among public soybean breeding programs in the United States. Particularly, the United States Department of Agriculture (USDA) Soybean Germplasm Collection maintains and provides diverse exotic accessions to the soybean community. These germplasm exchange and breeding efforts are introducing new exotic genes into locally adapted germplasm to enhance the genetic diversity of commercial soybean varieties.

The soybean breeding program at the University of Arkansas System Division of Agriculture long-lastingly introduces diverse exotic genes into Arkansas soybean cultivars and breeding lines to develop germplasm with elite genetic traits such as high yield, biotic and abiotic stressors tolerance, and broad adaptation. In the last 2 decades, 9 elite germplasm R01-416F, R01-581F, R99-1613F, R01-2731F, R01-3474F, R10-5086, R11-6870, R10-2436, and R10-2710 with diverse genes and traits were developed and released by our soybean breeding program (Chen et al., 2007 and 2011; Manjarrez-Sandoval et al., 2018 and 2020). These have been used as crossing parents for different soybean breeding programs to enhance the genetic diversity of local soybean breeding lines. The project 'Soybean Germplasm Enhancement Using Genetic Diversity' effectively supports our soybean breeding program to enhance Arkansas soybean germplasm genetic diversity using exotic germplasm. Herein, we report the efforts and accomplishments conducted under this project in 2022.

Procedures

In 2022, multiple exotic germplasms with diverse elite traits such as high yield, early maturity (maturity group (MG) 3-4), and disease resistance were requested in exchange with other public breeding programs and the National Plant Germplasm System. These exotic germplasms were crossed with elite Arkansas varieties in Fayetteville, Ark., and F_1 seeds

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were harvested and sent to off-season nurseries for generation advancement. Breeding populations were advanced from F_1 to F_4 generations in Fayetteville, Ark. and off-season nurseries using a modified single-pod descent method (Fehr, 1987). Single plants from F_3 to F_4 breeding populations were selected, harvested, and threshed to grow single progeny rows for visual evaluation. The elite lines in the progeny rows were visually selected for 2023 preliminary yield trials. Lines in preliminary, intermediate, advanced, pre-commercial, and regional yield trials were evaluated for yield and other agronomic traits in multiple Arkansas locations and other southern states in 2022.

Results and Discussion

Yield Improvement Using Genetic Diversity. In the 2022 season, 5 MG 4 (R19-39444, R18-14147, R18-5798, R19-35367, and R18C-144) and 2 MG5 (R18-13337 and R18-13309) elite lines derived from exotic germplasm were evaluated for yield, maturity, and other agronomic traits in multistate USDA Uniform Trial (PIV-S-L), Arkansas Official Variety Tests (MG 4 and MG 5), and/or Arkansas pre-commercial yield trials (PCM4E, PCM4L, and PCM5E). Line R18-14147 demonstrated competitive yield performance (64.7 bu./ac, 100.2% check mean) and was selected to be released as a high-yielding MG 4 germplasm for Arkansas soybean production. Line R19-39444 was selected for further yield testing in the 2023 regional and Arkansas yield trials. Ten MG 4 and 2 MG 5 advanced lines with diverse exotic pedigrees were evaluated in multiple replicated advanced tests in seven Arkansas locations. Line R19-39415 yielded 69.3 bu./ac (93.4% check mean) and was selected for 2023 regional and Arkansas local yield trials. A total of 63 MG 4 and MG 5 intermediate lines were also evaluated for yield in 7 Arkansas locations. Fifteen lines with high yield potential were selected for 2023 advanced tests. Additionally, 25 MG 4 and MG 5 preliminary lines with exotic pedigrees were evaluated in 3 Arkansas locations. Six lines with good yield performance were selected for 2023 advanced yield trials. In 2022, more than 4,000 progeny rows with exotic and/or MG 4 pedigrees were evaluated for agronomic traits and uniformity in Kibler, Ark., and more than 300 lines were selected for 2023 preliminary yield tests. Multiple F_1 to F_4 breeding populations derived from diverse exotic parents were advanced in Arkansas and off-season nurseries, and several thousand single plants were picked up from F_3 and F_4 populations for 2023 progeny rows. Nine new crosses with exotic pedigrees were made in Fayetteville, Ark., and F_1 seeds were sent to off-season nurseries for generation advancement.

Disease Resistance Enhancement Using Genetic Diversity. In 2022, 3 pre-commercial MG 4 lines (R18C-11737, R18C-13665, and R18C-11151) and 2 pre-commercial MG 5 lines (R18C-11127 and R18C-11272) with genetically diverse and disease-resistant pedigrees were evaluated for yield in multi-state trials (USDA Uniform PIV-S-L and PV-E tests), Arkansas Variety Tests, and/or Arkansas pre-commercial yield trials (PCM4E, PCM4L, and PCM5E). Line R18C-13665 showed good yield performance (67.0 bu./ac, 90.2% check mean) and was selected for 2023 regional state and Arkansas pre-commercial yield trials. A total of 20 preliminary (16 MG 4 and 4 MG 5) lines with sudden death syndrome (SDS)-resistant pedigrees were evaluated for yield in multiple replicated tests in 3 Arkansas locations. Two MG 4 lines (R21KB-07328 and R21KB-07177) with good yield performances were selected for 2023 advanced yield trials. Eight F_2 and 5 F_3 breeding populations derived from exotic parents with disease resistance were grown for advancement purposes in Fayetteville, Ark. and in the off-season nursery. These populations were harvested as bulk or modified-pod picks. In addition, A total of 10 new crosses with southern root-knot nematode (RKN)-resistant pedigrees were made in the summer of 2022 and F_1 seeds were harvested and sent to off-season nurseries in Puerto Rico.

Practical Applications

The University of Arkansas System Division of Agriculture's Soybean Breeding Program has made significant progress in enhancing Arkansas germplasm/line genetic diversity and developing value-added germplasm with diverse genes and traits through exchanging exotic germplasm among the U.S. public breeding community. The program also provides germplasm and breeding lines with diverse genetic traits to other public soybean breeding programs for cultivar development. 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.

Acknowledgments

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Literature Cited

Carter, T.E., 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. Dept. 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, 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.

Utilization of an Off-Season Nursery for Soybean Line Development Through Back-Crossing

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Abstract

The University of Arkansas System Division of Agriculture's Soybean Breeding Program works to meet the needs of Arkansas soybean growers by developing and releasing cultivars with high yield potential, broad disease resistance, and improved value-added traits. Most of the work done in the last 5 years has been primarily focused on conventional (non-GMO) maturity group 4 cultivar development. Therefore, there is a pressing need to rapidly build a pipeline for developing herbicide-resistant materials in the program. Three waves to convert non-GMO elite breeding lines into Enlist-E3® products using off-season nurseries were initiated in 2020 and 2021 to fulfill the need to develop herbicide-resistant material rapidly. The first products of these efforts will enter yield testing in Arkansas in 2023. A sustainable back-cross program for herbicide-resistant product delivery requires significant investments in multiple years of operations in off-season nurseries. Thanks to the funding provided for this project, we were able to initiate a fourth Enlist-E3® back-crossing wave in Chile in 2022, with a set of 277 breeding lines in intermediate and advanced yield testing stages in Arkansas. Initial crosses were made in the summer of 2022. Based on the 2022 yield performance of the recurrent parents in Arkansas, 21 crossing combinations proceeded to the first back-cross cycle. BC_1F_1 seeds will be harvested in February 2023, and lines will be advanced to the BC_3F_3 stage. We expect converted Enlist-E3® breeding lines from this wave to enter yield testing in Arkansas in April 2025.

Introduction

The University of Arkansas System Division of Agriculture's Soybean Breeding Program has been proactively developing maturity group (MG) 4 high-yielding soybean cultivars to meet the needs of Arkansas soybean growers. However, most of our variety development has been primarily focused on conventional (non-GMO) materials. To remedy this, in 2020, we began a back-crossing program to convert elite non-GMO breeding lines into Enlist-E3® products. This conversion process occurs exclusively in off-season nurseries where roughly 7 generations can be conducted in 3 calendar years. We currently have breeding lines from 3 waves (May 2020, September 2020, and April 2021) of Enlist-E3® back-crossing in off-season nurseries in Chile and Puerto Rico. However, back-crossing for product development is not a one-time effort but must be reinitiated yearly as new breeding lines are developed. A sustainable back-cross program for herbicide-resistant product delivery requires significant investments in multiple years of operations in off-season nurseries. Using off-season nurseries to convert MG 4 non-GMO breeding lines into Enlist-E3® supports the development of a pipeline for herbicide-resistant materials that ultimately will provide affordable high-yielding products for Arkansas soybean growers.

Procedures

In Spring 2022, 277 breeding lines in Arkansas's intermediate and advanced yield testing stages were sent to an off-season nursery in Chile to be crossed with 2 Enlist-E3® donors. Initial crosses were made in the summer, and BC_0F_1 seeds belonging to 269 crosses were harvested in October. The multi-environment yield performance of recurrent parents across Arkansas locations was examined, and advancement decisions were made. A total of 21 crossing combinations, whose recurrent parents were advanced for 2023 testing, were kept for the following back-crossing cycle in Chile. Between 1 and 15 BC_0F_1 seeds per crossing combination were planted in November and received a glufosinate (Basta®) application 2 weeks after planting. Foliar tissue samples were collected from each surviving plant for molecular confirmation of the Enlist-E3® genes. Plants carrying the Enlist-E3® genes were used as males and crossed back to their corresponding recurrent parents, with 6–38 flowers pollinated per cross. BC_1F_1 seeds were harvested in February 2023. Back-crosses will continue until reaching the BC_3F_3 generation, and molecular markers and herbicide spraying will be conducted simultaneously to confirm the presence of the Enlist-E3® genes. We expect converted Enlist-E3® breeding lines from the fourth wave to enter yield testing in Arkansas in April 2025.

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Enlist-E3®-converted lines (approximately 180) developed from the first wave of the Enlist back-crossing program will be tested in preliminary yield trials in 2023. These will be moved into 2024 advanced and regional trials in Arkansas and other mid-South states based on yield potential across multiple environments in 2023. In addition, 9 populations (approximately 900 Enlist-E3® converted lines) will be tested in progeny rows in 2023. The lines will be moved into 2024 preliminary yield trials if they have satisfactory agronomic traits.

Results and Discussion

The University of Arkansas System Division of Agriculture's Soybean Breeding Program initiated a fourth wave of Enlist-E3® back-crossing with 277 breeding lines in Chile in the summer of 2022. After the original crosses were made, BC_0F_1 seeds entered the first back-crossing cycle based on the yield performance of the recurrent parents in Arkansas. This multi-year project relies on off-season nurseries to turn 7 generations in 3 calendar years. We expect to conduct yield testing on the Enlist-E3®-converted lines from this wave in Arkansas in 2025.

E3-converted lines (approximately 180) developed from the first wave of the Enlist back-crossing program will be evaluated in preliminary yield trials in summer 2023. Nine populations (approximately 900 Enlist-E3® converted lines) developed from the second wave will be tested in Arkansas in progeny rows during 2023.

Practical Applications

The University of Arkansas System Division of Agriculture's Soybean Breeding Program must rapidly expand its footprint in herbicide-resistant cultivars. Supplementing the efforts by generating a fourth wave of conversions into Enlist-E3® enables the program to build a pipeline of traited materials without further straining the genetic gain realized in the conventional breeding program.

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Fast-Tracking MG 4 and MG 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 broadly adapted maturity group (MG) 4 and 5 soybean [*Glycine max* (L.) Merr.] cultivars with resistance to southern root-knot nematode (*Meloidogyne incognita*, SRKN). Southern root-knot nematode is one of Arkansas's most economically significant pathogens, causing an estimated 8.6-million-bushel production loss on average annually. There are currently limited offerings in high-yielding SRKN-resistant commercial lines available in Arkansas and the mid-South states. In 2022, a total of 20 MG 4 and 23 MG 5 advanced stage pre-commercial lines were evaluated in a 3 replication trial for resistance response to SRKN in a field setting in Kerr, Arkansas, as well as a greenhouse setting in the University of Arkansas System Division of Agriculture's Nematode Diagnostic Lab (ANDL) in Hope, 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 g/root, and reproductive factor. Additionally, 14 MG 4 and 10 MG 5 entries from the Arkansas Official Variety Trial were screened in a field in Kerr, Ark., and at the ANDL in Hope, Ark. for galling versus reproduction responses. Data were subsequently analyzed to identify lines with possible resistance. Three lines (R18-10919, R18-14502, R19C-1081) were found to have resistance to SRKN. R18-10919, R18-14502, and R19C-1081 are to be used in the University of Arkansas System Division of Agriculture's Soybean Breeding Program's crossing block to develop multiple breeding and mapping populations with SRKN resistance.

Introduction

Southern root-knot nematode (*Meloidogyne incognita,* Kofoid and White; SRKN) can limit soybean yields by as much as 60% depending on population densities (Fourie et al., 2010; Canella Vieira et al., 2021). It has surpassed soybean cyst nematode (*Heterodera glycines*) as Arkansas's primary yield-limiting plant-parasitic nematode (Kirkpatrick and Sullivan, 2015). Developing resistant cultivars is the most cost-effective and environmentally sustainable practice to control SRKN (Khanal et al., 2018; Canella Vieira et al., 2021). Despite the need for genetic resistance to manage and control SRKN through resistant cultivars, the genes and mechanisms of resistance are still unknown (Mazzetti et al., 2019; Canella Vieira et al., 2022).

Procedures

In 2022, a total of 14 MG 4 and 10 MG 5 entries from the Arkansas Official Variety Test (OVT) were screened for SRKN resistance in a field in Kerr, Ark., as well as 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. In contrast, eggs of *M. incognita* were used as an inoculum in the greenhouse test. Separate from the Official Variety Trial, 20 MG 4 and 23 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. The field and greenhouse evaluations used the same parameters and procedures as the OVT screening. Results from the trial for the PCM lines did not show good separation between the susceptible and tolerant responses due to late planting.

Results and Discussion

R18-14502, a new high-yielding MG 4 conventional line to be released in 2023, was categorized as moderately resistant in the field setting in Kerr, Ark., but was categorized as moderately susceptible in the ANDL greenhouse test for OVT. Additionally, R18-10919 was categorized as resistant in the field setting in Kerr, Ark., and was placed into the

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moderately resistant category in the ANDL greenhouse test for the PCM trials. Both lines do offer some promise in field application, but the contrasting responses of R18-14502 suggest the possibility of multiple mechanisms of resistance that need further study and characterization. These lines must be screened again to confirm responses alongside a moderately resistant cultivar, 'Forrest,' and a susceptible check. R19C-1081 was rated as moderately resistant in the PCM greenhouse tests and will be included in 2023 PCM trials along with R18-10919, as both lines showed acceptable performance in 2022 yield trials. R18-10919 and R19C-1081 will again be screened in the 2023 SRKN tests.

An updated list of entries for the 2023 OVT and 2023 PCM tests that were advanced in 2022 will be screened under the greenhouse and field conditions as in the previous growing season. Identifying new lines and confirming previous findings will support the development of SRKN-resistant cultivars adapted to Arkansas and mid-South states. Due to the yield performance and the potential SRKN resistance of R18-10919, R18-14502, and R19C-1081, new populations are set to be developed in the University of Arkansas System Division of Agriculture's Soybean Breeding Program's 2023 crossing block. Products of the crosses will be sent to an off-season nursery where populations will be advanced to the F_4 generation to fast-track the process of cultivar development.

There are 374 lines to be evaluated for selection in 2023 progeny rows with R18-14502 in the pedigree, offering potential SRKN resistance. Any lines that are selected will be advanced for yield evaluation in 2024. SRKN-resistant lines advanced through 2 years of yield trials may be used as a parent in future crossing blocks and proposed for release pending satisfactory yield performance. There were 26 lines from 2022 preliminary yield trials selected to be evaluated in 2023 final yield trials with R14-1422 (2 lines) and R13-13997 (24 lines) in their parentages. R14-1422 and R13-13997 were identified as potentially resistant lines used in previous years' crossing blocks. Lines were selected based on physical appearance and agronomic criteria such as lodging resistance, plant architecture, and plant health and analyzed multi-location yield data. They will be evaluated in 2-replication trials across 6 locations in the 2023 growing season.

Practical Applications

Genetic resistance is the best approach to control plant-parasitic nematodes. SRKN-resistant cultivars have the potential to secure yield under high SRKN pressure, and no yield drag is observed without SRKN pressure. Furthermore, the market has limited availability of existing SRKN-resistant MG 4 cultivars. As parthenogenic nematodes, minimal diversity and evolution are expected. However, resistance breakdown has been observed in different crops. The impact of a resistance-breaking population in soybean, although rare, would be dramatic because of the high concentration and wide distribution of SRKN, the rather narrow base of genetic resistance, as well as the lack of alternative management options (Canella Vieira et al., 2021). Therefore, more efforts are necessary to identify and stack novel sources of resistance in developing soybean lines with enhanced and more durable SRKN resistance in the future.

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Literature Cited

Canella Vieira, C., P. Chen, M. Usovsky, T. Vuong, A.D. Howland, H.T. Nguyen, Z. Li, M.G. Mitchum, and G. Shannon. 2021. A major quantitative trait locus resistant to southern root-knot nematode sustains soybean yield under nematode pressure. Crop Science, 61:1−10. Accessed 6 July 2023. Available at: https://doi.org/10.1002/csc2.20443

Canella Vieira C., J. Zhou, M. Usovsky, T. Vuong, A.D. Howland, D. Lee, Z. Li, J. Zhou, G. Shannon, H.T. Nguyen, and P. Chen. 2022. Exploring Machine Learning Algorithms to Unveil Genomic Regions Associated with Resistance to Southern Root-Knot Nematode in Soybeans. Front. Plant Sci., 13:1-13. Accessed 6 July 2023. Available at: https://doi.org/10.3389/fpls.2022.883280

Fourie, H., A.H. McDonald, 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. Phyto. 108(5):532-541.

Kirkpatrick, T. and K. Sullivan. 2015. Incidence, population density, and distribution of soybean nematodes. *In*: J.R. Ross (ed.) Arkansas Soybean Research Studies 2015. 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.

Understanding Taproot Decline: A Three-Year Summary, 2020-2022

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Abstract

Taproot decline (TRD) (*Xylaria necrophora*) continues to be a disease of concern in southeast Arkansas soybean [*Glycine max* (L.) Merr.] production. Over the past 3 years, 207 varieties varying from maturity groups 3.9–6.0 were observed in field and laboratory trials searching for varieties that may express tolerance or resistance to the fungus. In addition, 6 seed treatments and 5 in-furrow fungicides were tested for activity against TRD. All varieties tested were found to be susceptible to TRD when infected as seedlings. Seed treatments and in-furrow fungicide tests were largely inconclusive, with thiophanate-methyl showing some promise in 2022 field trials.

Introduction

Taproot decline (TRD) is caused by the fungus *Xylaria necrophora* (Garcia-Aroca et al., 2021). The disease presents in early vegetative stages as chlorotic or dead plants located in clusters or streaks within fields. Additionally, in areas of symptomatic plants, gaps in plant stands are evident, with mummies of dead plants between the chlorotic plants. When dead plants from TRD are extracted from the soil, the taproot will be malformed and black, if present. In the latter reproductive stages (R5+, beginning seed development), the disease has a unique "leopard spot" or chlorotic appearance between the leaflet veins (Fig. 1). 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 specialized hyphae called stroma (Fig. 2). Splitting the root or lower stem longitudinally reveals mild vascular discoloration, and white mycelia are often 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 (Fig. 3). The regional distributions and yield loss in Arkansas have been unclear to date. However, it has been found as far north as Craighead County, and reports from some farmers and consultants indicate yield losses as high as 10 bu./ac in fields. We do not have seed treatment fungicides or varietal recommendations for growers to combat TRD. The objective of the following studies was to identify varieties and fungicides applied as either seed treatment or in-furrow that could help manage the disease.

Procedures

All field trials were inoculated at planting by placing sterilized Japanese millet (*Echinochloa esculenta*) infested with a locally obtained *Xylaria necrophora* isolate with the seed. Trials were planted into 38-in. beds in silt-loam soil at the University of Arkansas System Division of Agriculture's Rohwer Research Station near Kelso, Ark. Trials were arranged in a randomized complete block design, and all field trials were maintained according to the University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations. In 2020, a field trial consisting of 175 varieties was planted into 2-row plots, 10-ft long, at a seeding rate of 100 seed/row and replicated 3 times on 2 June. Percent disease incidence and severity were recorded on 6 Oct. by observing foliar symptoms and fungal signs on roots. Root incidence was collected by digging and washing 10 arbitrary roots per plot and recording the number exhibiting stroma. An in-furrow fungicide field trial was planted on 29 May to DG4967LL and divided into 2-row plots, 10-ft long, and replicated 4 times. Treatments consisted of 6 seed treatments and 5 in-furrow fungicides. Plant stand data was collected on 16 June. Root incidence was collected at maturity using the previously described method. Due to the destructive nature of the root sampling procedure, the trial was not harvested. Data were subjected to ANOVA (analysis of variance) followed by means separation of fixed effects using Fisher's least significant difference (LSD) at $P = 0.05$. In 2021, laboratory trials were established on 8 Oct. consisting of 20 varieties in wells measuring 3-in. deep by 2.5-in. wide. Five seeds per well were planted into a mixture of 1:1 sand to inoculum, where inoculum was prepared as mentioned above. Uninoculated wells were planted similarly using millet that was not infested with *X. necrophora*. Two replications were placed in a growth chamber where conditions were held at 20 °C with a 12.5-hour photoperiod. Two more replications were placed on a laboratory bench for observation where conditions were approximately 21 °C with

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9 hours of fluorescent lighting. Emergence data were recorded daily, and the trial was terminated on 25 Oct. Data were subjected to ANOVA followed by means separation of fixed effects using Fisher's LSD at $P = 0.10$. In 2021, field trials were lost due to widespread flooding in the area. In 2022, an in-furrow variety trial was established on 1 July and consisted of 29 varieties with 74 seeds planted per plot. Plots were 20 feet long and 4 rows wide and planted in clay soil in a split-plot design. The trial contained 3 replications. Topsin® (thiophanate-methyl) 20 fl oz/ac was applied in-furrow at planting in 10-gallons per acre water volume and compared against nontreated plots. Emergence data were collected on 14 June by counting the number of emerged plants per plot. The trial was not harvested due to significant stand loss. Data were subjected to ANOVA followed by means separation using Tukey's honestly significant difference (HSD) at $P = 0.05$.

Results and Discussion

Taproot decline disease incidence and severity were low, and results were inconclusive in 2020. In 2021, field trials were lost due to widespread flooding in the area. Laboratory trial data showed that all varieties tested performed poorly when inoculated, as plant emergence for both bench and growth chamber trials averaged just above 0. The best-performing varieties under those conditions were Dyna-Gro S45ES10 and Pioneer 43A42X (Table 1). Pioneer 43A42X is a variety that frequently exhibits foliar symptoms in fields where TRD occurs. This symptomology could indicate that foliar expression and seedling disease are unrelated. Thiophanate-methyl has shown some activity against seedling disease caused by X. necrophora in field studies (Tolbert et al., 2019) and was re-examined in 2022. The 2022 field trial had high incidence and severity, with the thiophanate-methyl in-furrow treatment emergence averaging 8 plants per plot compared to the nontreated, which averaged 5 plants per plot. Thiophanate-methyl treated plots had significantly higher percent emergence, averaging 11%, while the nontreated plots averaged 6%. No significant differences were observed between varieties.

Practical Applications

The data collected from these trials show the importance of finding resistant/tolerant varieties as TRD can potentially be a devastating soil-borne disease and significantly decrease stand. We will continue to search for ways to reduce the impact of this disease and develop an integrated management plan consisting of variety selection, crop rotations, and fungicides.

Acknowledgments

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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: 31 Mar. 2023. Available at: https://doi.org/10.1094/PHP-01-17-0004-RS

Tolbert, A.C., T.N. Spurlock, and R.C. Hoyle. 2019. Understanding Taproot Decline: A Potentially Yield Limiting Soybean Disease in Arkansas. In Arkansas Soybean Research Studies 2018. Arkansas Agricultural Experiment Station Research Series 663:44-48. Accessed 31 Mar. 2023. Available at: https://scholarworks.uark.edu/cgi/viewcontent.cgi?article=1158&context=aaesser

Table 1. Average number of emergent plants out of five by variety, inoculation, and location from a laboratory trial in Monticello, Ark., 2021.

Variety	Growth Chamber Inoculated	Growth Chamber Un-inoculated	Bench Inoculated	Bench Un-inoculated
R18-14229	0.0 b[†]	1.8	0.0 b	1.8
Credenz CZ4202XF	0.0 b	2.8	0.0 b	2.3
Asgrow SG45XF0	0.0 b	1.0	0.0 b	1.8
R18-14287	0.0 b	1.8	0.0 b	2.0
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
NK 42-T5XF	0.0 b	1.0	0.0 b	0.5
Dyna-Gro S45ES10	1.5 a	1.5	0.0 b	1.3
Amp 4448X	0.3 b	0.5	0.3 b	1.0
Local LS 4517 XFS	0.0 b	1.5	0.0 b	0.5
Asgrow AG42XF0	0.0 b	1.5	0.3 b	0.8
NK 45-P9XF	0.0 b	0.3	0.0 b	0.5
Armor 44-D49	0.3 b	1.8	0.0 b	1.5
Local LS4415XF	0.0 b	1.0	0.0 b	1.5
Progeny P4501XFS	0.0 b	1.3	0.0 b	2.0
Progeny P4505RXS	0.0 b	1.8	0.0 b	2.5
NK 43-V8XF	0.0 b	1.3	0.0 b	1.3
R18C-1450	0.0 b	0.0	0.0 b	2.0
NK 44-J4XFS	0.0 b	0.3	0.0 b	0.3
P43A42X	1.0 a	1.3	1.0 a	0.8
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 different according to Fisher's least significant difference (LSD) at P = 0.10.

Fig.1. Foliar symptoms of taproot decline on soybean.

Fig. 2. Belowground symptoms of taproot decline on soybean exhibiting a rotted taproot and black specialized hyphae called stroma. These signs and symptoms, when combined with the foliar symptoms of taproot, are diagnostic for the disease.

Fig. 3. Deadman's fingers associated with taproot decline. These can often be found growing from the remains of the previous year's crop, especially after a significant rain or irrigation.

On-Farm Soybean Fungicide Trial Summary, 2022

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

Abstract

Twelve large block foliar fungicide trials were established in soybean fields in 12 Arkansas counties in 2022. The objectives of this work were to determine the efficacy of fungicides applied and yield impacts associated with different foliar diseases that might occur. The severity of foliar diseases such as Septoria brown spot, Cercospora leaf blight, target spot, frogeye leaf spot, and aerial blight was determined at each location. Yield was collected in 11 of 12 trials. In 8 of 11 trials, fungicide application protected the crop above the application cost. There were numerically positive yield gains in all but one of the 11 trials where yield was collected.

Introduction

Soybean, *Glycine max*, (L.) Merr. is 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 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 yearly. 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

Twelve large block foliar fungicide trials, ranging in size from 15–50 acres, were established in soybean fields in 12 Arkansas counties in 2022. Treatments for each trial were Miravis Top® (serving as the fungicide standard), [contains the active ingredients pydiflumetofen (a succinate dehydrogenase inhibitor, SDHI) and difenoconazole (a demethylation inhibitor, DMI or triazole) from Syngenta (The Syngenta Group, Basel, Switzerland)], applied at 13.7 fluid ounces per acre and a nontreated control. Fungicides 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 R3 (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 (with 9 representing the most severe disease). 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 Matrice 300 RTK small unmanned aerial system (DJI, Shenzhen, China) equipped with a multispectral sensor (Micasense, Seattle, Wash., USA) 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 was 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 were 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 (HSD) at $P = 0.05$. All analysis was completed in an automated model using Python 3.6. Weather and soil data and high-resolution field images were included in the reports distributed to each cooperating farmer and county agent.

Results and Discussion

In all, 4 different fungal diseases were rated across the trial locations. Aerial blight, caused by *Rhizoctonia solani* AG 1-IA, was rated at 1 location; frogeye leaf spot, caused by *Cercospora sojina*, was rated at 11 locations; target spot, caused by *Corynespora cassiicola*, was rated at 10 locations,

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and Cercospora leaf blight, likely caused by *Cercospora flagellaris*, was rated at 2 locations. Table 2 includes trial locations, disease levels, treatment responses, and yield where available. The Ashley County location was the only trial with no treatment response, likely due to low disease levels. Yields were available for 11 of the 12 trials. Average yields for the trials ranged from 44.48 bushels per acre (bu./ac) to 102.62 bu./ac (Table 2). In previous years, fields were at R3, and the fungicide was applied on dates beginning in June and ending in August. These application timings offered the opportunity to compare a wider range of dates, with or without a yield response to an application, to the nontreated. In 2022, the earliest application timing was 14 July, the latest was 23 August, and there was no apparent trend in yield response. The one trial where yield was not collected had severe aerial blight, and visual estimation indicated both fungicides offered acceptable control (Fig. 2). In future years, an effort will be made to find fields to begin applications in early June through late August. As in previous years, these results point to the value of on-farm trials at various locations in the production area to determine product efficacy and yield impact of several different foliar diseases.

Practical Applications

In previous years, foliar diseases tended to be more severe in fields where the soybean crop was moving through the reproductive stages later in the season. Fungicides added value to the crop above their application costs in these fields more often than in those moving through reproductive stages earlier in the year. Moving forward, and due to the differences in maturity groups that may be planted in Arkansas, MG 3–MG 5, terminology should shift from defining fields as early or late planted to early maturing or later maturing when gauging foliar disease pressure (as a group 3 would mature sooner than a group 5 planted at similar times). Due to historical weather patterns, the group 5 varieties may have a higher likelihood of increased foliar disease pressure because it will be maturing more slowly. 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 check-off funds administered by the Arkansas Soybean Promotion Board. Support was also provided by the University of Arkansas System Division of Agriculture. The authors would also like to acknowledge the cooperating county agents Grant Beckwith – Arkansas County; Steven Stone – Lincoln County; Amy Greenwalt Tallent – Prairie County; Jerrod Haynes – White County; Chris Grimes – Craighead County; Jeffrey Works – Poinsett County; Andrew Sayger – Monroe County; Scott Hayes – Drew County; Brett Gordon – Woodruff County; Keith Perkins – Lonoke County; Kevin Norton – Ashley County and Courteney Sisk – Lawrence County.

Literature Cited

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., Elkins, C., and Norton, C., 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

Faske, T., Kirkpatrick, T., Zhou, J., and Tzanetakis, I. 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

Table 1. Fungicide trial location and products applied, 2022.

Trial	Approximate location†	Products applied	Rate applied
			fl oz/ac
Lincoln	-91.674681, 33.961256	Miravis® Top 1.62 SC	13.7
		Revytek® 3.33 SC	7
Arkansas	-91.513818, 34.548815	Miravis Top 1.62 SC	13.7
		Revytek 3.33 SC	7
Drew	-91.681539, 33.657595	Miravis Top 1.62 SC	13.7
		Revytek 3.33 SC	7
Monroe	-91.150563, 34.716825	Miravis Top 1.62 SC	13.7
		Revytek 3.33 SC	7
Lawrence	-91.036102, 36.055332	Miravis Top 1.62 SC	13.7
		Revytek 3.33 SC	7
White	-91.651156, 35.156234	Miravis Top 1.62 SC	13.7
		Lucento 4.17 SC	5.5
Poinsett	-90.648128, 35.483606	Miravis Top 1.62 SC	13.7
		Revytek 3.33 SC	7
Prairie	-91.578787, 34.981989	Miravis Top 1.62 SC	13.7
		Revytek 3.33 SC	7
Ashley	-91.675662, 33.281599	Miravis Top 1.62 SC	13.7
		Lucento 4.17 SC	5.5
Woodruff	-91.150554, 35.207762	Miravis Top 1.62 SC	13.7
		Revytek 3.33 SC	7
Lonoke	-91.789743, 34.674844	Miravis Top 1.62 SC	13.7
		Lucento 4.17 SC	5.5

† Longitude, latitude in geographic coordinate system 'WGS 1984.'

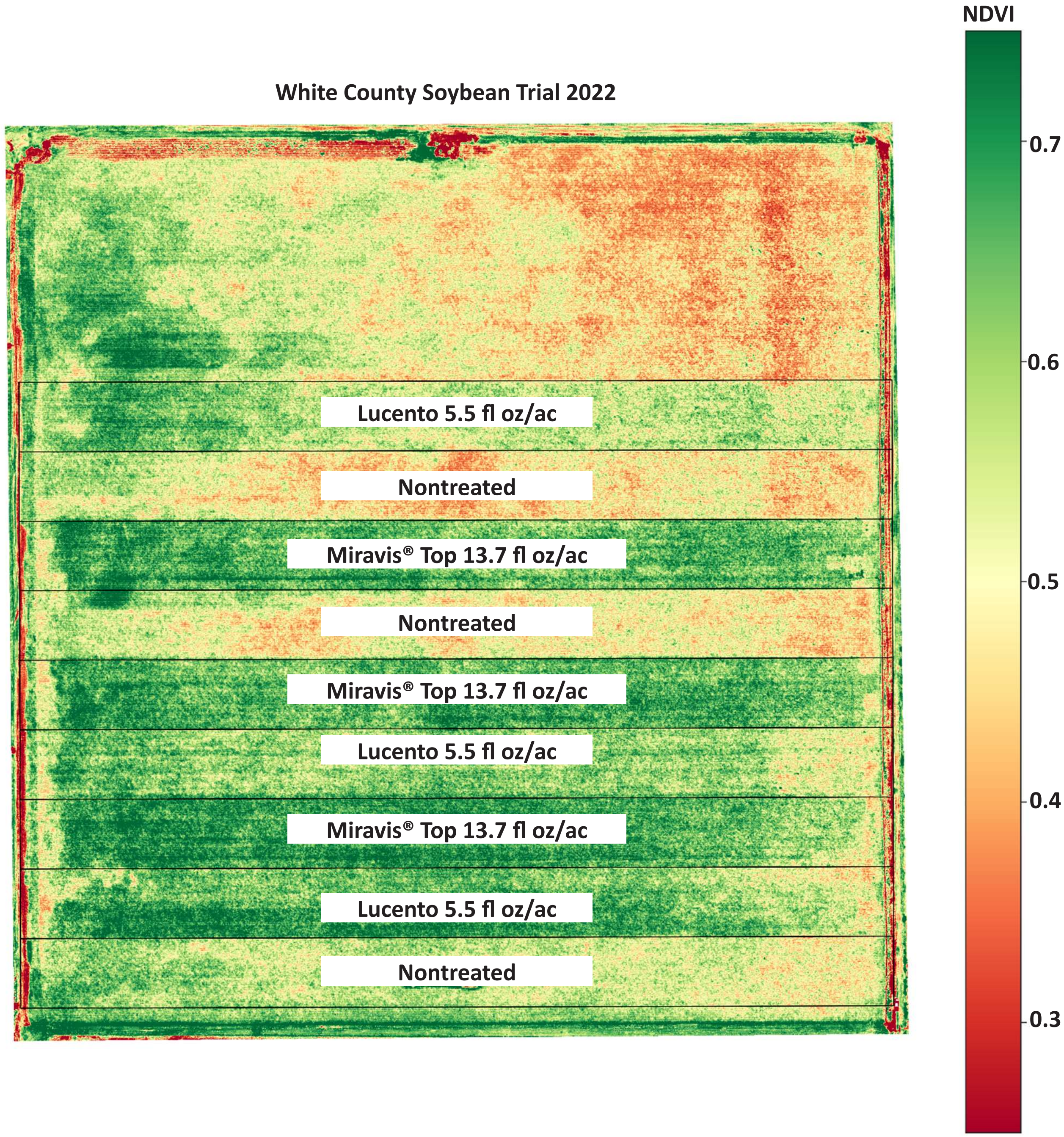

Fig. 1. An example of randomized complete block field plot design from the trial at White County, 2022. The fungicide treatment blocks are overlayed onto a vegetation index calculated from aerial imagery collected by a drone. The normalized difference vegetation index shows the fungicide-treated blocks as greener when these data were collected (R6).

Table 2. Summary of fungicide trial results, 2022.

Trial	Application date (Growth stage)	Diseases rated	Disease levels	Treatment response[†]	Average yield[‡]
Arkansas	7/14/2022	target spot/frogeye leaf spot	high/moderate	**/*	74.48***
Poinsett	7/15/2022	target spot/frogeye leaf spot	moderate/ moderate	**/**	67.91***
Drew	7/22/2022	target spot/aerial blight	low/high	NS/**	NA
Woodruff	7/26/2022	target spot/frogeye leaf spot	moderate/ moderate	***/**	70.78**
Lincoln	7/27/2022	target spot/frogeye leaf spot	moderate/low	**/ NS	61.51***
Monroe	7/29/2022	target spot/frogeye leaf spot	low/low	NS/***	102.62***
Ashley	8/3/2022	target spot/frogeye leaf spot	moderate/low	NS/NS	46.31***
Prairie	8/8/2022	target spot/frogeye leaf spot	moderate/low	*/*	59.3***
White	8/9/2022	target spot/frogeye leaf spot	moderate/ moderate	***/***	72.65***
Lawrence	8/15/2022	Cercospora leaf blight/frogeye leaf spot	moderate/low	**/NS	73.56
Craighead	8/16/2022	target spot/frogeye leaf spot	low/moderate	NS/**	44.48***

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

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

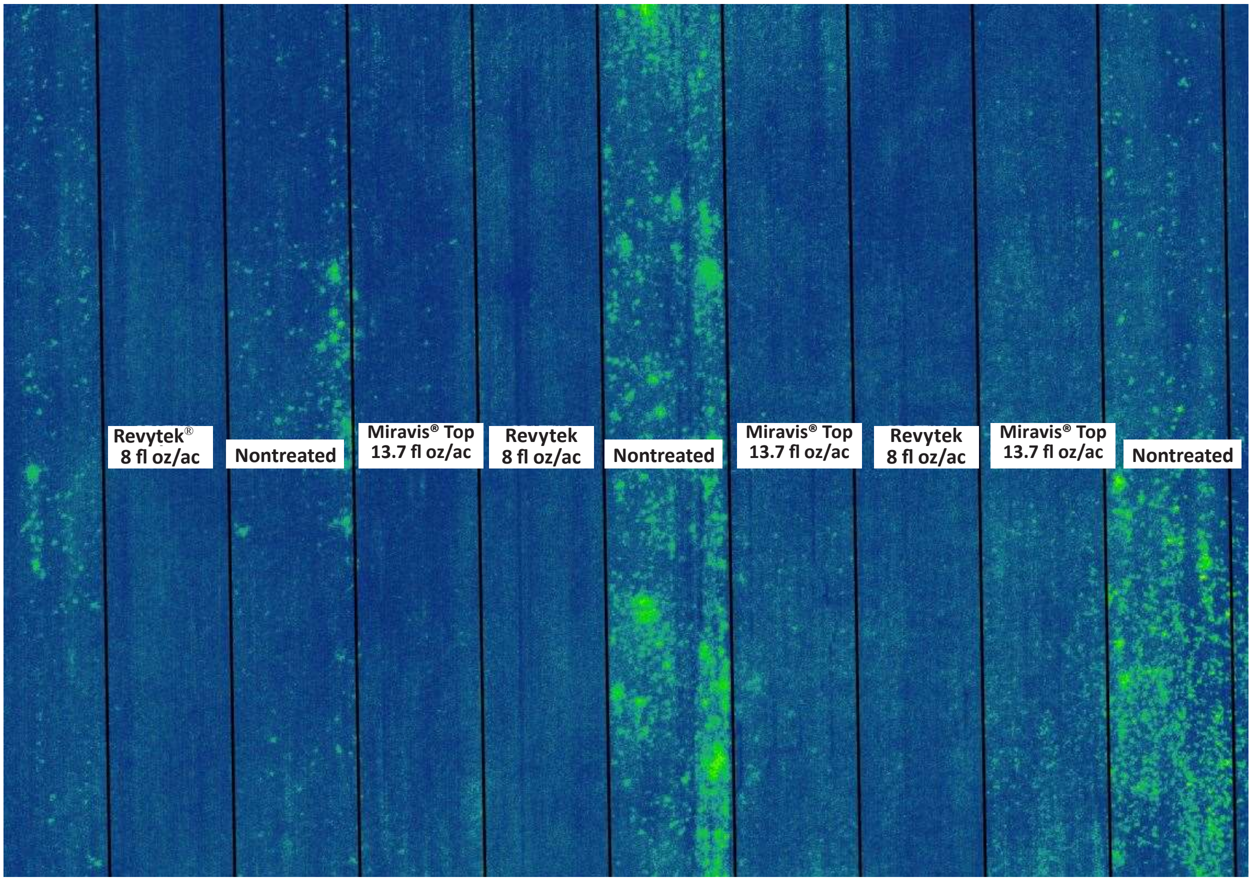

Fig. 2. Severe aerial blight highlighted in a vegetation index calculated from an aerial image at the Drew County soybean fungicide trial, 2022. The lighter green spots in the image are patches of aerial blight in the treatment blocks.

Determining the Impact of Variety and Fungicides on Post-Harvest Grain Quality, 2022

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

Abstract

Grain quality was determined using multiple trials in 2022. In one trial, 153 soybean varieties were grown, and the grain was harvested for post-harvest seed quality evaluations. Another trial consisted of 5 varieties, each with 3 fungicide treatments compared to those without fungicide. In each, fungal diseases were observed, but in low numbers (<4%). The variety trial was divided into groups by maturity, and differences were observed in purple seed stain incidence evaluations in maturity groups 4.4 and 4.6. Grain quality was good overall due to the low incidence and severity of diseases that impact grain quality.

Introduction

Seed quality can be impacted by insect damage or diseases caused by plant pathogens (Rupe and Luttrell, 2008). Common soybean fungal diseases impacting seeds include purple seed stain (PSS), Phomopsis seed decay (PSD), and frogeye leaf spot (FLS). Purple seed stain 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 of seed planted the following season, and increased seed decay and discoloration (Alloatti et al., 2015). Phomopsis seed decay caused by *Phomopsis longicolla* can cause deformed, split, or moldy grain (Fig. 2), altering seed viability and oil composition (Li et al., 2010). Frogeye leaf spot is caused by *Cercospora sojina* and is characterized by reddish-brown lesions on the grain, reducing quality (Telenko, 2019) (Fig. 3).

Procedures

Two field trials, a variety trial and a fungicide by variety trial (FXV), were planted at the University of Arkansas System Division of Agriculture's Rohwer Research Station on 31 May and 30 June, respectively. Both trials were arranged in a randomized complete block design on 38-in. row-spacings with plots 10- and 20-ft long, respectively. The variety trial had 153 individual soybean varieties replicated 3 times for a total of 459 plots.

The FXV trial included 5 varieties (LS3908XFS, CZ4410GTLL, LS4795XS, LS5119XFS, and DG52E80) and 3 fungicide treatments: Incognito® 10 fl oz/ac, which contains the active ingredient thiophanate-methyl (a beta-tubulin inhibitor) from ADAMA (Ashdod City, Israel), Miravis Top® 13.7 fl oz/ac, which contains the active ingredients pydiflumetofen (a succinate dehydrogenase inhibitor, SDHI) and difenoconazole (a demethylation inhibitor, DMI or triazole) from Syngenta (The Syngenta Group, Basel, Switzerland), Incognito + Miravis Top at 10 and 13.7 oz/ac, respectively, and a nontreated for each variety. Treatments were applied using a backpack sprayer propelled with carbon dioxide in 10 gal/ac water volume using TeeJet XR110015-VS tips (Spraying Systems Co, Glendale Heights, Ill.) at 4 mph. Treatments were replicated 5 times, applied at R3 (beginning pod), and rated for foliar diseases at R6 (full seed).

At harvest, seed samples were collected from the combine for each plot in both trials on 24 and 25 Oct, variety and FXV, respectively. The samples were collected in paper bags, labeled, and transported to the Monticello laboratory for evaluation.

Seed from both trials were rated for FLS, PSD, and PSS diseases on a percentage scale. In addition, the grain was also rated for percentages of insect damage. All data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Fisher's least significant difference (LSD) at $P = 0.10$.

Results and Discussion

In the FXV trial, foliar diseases were observed but in levels too low to be rated. Diseases were observed on seeds at less than 1% each. Insect damage averaged 17%, and grain without visual defects averaged 72%. Yield averaged 32 bu./ac with an average moisture content of 7.5%. No differences in any variables observed (PSS, PSD, FLS), and fungicide treatments did not affect yield.

The variety trial was divided into the following maturity groups (MG): MG 4.0-4.3, MG 4.4, MG 4.5, MG 4.6, MG 4.7, MG 4.8 Xtend (X), MG 4.8 non-Xtend (NX), MG 4.9, MG 5.0-5.2, and MG 5.3-5.6. In MG 4.4, differences in PSS were observed, with the group averaging 0.6% (0%–2.7%).

Delta Grow 44XF41 had significantly more PSS than all other varieties within that group. Some varieties, such as

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Progeny 4444RXS and Revere 4415XF, had no PSS observed (Fig. 4). Differences in PSS were also observed in MG 4.6 with the group averaging 0.3% (0%–3.2%) Delta Grow 46E10 having significantly more PSS than the other varieties (Fig. 5). There were no significant differences in PSS among varieties in other maturity groups. There were also no significant differences among varieties in any maturity group for FLS or PSD.

Practical Applications

While disease incidence and severity in these trials were low, the FXV trial demonstrates that automatic fungicide applications do not provide benefits in the absence of disease. The differences in disease within some maturity groups but not others suggest that the weather at specific growth stages, such as late R5 – R6, may influence the development of PSS or PSD on susceptible varieties and decrease grain quality. These results also support that some varieties may be more susceptible to diseases that cause poor grain quality than others.

Acknowledgments

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

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: J. Ross ed. Arkansas Soybean Handbook. p.6.

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.

Telenko, D. 2019. Fungal Diseases that Can Impact Soybean Pod and Seed Quality. Purdue University Extension. Accessed 1 April 2023. Available at: https://extension.purdue.edu/news/fieldcroppathology/2019/01/fungal-diseases-that-can-impact-soybean-pod-and-seed-quality.html?image

Fig. 1. Soybean seed exhibiting symptoms of purple seed stain.

Fig. 2. Soybean seed exhibiting symptoms of Phomopsis seed decay.

Fig. 3. Soybean seed exhibiting symptoms of frogeye leaf spot.

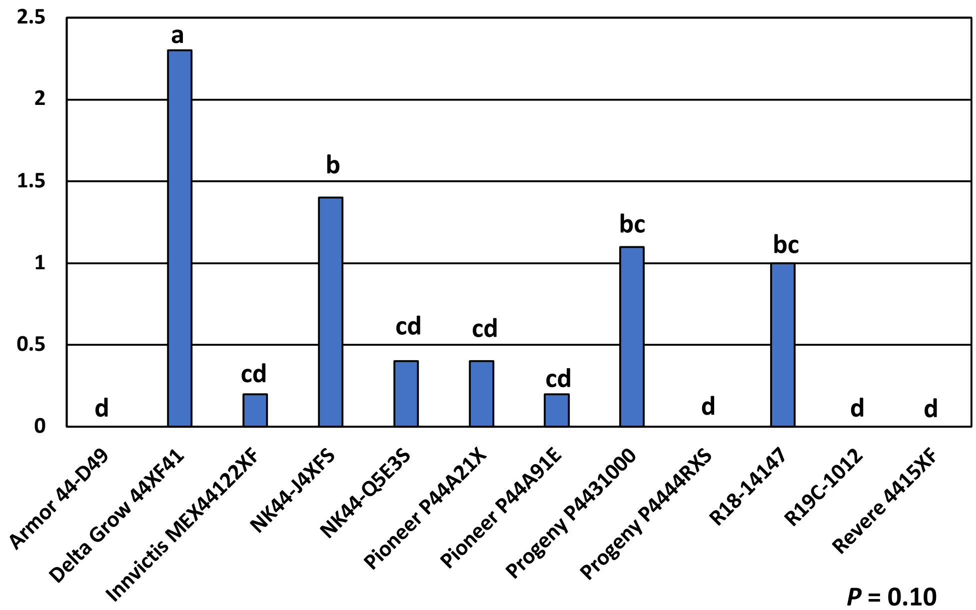

Fig. 4. Percent purple seed stain by variety within maturity group 4.4 in 2022. Means with the same letters are not significantly different using Fisher's least significant difference test at *P* = 0.10.

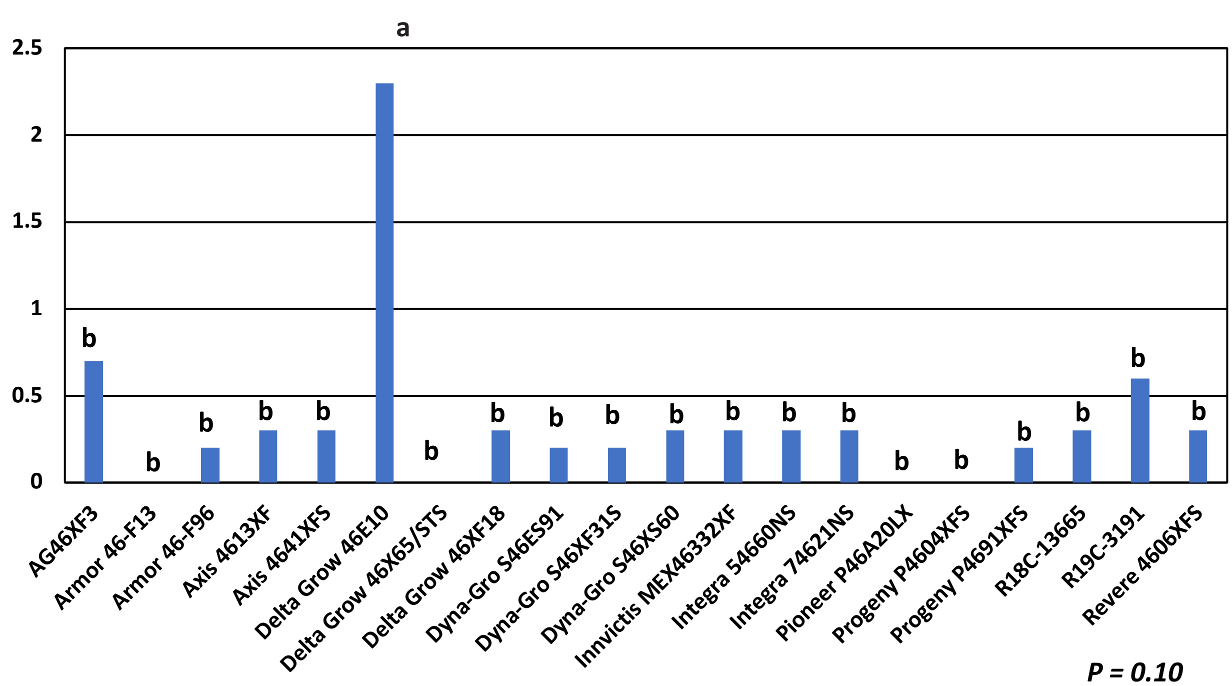

Fig. 5. Percent purple seed stain by variety within maturity group 4.6 in 2022. Means with the same letters are not significantly different using Fisher's least significant difference test at *P* = 0.10.

Discovery and Evaluation of a Novel Biocontrol Agent of Palmer Amaranth (Pigweed)

K.B. Swift,[1] T. Corbin,[1] K. Cartwright,[2] and B.H. Bluhm[1]

Abstract

Palmer amaranth (*Amaranthus palmeri* S. Watson), commonly known as Palmer pigweed, is problematic for soybean production throughout the mid-South. Palmer amaranth rapidly evolves resistance to herbicides; thus, alternative management tools are urgently needed. This project focused on identifying, optimizing, and commercializing bioherbicides derived from naturally occurring Palmer amaranth pathogens. In previous work, we identified 2 fungal pathogens (isolates AF22 and AF24) that were highly virulent on juvenile and adult Palmer amaranth plants. In the current study, we created a novel competition screen to identify additional candidate bioherbicide organisms. Seventy-seven taxonomically diverse Palmer amaranth pathogens (strains PWA1–PWA77) were applied simultaneously to soil containing germinating pigweed seeds. Pathogens were re-isolated from diseased pigweed seedlings, and their virulence on adult pigweed plants was evaluated individually. Strain PWA43 and re-isolated strains PWA78, PWA87, PWA98, and PWA110 consistently ranked among the most virulent strains in multiple assays. Morphologically, all 5 strains were highly similar, suggesting that PWA78, PWA87, PWA98, and PWA110 were re-isolations of strain PWA43. The genomes of strains PWA43 and PWA98 were sequenced and analyzed, which confirmed that PWA98 was a re-isolation of PWA43. PWA43 represents a novel bioherbicide candidate taxonomically distinct from previously identified candidates AF22 and AF24. The genomic resources created in this study will accelerate the optimization and commercial development of PWA43 as a bioherbicide for Palmer amaranth.

Introduction

Numerous pests threaten soybean [*Glycine max* (L.) Merr.] production in Arkansas to varying degrees, including weeds, insects, arthropods, pathogens, and nematodes (Baldwin et al., 2000; Lorenz et al., 2000; Kirkpatrick et al., 2014; Faske et al., 2014). Among all pests, weeds account for the greatest percentage of losses in row-crop agriculture (Oerke, 2006). In Arkansas, Palmer amaranth (*Amaranthus palmeri* S. Watson) has become the most difficult weed to control due to rapid growth, copious production of easily spread seed that can persist decades in soil, high levels of genetic diversity as a mandatory outcrossing species, and the demonstrated ability to evolve herbicide resistance rapidly (Chahal et al., 2015).

The ability of Palmer amaranth to evolve resistance to conventional herbicides is a serious problem for soybean production in Arkansas and much of the mid-South. Populations of Palmer amaranth have developed resistance to numerous pre and postemergence herbicides, including glyphosate, *S*-metolachlor, and, more recently, dicamba (Heap, 2023; Brabham et al., 2019; Foster and Steckel, 2022). Once herbicide resistance emerges, it can spread rapidly across production regions via the spread of resistant seeds and pollen, followed by interbreeding of resistant plants with local Palmer amaranth populations (Chahal et al., 2015).

Bioherbicides are plant control products consisting of (or derived from) living organisms and can complement or even replace conventional herbicides. Conceptually, bioherbicides have many attractive properties, including host specificity, environmental sustainability, and public acceptance (Hasan et al., 2021). However, a bioherbicide specifically targeting Palmer amaranth has not been commercially released.

For maximum control of Palmer amaranth, deploying multiple, taxonomically diverse bioherbicide organisms would be ideal. Such organisms could be deployed simultaneously or in rotation to deter the emergence of resistance. This concept is analogous to rotating multiple classes of conventional herbicides with distinct modes of action. In previous work, we identified 2 promising fungal pathogens (isolates AF22 and AF24) that were highly virulent on Palmer amaranth and are postulated to produce a host-specific toxin (Swift et al., 2022). Our current study aimed to identify additional, complementary bioherbicide candidates through a novel competition assay.

Procedures

Pathogen Isolations

Plant samples were surface sterilized prior to fungal isolation by immersion in 70% isopropanol for 1 minute, rinsing in sterile water for 30 seconds, and then immersion in 20% sodium hypochlorite for 2 minutes. Then, samples were rinsed in sterile water for 30 seconds and dried on autoclaved paper towels in a laminar flow hood. Once dry, diseased plant

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material was either plated onto fresh, sterile potato dextrose agar amended with carbenicillin (100 µg/mL) or transferred to moist chambers to induce fungal sporulation. Moist chambers consisted of glass Petri dishes lined with sterile paper towels dampened with sterile water. Moist chambers containing surface sterilized plant samples were incubated at room temperature in darkness to induce sporulation. Upon emergence of fungal reproductive structures, individual spores were collected with a needle under a stereomicroscope and transferred to potato dextrose agar plates amended with carbenicillin (100 µg/mL). When confirmed contamination-free, fungal cultures were cataloged and placed in long-term cryogenic storage at -80 °C.

Soil-Drench Assay

To prepare the inoculum, 77 taxonomically diverse Palmer amaranth pathogens (strains PWA1–PWA77) were grown on V8 juice agar plates (V8 agar) for 7–10 days. Cultures were homogenized individually with a commercial blender for 1 minute, combined into a single mixture, and homogenized for 3 minutes. The resulting inoculum (slurry of 77 cultures) was then applied to half of a greenhouse tray (21.44 in. by 10.94 in.) containing commercial potting soil. After moistening the soil, 3 rows of Palmer amaranth seeds were sown in each tray, with rows longitudinally bisecting the inoculated/uninoculated sections of the trays. Pigweed seedlings were evaluated for percent emergence (compared to uninoculated sections) and damping off symptoms (wilting, chlorosis, seedling death). Seedlings showing symptoms of damping off were collected for pathogen re-isolation (as described above).

Cut-Stem Assay

Fungal isolates collected from diseased Palmer amaranth plants were evaluated with a cut-stem assay to assess pathogenicity initially described by Twizeyimana et al. (2012) and modified by Swift et al. (2022). Briefly, fungi were cultured individually on V8 agar in darkness at room temperature. Palmer amaranth plants were grown from seed in a greenhouse with a 14-hr photoperiod in commercial potting soil. Healthy seedlings were transplanted 10 days after germination to individual 2.5-in. pots. Palmer amaranth plants were cut at the third to fifth node, inoculated with agar plugs from individual cultures, and covered with a sterile pipette tip. Disease severity was determined by measuring stem lesion lengths 12 and 16 days after inoculation. Data were analyzed as the average lesion length plus or minus the standard error of the mean for each isolate.

Genome Sequencing and Analysis

For strains PWA43 and PWA98, colonized plugs of V8 agar were cut from actively growing cultures and homogenized in 2 mL screw-cap centrifuge tubes containing 5 to 10 sterile glass beads (2 mm diameter) and 1 mL sterile distilled water. Tubes were placed in a Qiagen TissueLyser and shaken at a frequency of 30 beats per second for 5 minutes. Each tube of disrupted tissue was transferred into a 250 mL Erlenmeyer flask containing 50 mL of yeast extract peptone dextrose medium + 100 µg/ml carbenicillin. Inoculated flasks were incubated in darkness at room temperature for 6 to 10 days and agitated daily for aeration. Fungal tissue was harvested from flasks, rinsed, dried, and ground with a mortar and pestle in liquid nitrogen. For each strain, 5 g of frozen ground tissue was submitted to BGI Americas (Cambridge, Mass.) for DNA extraction and whole-genome sequencing on the DNBSEQ platform. Target genome sequence coverage was 40x. Data were processed with Qiagen CLC Genomics Workbench 22.0.2 for quality control analyses, de novo genome assembly, comparative genomic analyses, and alignments.

Results and Discussion

Palmer amaranth seedling emergence was low yet somewhat variable in the soil drench assay, ranging from 7% to 28% over 3 replications. Seeds that imbibed but failed to emerge displayed a range of symptoms, with darkening/rotting of nascent roots and shoots observed most frequently. Among seedlings that emerged, most displayed symptoms of damping off within 3–5 days after emergence, including wilting, chlorotic leaves, necrotic stem tissue, and lesions on stems and leaves. In 3 replications of the soil drench assay, no Palmer amaranth seedlings growing in inoculated soil survived beyond 14 days after emergence.

Thirty-four fungi were isolated from diseased and dead Palmer amaranth seedlings (strains PWA78–PWA111). The isolates broadly fell into 2 groups. Group 1 was comprised of saprophytic fungi, including *Alternaria* spp., *Penicillium* spp., *Fusarium* spp., *Epicoccum* spp., and several other common plant-decomposing fungal genera. These isolates were most likely either naturally present in the soil or on the Palmer amaranth seeds' surfaces and subsequently colonized dead plant tissue. Group 2 isolates were morphologically indistinguishable, with colony character and conidial shape highly consistent with Colletotrichum spp. (Fig. 1; PWA78, PWA87, PWA98, and PWA110 as representative examples). This similarity suggested that the most virulent isolate in the assay was a single strain in the inoculum and that Group 2 likely represented multiple re-isolations of a single parental strain.

Group 2 isolates were compared to strains PWA1–PWA77 to assess whether one of the inoculum strains could be tentatively identified as the progenitor of Group 2. One strain, PWA43, strongly resembled Group 2 isolates in growth rate, colony character, and conidial shape (Fig. 1). Strain PWA43 was also one of the most virulent isolates in cut stem assays, with ratings comparable to Group 2 re-isolation strains (Swift et al., 2022). These similarities supported the preliminary identification of strain PWA43 as the primary cause of Palmer amaranth lethality in the soil drench assay.

To conclusively demonstrate that PWA43 was a progenitor of Group 2 isolates, we performed whole-genome sequencing and assembly on strains PWA43 and PWA98, selected randomly among Group 2 isolates. The genome assemblies of both organisms were similar in size and of high coverage and quality (Table 1). Contigs were of sufficient size (N50 values of 196,483 bp and 210,011 bp for PWA43 and PWA98, respectively) for whole-genome alignments, which revealed high levels of nucleotide identity and synteny (Fig. 2). Based on the genomic analyses, we confirmed that strain PWA98 was a re-isolation of PWA43 from diseased pigweed seedlings. A preliminary phylogenetic analysis based on the internal transcribed spacer (ITS) sequence confirmed that PWA43 is a member of the fungal genus Colletotrichum and is potentially an undescribed species.

In previous work, we identified 2 promising bioherbicide organisms, isolates AF22 and AF24 (Swift et al., 2022). The discovery of PWA43 provides a new, taxonomically diverse bioherbicide candidate. Taxonomic diversity among bioherbicide candidates is important, as different groups of fungi utilize different strategies to kill plants. Thus, similar to how herbicides with different modes of action should be rotated to minimize the emergence of resistance, rotating diverse bioherbicides will extend the useful life of such products. Broad-spectrum virulence on juvenile and adult Palmer amaranth is also highly desirable in a bioherbicide. With this approach, a single bioherbicide could be utilized to kill juvenile plants before they compete for space or nutrients or produce offspring while also curbing the population of adult plants.

In future work, we will optimize the virulence and commercial potential of PWA43 through various approaches, including non-transgenic genome editing. The genome sequencing resources created in this project will directly facilitate such efforts.

Practical Applications

Palmer amaranth is one of the most widespread and problematic weeds for Arkansas soybean producers. Bioherbicides are a promising alternative management tool for herbicide-resistant weeds like Palmer amaranth. The novel competition screen described in this study helps remove one of the major roadblocks in bioherbicide development, namely the rapid identification of promising candidates. Application of this approach highlighted strain PWA43 as an excellent bioherbicide candidate, and the genomic resources created in this project will support the optimization and commercialization of the strain. In conjunction with the earlier discovery of bioherbicide candidates AF22 and AF24, we envision PWA43 as a future component of a bioherbicide rotation strategy, combined with conventional integrated pest management tools, to suppress Palmer amaranth populations in Arkansas.

Acknowledgments

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Literature Cited

Baldwin, F., L. Oliver, and K. Smith. 2000. Weed Control. Arkansas Soybean Production Handbook. Chapter 9. Accessed 30 April 2023. Available at: https://www.uaex.uada.edu/publications/pdf/mp197/chapter9.pdf

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. doi:10.1017/wet.2019.44.

Chahal, P.S., J.S. Aulakh, M. Jugulum, and A.J. Jhala. 2015. Herbicide-resistant Palmer amaranth (A*maranthus palmeri* S. Wats.) in the United States—Mechanisms of Resistance, Impact, and Management. Pages 1–29 in A. Price, ed. Herbicides, Agronomic Crops, and Weed Biology. InTech, Rijeka, Croatia. doi: 10.5772/61512.

Faske, T., T. Kirkpatrick, J. Zhou, and I.E. Tzanetakis. 2014. Soybean Disease. Arkansas Soybean Production Handbook. Chapter 11. Accessed 30 April 2023. Available at: https://www.uaex.uada.edu/publications/pdf/mp197/chapter11.pdf

Foster, D.C., and L.E. Steckel. 2022. Confirmation of Dicamba-resistant Palmer amaranth in Tennessee. Weed Technol. 36: 777–780. https://doi.org/10.1017/wet.2022.87

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.

Heap, I. 2022. The international herbicide-resistant weed database. Accessed 30 April. 2023. Available at: http://roadsideweeds.com/Summary/SpeciesbySOATable.aspx

Kirkpatrick, T., T. Faske, and B. Robbins. 2014. Nematode Management. Arkansas Soybean Production Handbook. Chapter 10. Accessed 30 April 2023. Available at: https://www.uaex.uada.edu/publications/pdf/mp197/chapter10.pdf

Lorenz G., D. Johnson, G. Studebaker, C. Allen, and S. Young, III. 2000. Insect Pest Management in Soybeans. Arkansas Soybean Production Handbook. Chapter 12. Accessed 30 April 2023. Available at: https://www.uaex.uada.edu/publications/pdf/mp197/chapter12.pdf

Oerke, E.-C. 2006. Crop Losses to Pests. J. Agri. Sci. 144:31-43.

Swift, K.B., K. Cartwright, and B.H. Bluhm. 2022. Accelerated Development of Bioherbicides to Control Palmer Amaranth (Pigweed). In: J. Ross, ed. Arkansas Soybean Research Studies 2021. Agricultural Experiment Station, Research Series 689:72–76. Fayetteville.

Twizeyimana, M., C.B. Hill, M. Pawlowski, C. Paul, and G.L. Hartman. 2012. A Cut-stem Inoculation Technique to Evaluate Soybean for Fesistance to *Macrophomina phaseolina*. Plant Dis. 96:1210-1215.

Field Performance of Thirty-Six Soybean Varieties Marketed as Resistant to Southern Root-Knot Nematode, 2022

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Abstract

The susceptibility of 36 soybean cultivars to the southern root-knot nematode (*Meloidogyne incognita*) was evaluated in 3 field trials. The damage threshold was severe in all trials, with an average population density of 1,843 second-stage juveniles/100 cm^3 of soil at harvest. Host susceptibility was based on the percent of the root system galled at the R5–R6 growth stage. Cultivars were considered very resistant if the percentage of root system galled was between 0.0% to 1.0%, resistant from 1.1% to 4.0%, and moderately resistant from 4.1% to 9.0%. Of the maturity group 4, Roundup Ready®, Roundup Ready/Xtend®, XtendFlex®, and Enlist® E3 cultivars, Pioneer P43A42X and Delta Grow DG4940 GLY were resistant. At the same time, Petrus Seed 49G16, Dyna-Gro S48EN02, Progeny P4431E3, Local LS4918E3S, Go Soy 493E22N, AgriGold G4881E3, Delta Grow 46E10, and Pioneer 46A35X were moderately resistant. In the maturity group 5 Roundup, Roundup Ready/Xtend, XtendFlex, and Enlist E3 trial, Pioneer P52A14E, Pioneer P56A71E, and Delta Grow 54XF20 were resistant, Delta Grow 55X25 RR2X, Local Seed LS5588X, Syngenta NK52-D6E3, Pioneer P54A54X, and Progeny P5554RX were moderately resistant. The 5 resistant cultivars would be preferred in fields with a high density of southern root-knot nematode; however, the other 13 moderately resistant cultivars would be useful at lower nematode densities.

Introduction

The southern root-knot nematode (SRKN), *Meloidogyne incognita*, is one of the world's most economically important plant parasites and significantly impacts soybean production. (Gorny et al., 2021). During the 2021 cropping season, yield losses by SRKN were estimated at 6.66 million bushels in Arkansas and 17.11 million bushels across the U.S. (Allen et al., 2021). It has a host range of over 3,000 plant species, including a broad range of economically important host crops and many grass/weed species (Traverso et al., 2022). In Arkansas, it is considered one of the most damaging nematodes that affects soybean production. Management strategies for SRKN 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 effective when hosts such as peanuts (*Arachis hypogaea* L.) or a few grain sorghum hybrids 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 to manage RKN (Kirkpatrick et al., 2014). Unfortunately, resistance is limited in the most common maturity groups (MG 4) grown in the state (Emerson et al. 2022) 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's Cooperative Extension Service (CES). It only provides information on cultivars entered into their Official Variety Testing Program (OVT). This study aimed to expand on the RKN susceptibility and yield response of a few MG 4 and 5 cultivars that are marketed as resistant or identified as resistant from the OVT.

Procedures

Thirty-six soybean cultivars were evaluated in a farmer's field that was naturally infested with *Meloidogyne incognita* near Kerr, Ark. Cultivars were selected based on individual company ratings as resistance and are marketed as MG 4 and 5's for Arkansas (Table 1–3). Experiments were divided between maturity groups and herbicide tolerance: 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 14 June 2022 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 42 second-stage juveniles (J2)/100 cm^3 of soil with a final popu-

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lation density of 1,843 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 17 Oct. 2022 using an SPC-40 Almaco combine equipped with a Harvest Master weigh system (Harvest Master, Logan, Utah).

Data were subject to analysis of variance using ARM 2023.0 (Gylling Data Management, Inc., Brookings, S.D.). Mean separations were performed when appropriate using Tukey's honestly significant difference (HSD) test at $P = 0.05$.

Results and Discussion

Of the maturity group 4 Roundup Ready, Xtend, Xtend Flex, and Enlist E3 cultivars, there was a wide range in susceptibility, with 2.9% to 31% of the root system galled. One cultivar was resistant to the SRKN, Pioneer 43A42X, and had a lower ($P = 0.05$) gall rating than Delta Grow DG4880, the susceptible control (Tables 1 and 2); however, this cultivar had a slightly higher gall rating in 2021 and was moderately resistant in one of the trials in this study. This difference is an indication and an example of the variability in nematode populations across field trials and from year to year. This resistant cultivar had an average grain yield of 60 bu./ac, which was 21 bu./ac greater than the susceptible cultivars' average yield (39 bu./ac).

Of the maturity group 5, Roundup Ready, Xtend, Xtend Flex, and Enlist E3 cultivars, 3 were resistant. Susceptibility ranged from 1.3% to 26.3% of the root system galled across MG 5 cultivars. Delta Grow DG54XF20, Pioneer 52A14E, and Pioneer P56A71E were resistant, and all had a lower ($P = 0.05$) gall rating than Delta Grow DG52E80, the susceptible control cultivar (Table 3). These resistant cultivars' grain yield average was 44 bu./ac, which was 12 bu./ac greater than the susceptible cultivars' average yield (32 bu./ac).

Practical Applications

The southern root-knot nematode is an important yield-limiting pathogen affecting soybean production worldwide. Data from this trial provides information on cultivars' susceptibility to the southern root-knot nematode and its impact on susceptible soybean cultivars in Arkansas. Cultivar selection should be based on at least 2 years of screening, as there is variation in root galling, field location, and yield between seasons.

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Literature Cited

Allen T. W., Bissonnette, K., Bradley, C. A., Dufault, N. S., Faske, T. R, Isakeit, T., Kemerait, R. C., Koehler, A., Langston, D., Lofton, J., Mueller, J. D., Padgett, G. B., Price, P. P., Sikora, E. J., Small, I.M., Vann, R., and Young, H. 2021. Southern United States soybean disease loss estimate for 2020. Proceedings of the Southern Soybean Disease Workers, Pensacola, Fla., 4–5 March 2021.

Emerson, M., J. Kelly, and T. R. Faske. 2022. Field performance of forty group 4 and 5 soybean cultivars in a root-knot nematode-infested field. *In:* J. Ross, ed. Arkansas Soybean Research Studies 2022. Arkansas Agricultural Experiment Station Research Series 698:67-71. Fayetteville.

Gorny, A., Ye, W., Cude, S., and Thiessen, L. 2021. Soybean Root-knot Nematode: A Diagnostic Guide. Plant Health Progress 22:164–175.

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

Traverso, E., and Koehler, A. 2022. Root-knot Nematodes in Delaware. Accessed 3 Oct. 2023. Available at https://www.udel.edu/content/dam/udelImages/canr/pdfs/RKN-Factsheet-2022_final.pdf

Table 1. Susceptibility and yield of fifteen Roundup Ready®, Xtend®, Xtend Flex®, and Enlist E3® maturity group 4 soybean cultivars grown in a southern root-knot nematode infested field.

Cultivar	Root System Galled†	Susceptibility‡	Yield
	(%)		(bu./ac)§
Pioneer P43A42X (check)	2.9 d¶	R	63.5 a
Petrus Seed 49G16	4.9 cd	MR	61.0 a
Dyna-Gro S48EN02	5.7 cd	MR	60.9 a
Delta Grow DG4940 GLY	3.8 cd	R	60.3 a
Progeny P4431E3	6.0 cd	MR	60.1 a
Local LS4918E3S	7.9 cd	MR	60.0 a
Progeny P4444RXS	9.4 cd	MS	57.9 ab
Stine 49EE21	11.3 bc	MS	57.7 ab
NK45-V9E3	11.3 bc	MS	55.6 abc
Delta Grow 47E20	12.7 bc	MS	49.1 a-d
Stine 46EB22	10.8 bcd	MS	48.5 a-e
Delta Grow DG49E20 (check)	22.6 ab	S	43.5 b-e
NK46-B4XFS	27.7 a	S	39.5 cde
Delta Grow DG4880 GLY (check)	21.7 ab	S	37.3 de
Donmario DM48E62S	28.4 a	S	32.4 e

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

‡ Susceptibility was based on percent of root system galled where 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.

§ 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. Susceptibility and yield from fourteen Roundup Ready®, Xtend®, Xtend Flex®, and Enlist E3® maturity group 4 soybean cultivars grown in a southern root-knot nematode infested field.

Cultivar	Root System Galled†	Susceptibility‡	Yield
	(%)		(bu./ac)§
Pioneer P43A42X (check)	3.5 d¶	R	55.9 a
Go Soy Ireane	4.5 d	MR	54.2 ab
NK44-Q5E3S	13.2 abcd	MS	53.5 ab
Go Soy 493E22N	6.9 cd	MR	52.4 ab
AgriGold G4881E3	8.7 bcd	MR	52.3 ab
Delta Grow 46E10	6.1 cd	MR	51.8 ab
Pioneer P46A35X	7.8 cd	MR	50.7 ab
Delta Grow DG49E20/STS (check)	26.0 ab	S	42.8 abc
NK42-T5XF	25.9 ab	S	42.2 abc
NK49-T6E3	19.0 abc	MS	41.1 abc
Delta Grow DG4880 GLY (check)	31.0 a	S	41.1 abc
NK44-J4XFS	29.5 ab	S	40.9 abc
NK43-Y9XFS	19.6 abc	MS	37.8 bc
NK45-P9XF	30.0 a	S	32.8 c

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

‡ Susceptibility was based on percent of root system galled where 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.

§ 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. Susceptibility and yield from ten Roundup Ready®, Xtend®, Xtend Flex®, and Enlist E3® maturity group 5 soybean cultivars grown in a southern root-knot nematode infested field.

Cultivar	Root System Galled†	Susceptibility‡	Yield
	(%)		(bu./ac)§
Pioneer P52A14E (check)	1.3 c¶	R	51.2 a
NK52-D6E3	7.7 abc	MR	50.5 a
Pioneer P54A54X	8.8 abc	MR	47.7 a
Local Seed LS5588X	4.8 bc	MR	44.8 a
Delta Grow 55X25 RR2X	4.1 bc	MR	43.8 ab
Delta Grow 54XF20	3.5 bc	R	43.1 ab
Progeny P5554RX	6.7 abc	MR	41.6 ab
Pioneer P56A71E	2.1 bc	R	39.1 ab
Delta Grow DG52E80 (check)	26.3 a	S	32.0 b
NK55-T5XF	11.1 ab	MS	31.5 b

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

‡ Susceptibility was based on percent of root system galled where 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.

§ 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.

PEST MANAGEMENT: DISEASE CONTROL

Reproduction of *Meloidogyne incognita* and *Rotylenchulus reniformis* on Five Sesame Varieties

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

Abstract

Sesame (*Sesame indicum*) is being used in some states to manage the southern root-knot nematode (*Meloidogyne incognita*) and reniform nematode (*Rotylenchulus reniformis*) in field crops. There is no information on the host suitability of sesame to Arkansas biotypes of these nematode species. In a greenhouse pot assay, nematode reproduction was evaluated on 5 sesame varieties, S32, S3251, S4302, S4326, and 20130-19. All varieties supported less nematode reproduction for *M. incognita* and *R. reniformis* compared to a susceptible soybean cultivar, Delta Grow DG 4880 GLY. The results indicate that sesame would be a good rotational host option to manage these nematode species in Arkansas.

Introduction

Sesame (*Sesame indicum*) is an option as a rotational crop in soybean [*Glycine max* (L.) Merr.] production to manage plant-pathogenic nematodes. A few studies have reported on the reproduction of the southern root-knot nematode (*Meloidogyne incognita*) and reniform nematode (*Rotylenchulus reniformis*) on sesame. While most studies agree that sesame is a poor host for the southern root-knot nematode, other studies report that sesame ranges in host suitability from poor to good for the reniform nematode (Anter et al., 1989; Starr and Black, 1995; Rodriguez-Kabana et al., 1998; Walker et al., 1998).

Sesame has been grown from time to time in Arkansas as a rotation crop, and acreage has varied greatly in recent years. According to the USDA Farm Service Agency, 50,000 acres were planted in 2021 in the U.S., with 95 acres in Arkansas (Greene County). However, in 2013, there were about 15,000 acres across the state. Sesame has low input cost and is profitable compared to other crops, but wet weather conditions at harvest can prove risky for sesame production, which can take 150 days to mature. Thus, in some years, sesame fields have gone unharvested. Though sesame was reported to be a suitable rotational crop to manage soybean nematodes, there is no information about how nematode biotypes from Arkansas reproduce on sesame.

Furthermore, as varieties are selected for improved yield potential, they are not screened for suitability to soybean nematodes. The objective of this study was to assess the reproduction of *M. incognita* and *R. reniformis* on commercially available soybean varieties that may be grown in the future in the mid-southern U.S.

Procedures

An isolate of *M. incognita* (Leachville) and *R. reniformis* (Kerr) were collected on soybean in Arkansas and maintained in a greenhouse on a susceptible tomato cultivar, Rutgers. Eggs were used as inoculum for *M. incognita* and mixed-life stages for *R. reniformis*. The 5 sesame varieties, S32, S3251, S4302, S4326, and 20130-19, were provided by Sesaco Corporation (Austin, Texas).

In the *M. incognita* experiment, 2 sesame seeds were planted into cone-tainers (164 cm^3) filled with pasteurized coarse sand. Seedlings were thinned to 1 plant per pot 7 days after planting. Each seedling was inoculated with 5,000 eggs 21 days after planting in 2 ml of water dispersed in 3 1-inch-deep cavities around each seedling.

A susceptible soybean cultivar, Delta Grow DG 4880 GLY, was used as a comparative control. The soybean cultivar was planted 7 days after the sesame but inoculated at the same time. The treatments were arranged in a randomized complete block design, and the experiment was conducted once. Roots were sampled 28 days after inoculation, rinsed free of soil, and eggs were extracted with 1% NaOCl. Eggs were enumerated with a stereoscope and reported as eggs per gram of root.

In the *R. reniformis* experiment, 6 sesame seeds were planted into 6-inch clay pots filled with pasteurized loamy sand soil. Seedlings were thinned to 3 per pot 7 days after planting. Each seedling was inoculated with 1,400 mixed-life stages of the reniform nematode 14 days after planting in 2 ml of water dispersed in 3 1-inch-deep cavities around each seedling. A susceptible soybean cultivar, Delta Grow DG 4880 GLY, was used. The soybean cultivar was planted

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7 days after the sesame but inoculated at the same time. The treatments were arranged in a randomized complete block design, and the experiment was conducted once. Roots were sampled 49 days after inoculation, rinsed free of soil, and eggs were extracted with 1% NaOCl. Eggs were enumerated with a stereoscope and reported as eggs per gram of root.

Statistics: Data were subject to analysis of variance (ANOVA) and mean separation with the Waller-Duncan test at $\alpha = 0.05$ using SPSS 27.0 (IBM Crop, Armonk, N.Y.).

Results and Discussion

Reproduction by *M. incognita* ranged from 0 to 47 eggs/g root among sesame varieties. It was lower ($P \leq 0.05$) on all sesame varieties compared to the susceptible soybean cultivar (Fig. 1). Therefore supporting sesame as a poor host (Starr and Black, 1995; Walker et al., 1998). Reproduction by *R. reniformis* ranged from 18 to 1,423 mixed-life stages among sesame varieties. It was lower ($P \leq 0.05$) on all varieties than the susceptible soybean cultivar (Fig. 2). Therefore supporting variation in host suitability of sesame to the reniform nematode (Anter et al., 1989). Sesame was a poor host to *M. incognita* and *R. reniformis* compared to a susceptible soybean cultivar.

Sesame would be a good crop rotation option to manage *M. incognita*, whereas some sesame varieties should be used over others to manage *R. reniformis*. The variety, 20130-19, supported the lowest reproduction by *M. incognita* but the greatest by *R. reniformis*, indicating that resistance against one nematode does not confer resistance to another. Therefore, it would be important to confirm the host suitability of sesame varieties against the specific soybean nematode to be managed.

Practical Applications

Sesame is a poor host to *M. incognita* and *R. reniformis* compared to a susceptible soybean cultivar and could be used to suppress nematode densities in rotation with soybean.

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Literature Cited

Anter, E.A., M.M Abd-El-Gawad, and N.M. Abu-Hagaza. 1989. Reaction of sesame, *Sesamum indicum* L., genotypes to the infection of reniform nematode, *Rotylenchulus reniformis* Linford and Oliviera. Ann. Ag. Sci., Moshtohor 27:1266-1267.

Rodriguez-Kabana, R., W.S. Gazaway, D.W. Weaver, P.S. King, and C.F. Weaver. 1998. Host suitability of selected tropical legumes and other crops for the reniform nematode, *Rotylenchulus reniformis*, Linford and Oliveira, 1940. Nematropica 28:195-203.

Starr, J.L., and M.C. Black. 1995. Reproduction of *Meloidogyne arenaria, M. incognita,* and *M. javanica* on sesame. J. Nematol. 27:624-627.

Walker, J.T., J.B. Melin, and J. Davis. 1998. Response of *Sesamum indicum* and *S. radiatum* accessions to root-knot nematode, *Meloidogyne incognita*. Supplement to the J. Nematol. 40:611-615.

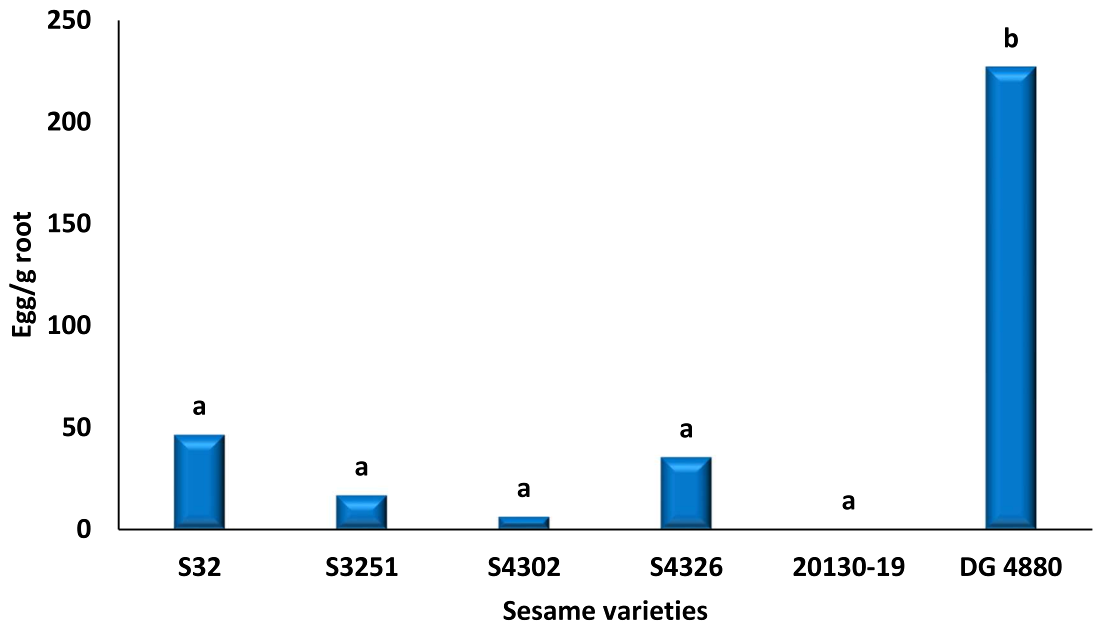

Fig. 1. Reproduction of *Meloidogyne incognita* on 5 sesame varieties in a greenhouse pot experiment. The soybean cultivar, Grow DG 4880 GLY, is susceptible to *M. incognita*. Different letters above bars indicate a difference at α = 0.05 according to the Waller-Duncan test.

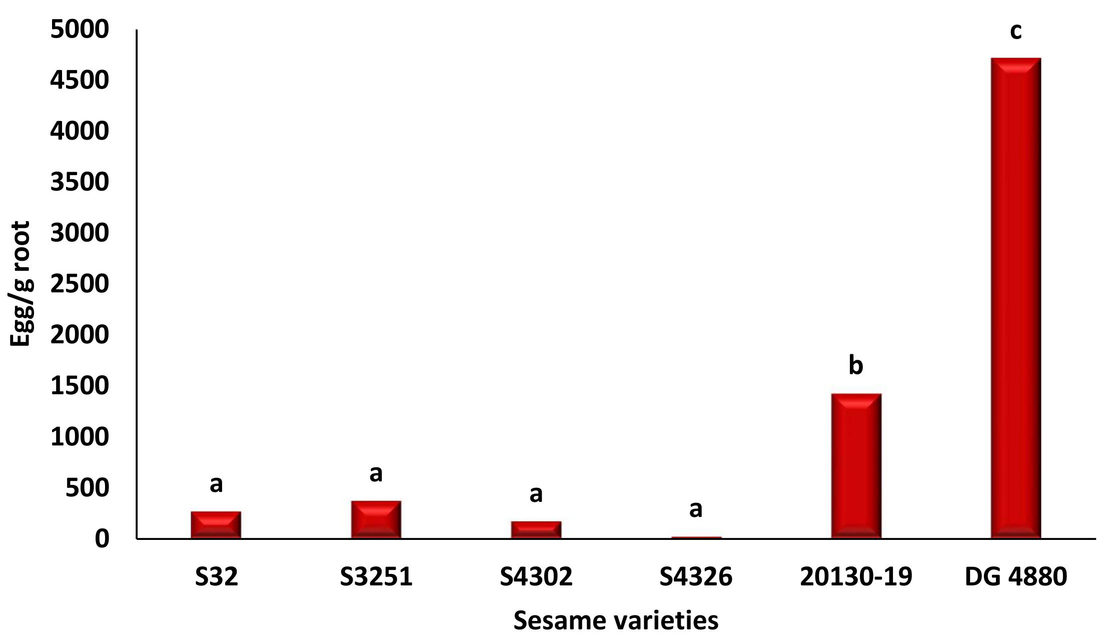

Fig. 2. Reproduction of *Rotylenchulus reniformis* on 5 sesame varieties in a greenhouse pot experiment. The soybean cultivar, DG 4880 GLY is susceptible to *R. reniformis*. Different letters above bars indicate a difference at α = 0.05 according to the Waller-Duncan test.

PEST MANAGEMENT: INSECT CONTROL

Efficacy of Selected Insecticides on Grasshoppers in Soybean

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Abstract

Grasshoppers are an occasional soybean pest in Arkansas, typically becoming an issue only in droughty years. This pest can be difficult to control due to its tolerance to many insecticides and high mobility. A trial was conducted on soybeans in Lincoln County, Ark., evaluating lambda-cyhalothrin 1.83 oz/ac (Warrior® II), bifenthrin 6.4 oz/ac (Discipline®), lambda-cyhalothrin 1.83 oz/ac + diflubenzuron 2 oz (Warriror II + Dimilin®), chlorantraniliprole (Vantacor®), lambda-cyhalothrin + acephate (Warrior II + Orthene®), lambda-cyhalothrin + chlorantraniliprole (Besiege®) for control of grasshoppers in soybean. Of the tested insecticides, lambda-cyhalothrin 1.83 oz/ac + acephate 0.5 lb/ac provided the greatest control.

Introduction

Grasshoppers are an occasional pest of soybean [*Glycine max* (L.) Merr.] in Arkansas, with the most common species infesting soybean being the redlegged grasshopper (*Melanoplus femurrubrum*) and the differential grasshopper (*Melanoplus differentialis*). Outbreaks of both species are more common in droughty years due to the greater survival rate of eggs and nymphs (Higley, 1994). Both species undergo 1 generation per year, with nymphs emerging in May to early June. Infestations typically occur along field edges, along grassy sites such as pastures and roadsides. Both nymphs and adults can cause injury through defoliation and pod feeding, and larger populations can cause severe yield loss. Grasshoppers are somewhat tolerant to many insecticides and are notoriously difficult to control and sample due to their high mobility.

Procedures

The trial was conducted on a grower field in Lincoln County, Ark., in 2022. Tested insecticides were lambda-cyhalothrin 1.83 oz/ac (Warrior® II), bifenthrin 6.4 oz/ac (Discipline®), lambda-cyhalothrin 1.83 oz/ac + diflubenzuron 2 oz (Warriror II + Dimilin®), chlorantraniliprole (Vantacor®), lambda-cyhalothrin + acephate (Warrior II + Orthene®), lambda-cyhalothrin + chlorantraniliprole (Besiege®). Plots were sprayed on 23 June and sampled 4, 7, 13, and 20 days after application (DAA). Plot size was 25 ft by 100 ft. 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. The data were subjected to analysis of variance and means separated using Duncan's New Multiple Range Test ($P = 0.10$) in Agriculture Research Manager V.9 (Gylling Data Management, Inc., Brookings, S.D.)

Results and Discussion

Lambda-cyhalothrin 1.83 oz/ac + acephate 0.5 lb/ac was the only treatment to reduce the density of grasshoppers at any of the 4 sample dates and, when analyzed across all sample dates, was the only product with significantly fewer grasshoppers than the untreated check. These data indicate that a pyrethroid, in combination with acephate, will likely provide the greatest control of a grasshopper infestation. Increasing the rate of acephate from 0.5 lb/ac to 0.75 lb/ac will likely provide greater control and will be tested in the future. Because of the relatively low cost of this combination and its effectiveness, it will be our control recommendation on soybeans going forward.

Practical Applications

Grasshoppers are an occasional pest of soybeans in Arkansas; however, they can be somewhat difficult to control when they do occur. This trial's results will help us understand what insecticides provide the greatest control of this pest.

Acknowledgments

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Literature Cited

Higley, L.G., and D.J. Boethel.1994. Handbook of soybean insect pests. Vol. 1. Entomological Society of America. pp. 57–59.

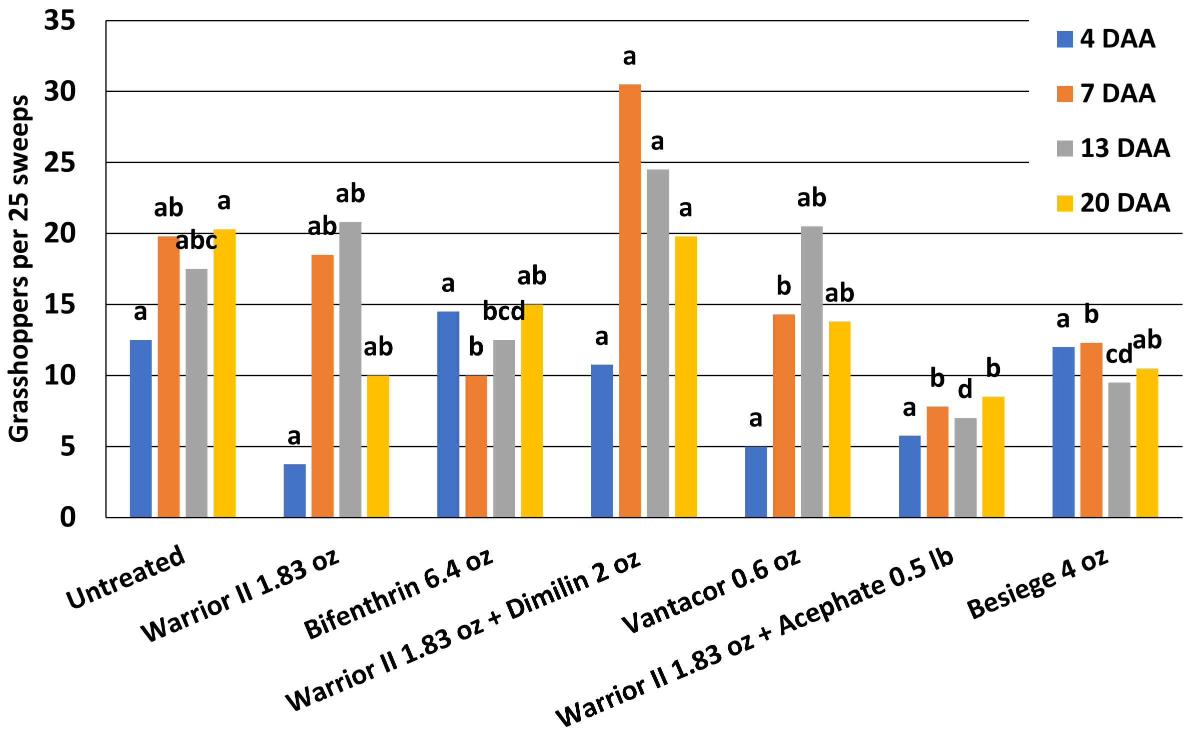

Fig. 1. Efficacy of selected insecticides for control of grasshoppers in soybean. Bars with the same letter are not statistically significant (*P* = 0.10). DAA = days after application.

Preliminary Tests on the Impact of Water Quality on Insecticide 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 water quality in a carrier solution. Multiple experiments were conducted to evaluate the impact of water hardness and pH on chlorantraniliprole efficacy for controlling corn earworms. In the first experiment, leaf dip assays were conducted to evaluate the effects of water pH on chlorantraniliprole. Serial dilutions were used to achieve the concentration of 6 ng/mL of chlorantraniliprole in 3 different water samples with a pH of 6.47, 8.31, and 9.12, respectively. Larvae were placed on 0.5-in. leaf discs after drying and observed for mortality 48 hours after application. In the next experiment, leaf dip assays were conducted similarly but with water at a hardness of 11 ppm, 178 ppm, and 430 ppm, respectively. A third experiment was conducted in the greenhouse where Prevathon® at a rate of 14 oz/ac was mixed with water with a hardness of 10.9 ppm, 178 ppm, and 430 ppm, respectively, then applied to soybean plants. Leaves were pulled from the soybean plants at 1, 7, 21, 28, and 35 days. Larvae were placed on 0.5 in. leaf discs and checked for mortality at 48 hours. In the final experiment, water samples with a hardness of 10.9 ppm, 178 ppm, and 430 ppm, respectively, were mixed with Vantacor® 1.2 oz/ac, Intrepid Edge® 5 oz/ac, Denim® 8 oz/ac, and Besiege® 7 oz/ac then sprayed on soybeans and evaluated at 4, 7, and 10 days after treatment for the control of corn earworm. The hardness leaf dips and pH leaf dips showed that as water hardness or pH increased, the % mortality decreased. In the greenhouse and field trials, there were no significant differences.

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. Two measures of water quality consist of hardness and pH. Water hardness is the density of cations such as calcium, magnesium, and iron present in water (Devkota, 2016). The positively charged ions bind with the negatively charged ions in the pesticide. This change in the solution's structure causes the pest not to absorb the molecules, enter at a slower rate, or form insoluble salts. These will show how effective a pesticide is (Tharp and Sigler, 2013). Water hardness in the mid-South ranges from very soft to very hard (Water Quality Association, 2022). The pH of water is a measure of its acidity or alkalinity. Water at various pH ranges in a spray solution may affect how long the molecule in the pesticide stays intact, affecting its efficacy. 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 and pH on corn earworm (*Helicoverpa zea*) insecticides in soybean [*Glycine max* (L.) Merr.].

Procedures

Hardness Leaf Dip

All soybean leaf dip assays were conducted using Vantacor at the University of Arkansas System Division of Agriculture's Lonoke Research and Extension Center. The leaf dip assay evaluating water hardness was conducted 3 times. Chlorantraniprole at 6 ng/mL was mixed into waters with a hardness of 11, 178, and 430 ppm. These assays used chlorantraniliprole 6 ng/mL with 3 water samples with their respective hardnesses. Leaf discs measuring 0.5 in. in diameter were dipped into each treatment. Leaves were allowed to dry and placed in thirty 100-mm Petri dishes of each treatment with a damp cotton pad and a second instar corn earworm larva. The larvae were checked at 48 h for mortality. Mortality data was analyzed using JMP 16.2

pH Leaf Dip

All soybean leaf dip assays were conducted using Vantacor at the University of Arkansas System Division of Agriculture's Lonoke Research and Extension Center. This assay consisted of 4 treatments, including the untreated check.

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Chlorantraniliprole 6 ng/mL was mixed with 3 water samples with pH of 6.5, 8.0, and 9.4. Leaf discs with a diameter of 0.5 in. were dipped into each treatment. Leaves were allowed to dry and placed in thirty 100 mm VWR petri dishes of each treatment with a damp cotton pad and a second instar corn earworm larva. The larvae were checked at 48 h for mortality.

Greenhouse Trial

Greenhouse trials were conducted at the Lonoke Research and Extension Center. Vantacor® 1.2 oz/ac was mixed with 3 water samples with a hardness of 11 (soft), 178 (hard), and 425 (very hard) ppm, then applied to 30 V4–V5 soybean plants for each treatment. Applications were made using the Generation 4 Research Tracker Sprayer (Devries Manufacturing, Hollandale, Minn.). After application, plants were placed back into the greenhouse. Leaves were pulled from the third node from the top of the plant at 1, 7, 21, 28, and 35 days after treatment. Larvae were placed on the leaves and checked for mortality at 48 h.

Field Trial

A field trial was conducted in the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart. Plot size was 12.5 ft. wide (4 rows) by 40 ft. Trials were arranged as a randomized complete block with 4 replications. Vantacor 1.2 oz/ ac, Intrepid Edge® 5 oz/ac, Denim® 8 oz/ac, and Besiege® 7 oz/ac were each mixed with water samples with a water hardness of 11 ppm, 186 ppm, and 425 ppm, respectively, including an untreated check for a total of 13 treatments. All treatments were mixed and allowed to sit for 3 hours before application. Applications were made using a Bowman Mudmaster at 10 gallons per acre using a TXVS-6 hollow cone nozzle. Plots were sampled using a sweep net 3, 7, and 10 days after application, and corn earworm larva numbers were recorded. The trial was set up in RCB, 4 reps of each treatment. Data were analyzed using JMP 9.4.

Results and Discussion

Hardness Leaf Dip

As water hardness increased, the percent mortality decreased (P = 0.02) (Fig. 1). Chlorantraniliprole mixed with water with a hardness of 420 ppm resulted in a 20% approximate decrease in mortality as compared to water with a hardness of 11 ppm.

pH Leaf Dip

As water pH increased, percent mortality decreased ($P < 0.01$) (Fig. 2). Chlorantraniliprole mixed with water with a pH of 9.4 resulted in a 20% approximate decrease in mortality as compared to water with a pH of 6.5.

Greenhouse Trial

In the greenhouse trial, there were no differences in the residual control provided by Vantacor mixed with hard and soft water (Fig. 3). However, Vantacor mixed with very hard water provided significantly less residual control than when mixed with soft or hard water. Vantacor mixed with soft or hard water lost approximately 0.5% and 0.75% of residual control per day and Vantacor mixed with very hard water lost approximately 1.5% residual control per day.

Field Trial

There were no significant differences in control between treatments at 4, 7, or 10 days after application (Figs. 4, 5, 6). There was not enough data for there to be differences in this trial. This trial must be replicated several times to see if the trends are significant.

Practical Applications

Many growers overlook water quality, but it can potentially have a large impact. Results from these studies indicate that chlorantraniliprole efficacy decreases as water hardness and pH increase. These trials and future research will be used to help make recommendations to growers to improve insect control in soybeans.

Acknowledgments

We thank the Arkansas Soybean Promotion Board for funding along with Helena Agri-Enterprises. Support was also provided by the University of Arkansas System Division of Agriculture.

Literature Cited

Devkota, P. 2016."The influence of carrier water quality, co-applied foliar fertilizer, and water conditioning adjuvant on herbicide efficacy" Open Access Dissertations. 1213. Accessed 10 Aug. 2023. Available at: https://docs.lib.purdue.edu/open_access_dissertations/1213

H_2O 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

Tharp, C., and A. Sigler. 2013. Pesticide performance and water quality. Accessed 10 Aug. 2022. Available at: https://www.montana.edu/extension/lewisclark/documents/MSU_Pesticide_Performance_and_Water_Qual.pdf

Whitford, F., D. Penner, B. Johnson, L. Bledsoe, N. Wagoner, J. Garr, K. Wise, J. Obermeyer, 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

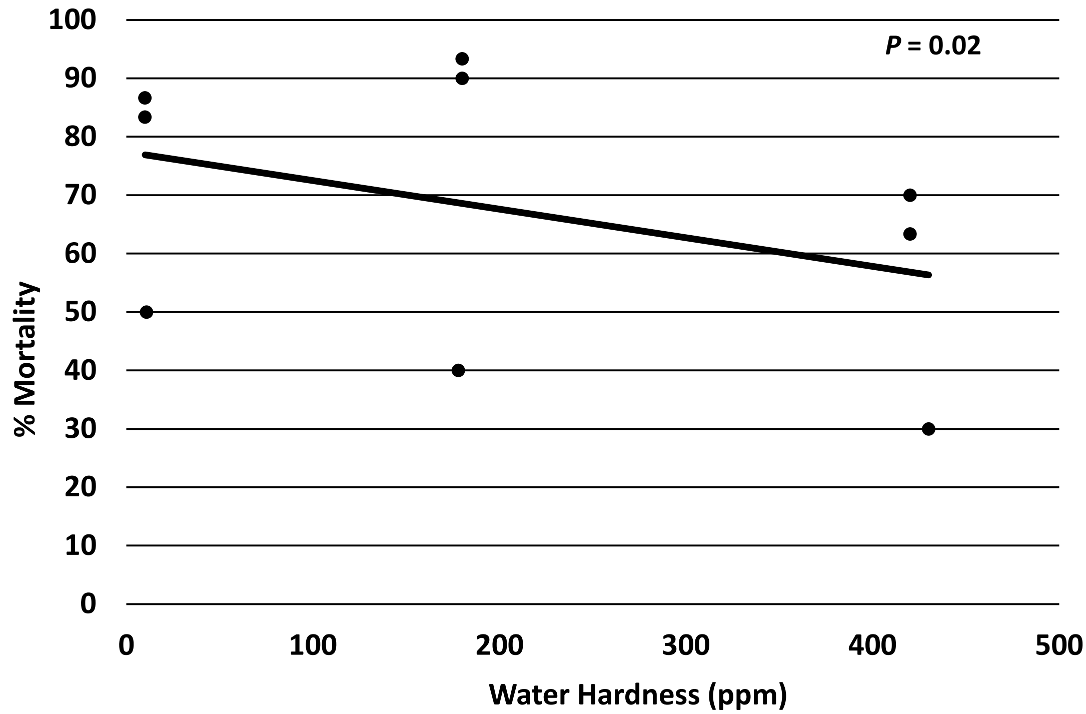

Fig. 1. Impact of water hardness on Vantacor® efficacy on *Helicoverpa zea* in leaf dip assays 48 hours after application.

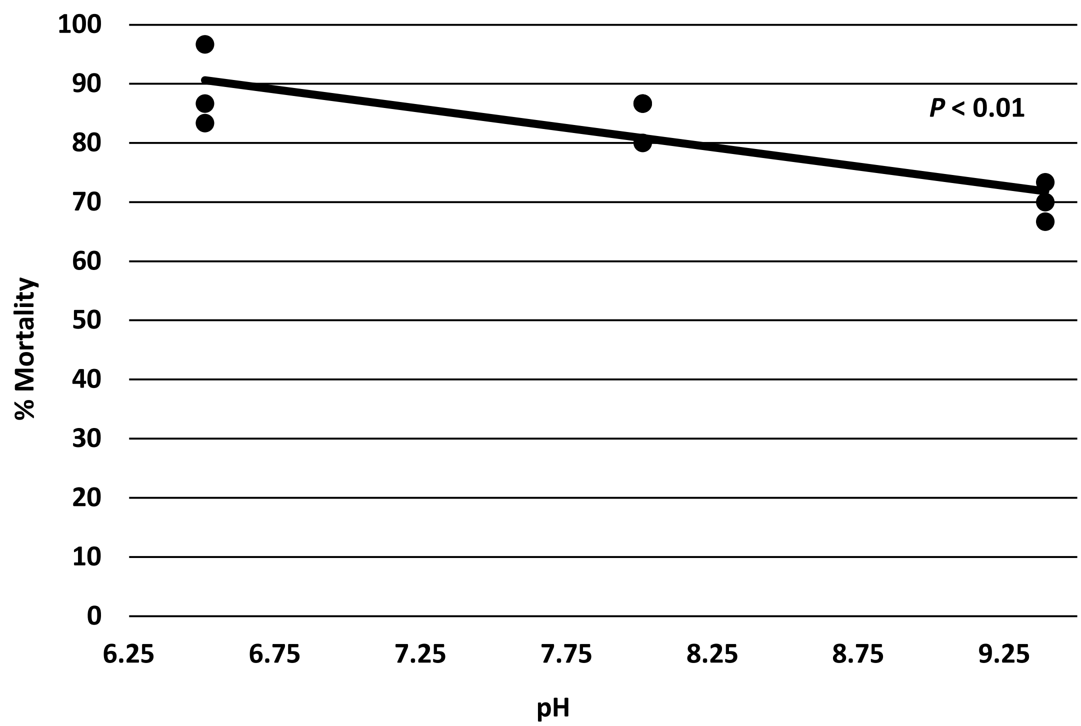

Fig. 2. Percent mortality of *Helicoverpa zea* for the effects of water pH on Vantacor® in leaf dip assays

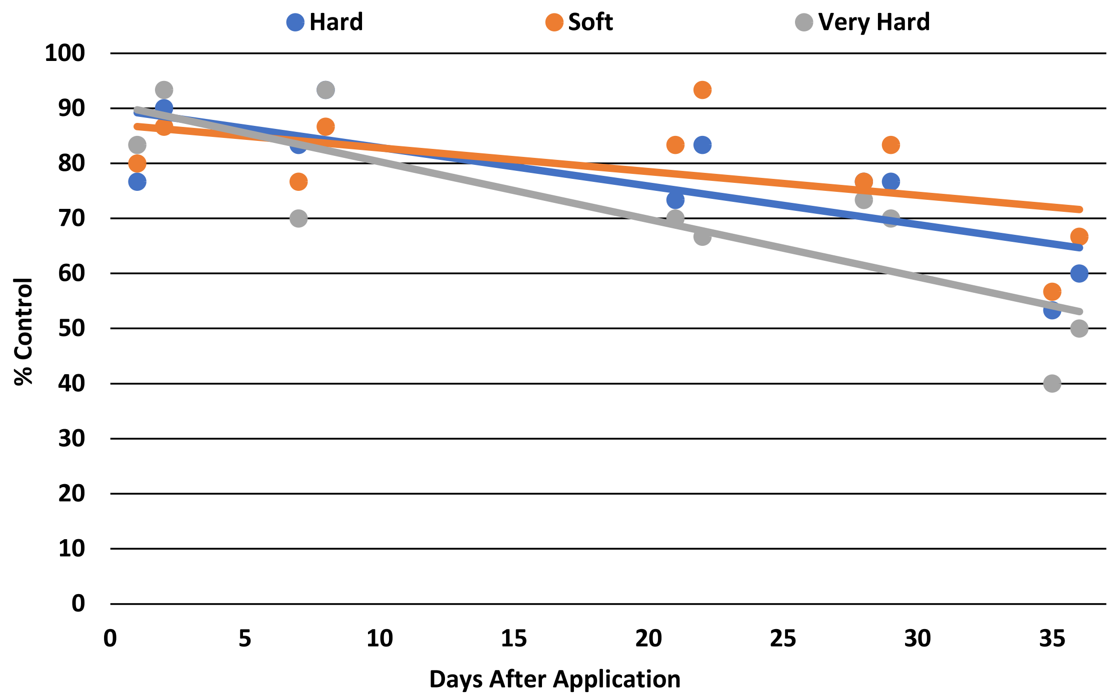

Fig. 3. Percent control of chlorantraniliprole residual control for *Helicoverpa zea* in the greenhouse.

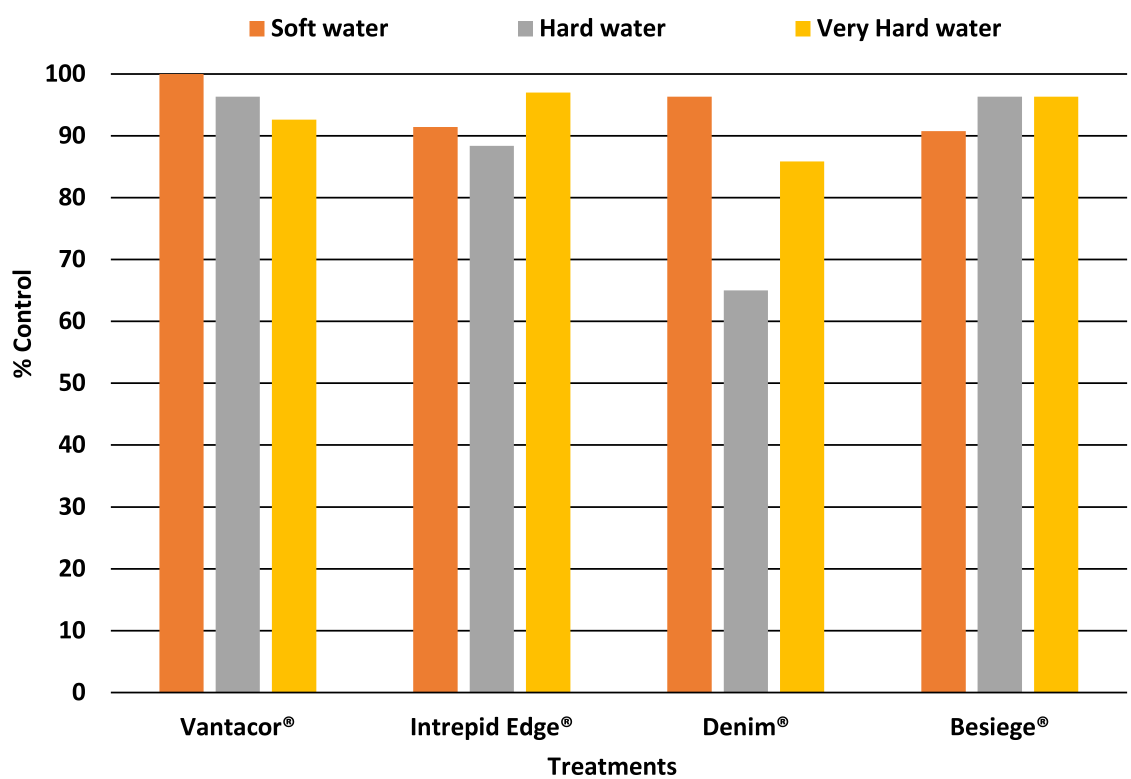

Fig. 4. Percent control of soybean insecticides at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., with soft, hard, and very hard water 4 days after application.

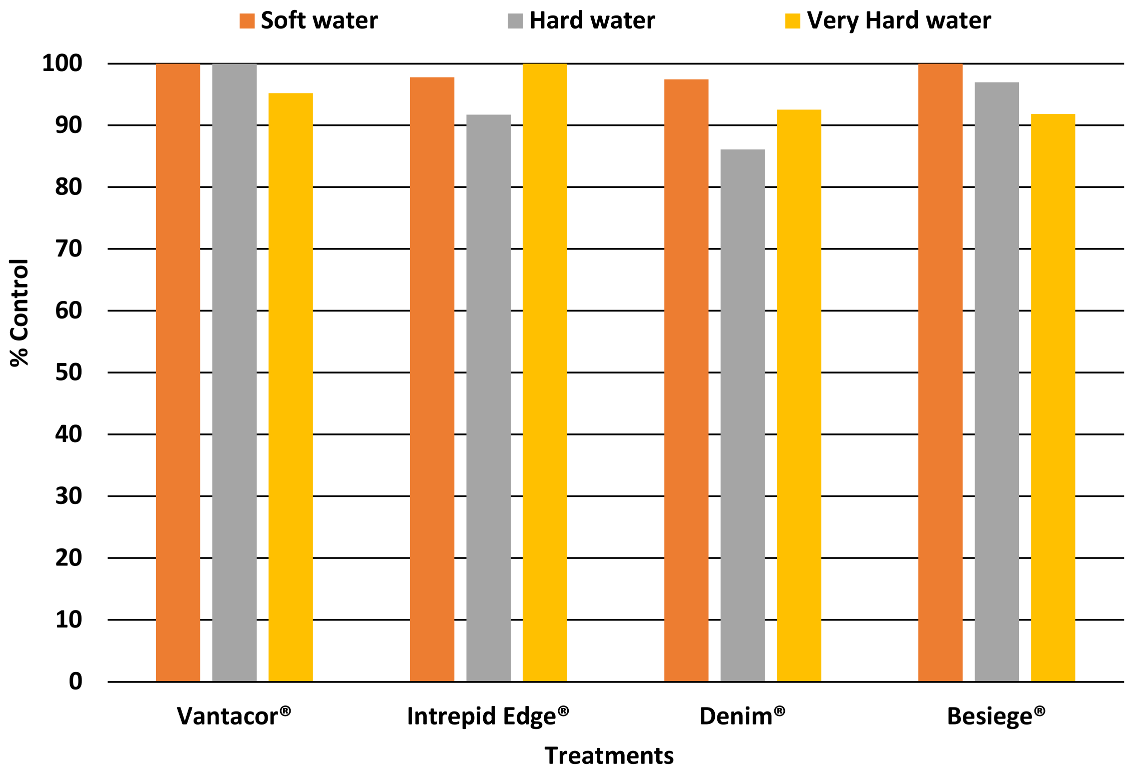

Fig. 5. Percent control of soybean insecticides at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., with soft, hard, and very hard water 7 days after application.

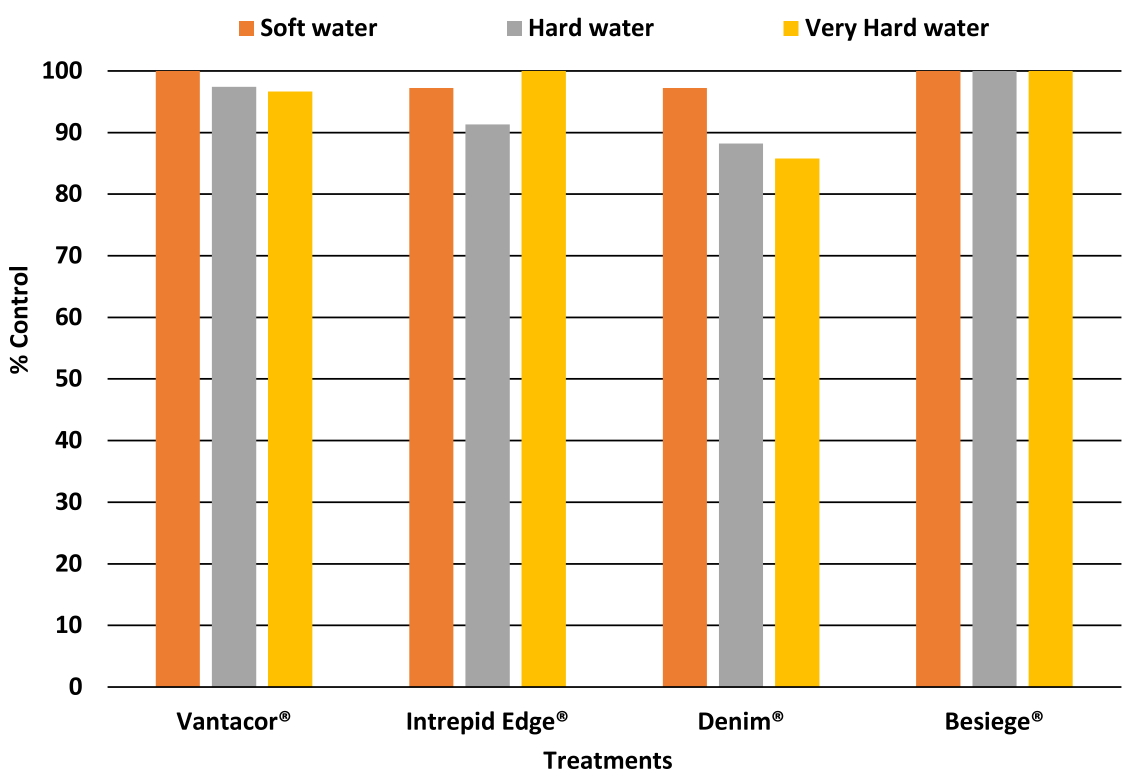

Fig. 6. Percent control of soybean insecticides at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark., with soft, hard, and very hard water 10 days after application.

Comparison of the Glufosinate Response Among Palmer Amaranth Populations from 2001 Versus 2020–2021

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Abstract

Glufosinate is a commonly used postemergence herbicide to control weeds in glufosinate-resistant cropping systems. Recently, glufosinate resistance was detected in Palmer amaranth (*Amaranthus palmeri* S. Wats.) accessions from Arkansas, and the amplification and overexpression of chloroplastic glutamine synthetase enzyme (*GS2*) was confirmed to be the resistance mechanism in one resistant population. It is uncertain when this variation in the gene occurred, and this study aimed to verify if the *GS2* copy number has increased over the years across Palmer amaranth populations with reduced susceptibility to glufosinate compared to accessions collected in 2001. Ten accessions from 2001 (A-01) and 13 accessions collected in 2020 or 2021 (A-20) were selected for this experiment. Seventy-five plants per accession were sprayed with glufosinate at 0.51 lb ai/ac to assess mortality. Gene copy number assay was conducted with DNA extracted from nontreated plants from A-01 and glufosinate survivors from A-20 accessions. Three biological replications were extracted for each accession, and each sample was assessed twice in each primer pair. Gene copy number was calculated relative to the Palmer amaranth reference gene. Glufosinate mortality decreased when comparing Palmer amaranth populations from 20+ years ago to those recently collected. All A-20 accessions tested had at least 3 survivors, while A-01 accessions had 100% mortality. Three clusters were formed with the mortality data. Cluster 1 comprised accessions with high mortality (96% to 100%) and included 2 A-20 accessions and all A-01 accessions. The other clusters only included A-20 accessions; mortality ranged from 82% to 93% and 52% to 68% in clusters 2 and 3, respectively. No significant difference was detected for gene copy number among the accessions when grouped by collection year. These results indicate that increased glufosinate tolerance is due to an unidentified mechanism(s), and additional investigations are necessary.

Introduction

The launching of glufosinate-resistant crops and the rapid proliferation of resistant weeds to glyphosate influenced farmers to implement a different chemical control option (Takano and Dayan, 2020). Glufosinate is a commonly applied postemergence option to control weeds in cropping systems carrying this resistance trait, and it is one of the foundational postemergence herbicides to manage resistant weeds in Enlist®, XtendFlex®, and LibertyLink® systems. Unsurprisingly, glufosinate use has increased exponentially over the last few years (USGS, 2018). Recently, glufosinate resistance was detected in Palmer amaranth (*Amaranthus palmeri* S. Wats.) accessions from Arkansas (Priess et al., 2022). Further investigations showed that the amplification and overexpression of chloroplastic glutamine synthetase enzyme (*GS2*) was the resistance mechanism in one of the resistant populations. Subsequent studies with a glufosinate-resistant Palmer amaranth population from Missouri also exhibited overproduction of the *GS2* enzyme (Nogueira et al., 2022). It is uncertain when this variation in the gene occurred, and this study aimed to verify if the *GS2* copy number has been increasing over the years across Palmer amaranth populations with reduced susceptibility to glufosinate compared to accessions collected in 2001.

Procedures

An experiment was conducted in greenhouses at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark., in 2022. Ten Palmer amaranth accessions from 2001 (A-01) and 13 accessions collected in 2020 or 2021 (A-20) were selected for this experiment. The resistance profile of the A-01 accessions is provided in Bond (2004). This experiment was organized in a completely randomized design with 3 replications. Each replication had 25 plants per accession. Seventy-five plants per accession were sprayed with glufosinate at 0.51 lb ai/ac to assess mortality. Applications were conducted in a spray chamber configured to deliver 20 gal/ac at 1 mph with flat fan 1100067 nozzles (TeeJet Technologies, Glendale Heights, Ill. USA) at 40 psi. Palmer amaranth seedlings were 3- to 4-inches at the time of application. Leaf tissue was collected prior to the applica-

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tion from nontreated plants. The total number of plants per accession in each replication was counted before application and 21 days after treatment (DAT) to calculate mortality (%). Mortality data were subjected to hierarchical cluster analysis using Ward's Minimum method in JMP Pro v. 17 (SAS Institute, Cary, N.C., USA).

At 21 DAT, young leaf tissue was collected from glufosinate survivors. There were no survivors among A-01 accessions. Therefore, a gene copy number assay was conducted with DNA extracted from nontreated plants from A-01 and glufosinate survivors from A-20 accessions. Three biological replications were extracted from each accession. Quantitative real-time polymerase chain reactions (qPCR) were conducted to quantify the *GS2* copy number. The *GS2* primer pair (Forward: 5'- ATCGTGGTTGCTCTATCCGTG-3'; Reverse: 5'-GTTTCTGCGAGCAAACCTGTT-3') was used to amplify the *GS2* gene. The genomic copy number of *GS2* was calculated relative to Peter Pan-like (PPAN), a known Palmer amaranth reference gene (González-Torralva and Norsworthy, 2021). Each sample was assessed twice in each primer pair. Positive (glufosinate-resistant Palmer amaranth), negative (glufosinate-susceptible Palmer amaranth), and blank controls using primers without DNA (substituted by deionized water) were included in each qPCR plate. The qPCR settings followed a previous methodology (Carvalho-Moore et al., 2022; González-Torralva and Norsworthy, 2021). Quantification cycles (Cq) were produced by CFX Maestro software, and the genomic copy number was calculated using a modified version of the $2^{-\Delta\Delta Ct}$ method (Gaines et al., 2010; Livak and Schmittgen, 2001). The data were grouped by collection year and subjected to analysis of variance using JMP Pro v.17. The correlation between mortality and *GS2* copy number was also calculated.

Results and Discussion

Glufosinate mortality decreased when comparing Palmer amaranth populations from more than 20 years ago to those recently collected. All A-20 accessions tested had at least 3 survivors, while A-01 accessions had 100% mortality. Three clusters were formed with the mortality data (Table 1). Cluster 1 comprised accessions with high mortality (96% to 100%) and included two A-20 accessions and all A-01 accessions. The other clusters only included A-20 accessions, and mortality ranged from 82% to 93% and 52% to 68% in clusters 2 and 3, respectively. No difference was detected for gene copy number among the accessions when grouped by collection year (Fig. 1). Inheritance experiments with a glufosinate-resistant Palmer amaranth population from North Carolina showed that resistance is also unlikely due to a single gene (Jones, 2022). Mortality was not correlated with the *GS2* copy number (r = 0.31). Contradictory to these results, the resistance level in a glyphosate-resistant tall waterhemp (*Amaranthus tuberculatus* [Moq.] J.D.Sauer) population was directly correlated with the amplification of the enzyme targeted by glyphosate (Dillon et al., 2017).

Practical Applications

When comparing Palmer amaranth populations collected in 2020–2021 versus the ones collected more than 20 years ago, it is evident that glufosinate efficacy has decreased among Palmer amaranth populations throughout the years. Postemergence options to control Palmer amaranth are scarce due to herbicide resistance, and glufosinate is a valuable chemistry to manage this weed. Herbicide stewardship practices such as crop-herbicide rotation, zero-threshold tolerance, and overlap of multiple sites of action are highly recommended. Furthermore, results indicate that increased glufosinate tolerance in Palmer amaranth accessions is unlikely due to the amplification of the targeted enzyme (*GS2*), which is the mechanism detected in a confirmed glufosinate-resistant accession. The mechanism conferring this decreased response remains unclear, and additional investigations are necessary.

Acknowledgments

The authors thank their fellow Weed Science colleagues 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 acknowledge the support provided by Arkansas soybean producers through checkoff funds administered by the Arkansas Soybean Promotion Board. The authors also thank BASF Corporation for funding this research.

Literature Cited

Bond, J.A. 2004. Variation in Palmer amaranth (*Amaranth palmeri*) across the southern United States. Ph.D. Dissertation. Fayetteville, Ark.: University of Arkansas. 113 p.

Carvalho-Moore, P., J.K. Norsworthy, F. González-Torralva, J.I. Hwang, J.D. Patel, L.T. Barber, T.R. Butts, and J.S. McElroy. 2022. Unraveling the mechanism of resistance in a glufosinate-resistant Palmer amaranth (*Amaranthus palmeri*) accession. Weed Sci. 70:370-379.

Dillon, A., V.K. Varanasi, T.V Danilova, D.H. Koo, S. Nakka, D.E. Peterson, P.J. Tranel, B. Friebe, B.S. Gill, and M. Jugulam. 2017. Physical mapping of amplified copies of the 5-enolpyruvylshikimate-3-phosphate synthase gene in glyphosate-resistant *Amaranthus tuberculatus*. Plant Physiol. 173:1226-1234.

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. 2010. Gene amplification confers glyphosate resistance in *Amaranthus palmeri*. Proc. Natl. Acad. Sci. 107:1029–1034

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

Jones, E.A.L. 2022. Glufosinate resistance in North Carolina and the development of a rapid assay to confirm the evolution of glufosinate-resistant weeds. Ph.D. Dissertation. Raleigh, N.C.: North Carolina University.

Livak, K.J., and T.D. Schmittgen. 2001. Analysis of relative gene expression data using real-time quantitative PCR and the 2−ΔΔCT method. Methods 25:402-408.

Noguera, M.M., A. Porri, I. S. Werle, J. Heiser, F. Brändle, J. Lerchl, B. Murphy, M. Betz, F. Gatzmann, M. Penkert, C. Tuerk, L. Meyer, and N. Roma-Burgos. 2022. Involvement of glutamine synthetase 2 (GS2) amplification and overexpression in *Amaranthus palmeri* resistance to glufosinate. Planta 256:57.

Priess, G.L., J.K. Norsworthy, N. Godara, A. Mauromoustakos, T.R. Butts, T.L. Roberts, T. Barber. 2022. Confirmation of glufosinate-resistant Palmer amaranth and response to other herbicides. Weed Technol. 36:368-372.

Takano, H.K., and F.E. Dayan. 2020. Glufosinate-ammonium: a review of the current state of knowledge. Pest Manag. Sci. 76:3911-3925.

USGS. 2018. United States Geological Survey. Glufosinate: Estimated Annual Agricultural Pesticide Use. Accessed 1 March 2023. Available at: https://water.usgs.gov/nawqa/pnsp/usage/maps/show_map.php?year=2018&map=GLUFOSINATE&hilo=L

Table 1. Ward's hierarchical clustering of Palmer amaranth accessions collected in 2001 (A-01) or recently (A-20) based on mortality 21 days after treatment with glufosinate at 0.51 lb ai/ac.

Cluster	Number of accessions	Accessions present		Mortality (%)	
		A-01	A-20	Minimum	Maximum
1	12	Present	Present	96	100
2	9	Absent	Present	82	93
3	2	Absent	Present	52	68

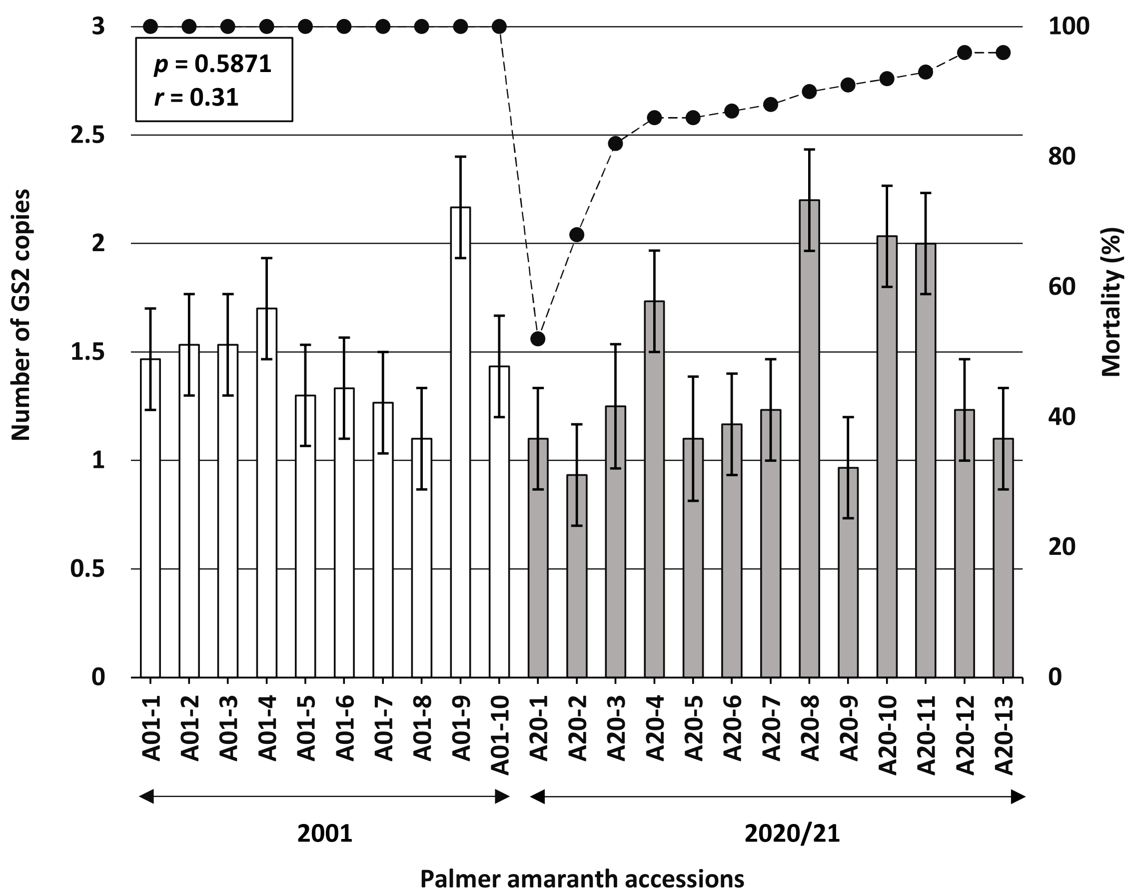

Fig 1. Chloroplastic glutamine synthetase (*GS2*) copy number calculated relative to Peter Pan-like (PPAN) reference gene in Palmer amaranth accessions collected in 2001 (white bars) and 2020 or 2021 (gray bars). The black line shows the mortality, and each marker represents the average per accession. Error bars represent standard errors (n = 3).

The Use of Fall Residuals for Ryegrass Management Ahead of Soybean

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Abstract

Italian ryegrass [*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot] has become more problematic and difficult to control because it is resistant to multiple herbicides. Fall-applied residual herbicides have effectively controlled other winter annual weeds and could be another option in controlling Italian ryegrass. The objective of this study was to evaluate multiple residual herbicides for the control of Italian ryegrass in the fall and the following spring before planting soybean [*Glycine max* (L.) Merr.]. Before any weed emergence, a field experiment was initiated at the University of Arkansas System Division of Agriculture's Jackson County Extension Center near Newport, Ark., in the fall of 2021. Treatments in this experiment consisted of Anthem® Flex (4 fl oz/ac), Command® (20 fl oz/ac), Dual Magnum® (1.33 pt/ac), Outlook® (16 fl oz/ac), Prowl® (2.1 pt/ac), Treflan® (2 pt/ac), Warrant® (2.5 pt/ac), Warrant® (5 pt/ac), and Zidua® SC (3.75 fl oz/ac). Initial visual control of Italian ryegrass 14 days after application (DAA) (28 Oct. 2021) exceeded 95% for every herbicide treatment except for Prowl and the low rate of Warrant. Only Zidua SC, Anthem Flex, and Dual Magnum retained effective residual control at 60 DAA (13 Dec. 2021) (>95%) and 166 DAA (29 March 2022) (>90%). Overall, using Zidua SC, Anthem Flex, and Dual Magnum herbicides were the most effective options to control Italian ryegrass in the fall and following spring before planting soybean. These fall-applied treatments would improve overall Italian ryegrass management and delay the evolution of resistance to postemergence herbicides.

Introduction

Herbicide-resistant Italian ryegrass [*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot] has become problematic to producers across Arkansas during spring burndown herbicide applications (Bond et al., 2014). Fall-applied residual herbicide applications have been shown to be effective in controlling other winter annual weeds and could provide the same effect in controlling Italian ryegrass (Hasty et al., 2004). Fall applications tend to be more effective because they target the earlier development of the weed, making them easier to control (Hasty et al., 2004). Dense populations of Italian ryegrass can negatively impact soybean [*Glycine max* (L.) Merr.] stand, stunt plants, and reduce the overall yield of that year's crop (Reddy, 2001). The objective of this study was to evaluate multiple fall-applied residual herbicides for the control of Italian ryegrass in the fall and the following spring before planting soybean.

Procedures

A field experiment was initiated at the University of Arkansas System Division of Agriculture's Jackson County Extension Center near Newport, Ark., in the fall of 2021 to evaluate fall-applied residual options for controlling Italian ryegrass ahead of soybean planting. The experimental design was a randomized complete block design with 4 replications and 10 treatments applied to a silt loam soil (Table 1). The plot size of this experiment was 7.5 ft by 30 ft in length. Applications were made on 14 Oct. 2021, prior to any weed emergence, using a Bowman MudMaster with a 5-ft multi-boom system calibrated to deliver 10 gallons per acre using AIXR 110015 nozzles (TeeJet Technologies, Springfield, Ill. 62703). At the time of application, the air temperature was 82 ºF. Additionally, the Treflan treatment was mechanically incorporated into the soil at a 1-in depth immediately following the herbicide application as directed by the herbicide label. Visual control ratings were taken at 14 (28 Oct. 2021), 60 (13 Dec. 2021), and 166 (29 March 2022) days after application (DAA). The weed control ratings were based on a scale of 0% (no control) to 100% (complete control, no emerged Italian ryegrass). All data were subjected to analysis of variance, and means were separated using Tukey's honestly significant difference ($\alpha = 0.05$) using JMP Pro 17.0

Results and Discussion

At 14 DAA (28 Oct. 2021), all residual herbicides provided effective initial visual control (>95%) of Italian ryegrass except for Prowl® (2.1 pt/ac) and the low rate of Warrant® at

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2.5 pt/ac (Fig. 1). Only Zidua® SC (3.75 fl oz/ac), Anthem® Flex (4 fl oz/ac), and Dual Magnum® (1.33 pt/ac) retained high levels of visual Italian ryegrass control (>95%) at 60 DAA (13 Dec. 2021). Outlook® (16 fl oz/ac) and Command® (20 fl oz/ac) provided adequate control (>85%) at 60 DAA (13 Dec. 2021), while Prowl and the low rate of Warrant retained no residual control of Italian ryegrass (Fig. 1). At 60 DAA (13 Dec. 2021), Treflan® (2 pt/ac) (68%) and the high rate of Warrant (5 pt/ac) (54%) did provide some residual control of Italian ryegrass; however, they were not as effective as Zidua SC, Anthem Flex, and Dual Magnum. At 166 DAA (29 Mar. 2022), Zidua SC, Anthem Flex, and Dual Magnum still provided excellent control (>90%) of Italian ryegrass. Outlook (81%), Command (84%), and Treflan (63%) retained some control at 166 DAA (29 Mar. 2022) but would require an effective burndown herbicide application to start weed-free prior to soybean planting. Prowl and both rates of Warrant did not provide residual control of Italian ryegrass at 166 DAA (29 Mar. 2022) and should not be considered as options for fall-applied residual control (Fig. 1).

Practical Implications

Overall, several excellent options exist for fall-applied residual control of Italian ryegrass before planting soybean the following spring. Zidua SC, Anthem Flex, and Dual Magnum were the best fall-applied residual options in this research for controlling Italian ryegrass. Outlook, Command, and Treflan could be viable fall-applied residual options if other herbicides are limited but would likely need an additional herbicide application in the spring before soybean planting to start weed-free. Prowl and Warrant were not viable options for fall-applied residual control of Italian ryegrass but might be considered for other problematic winter annual weeds. Using fall-applied residuals will help enhance Italian ryegrass management efforts and mitigate the further evolution of herbicide resistance. As a result, they should be considered and implemented for future soybean crops.

Acknowledgments

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Literature Cited

Bond, J., T. Eubank, R. Bond, B. Golden, and H. Edwards. 2014. Glyphosate-Resistant Italian Ryegrass (*Lolium perenne* ssp. *multiflorum*) Control with Fall-Applied Residual Herbicides. Weed Technol. 28:361-370.

Hasty, R., C. Sprague, and A. Hager. 2004. Weed Control with Fall and Early-Preplant Herbicide Applications in No-Till Soybean. Weed Technol. 18:887-892.

Reddy, K. 2001. Effects of Cereal and Legume Cover Crop Residues on Weeds, Yield, and Net Return in Soybean (*Glycine max*). Weed Technol. 15:660-668.

Table 1. Herbicide treatments including trade name, active ingredient, rates used, and rates (lb ai/ac) for the residual control of Italian ryegrass (*Lolium perenne* L. ssp. *Multiflorum)* ahead of planting soybean [*Glycine max* (L.) Merr.] at the University of Arkansas System Division of Agriculture's Jackson County Extension Center in Newport, Ark. in 2021 through 2022.

Treatment	Trade Name	Active Ingredient	Rate (per acre)	Rate (lb ai/ac)
1	Nontreated Control	-	-	-
2	Zidua SC	pyroxasulfone	3.75 fl oz	0.12
3	Anthem Flex	pyroxasulfone + carfentrazone	4.0 fl oz	0.12 + 0.01
4	Prowl	pendimethalin	2.1 pt	0.99
5	Treflan	trifluralin	2.0 pt	1.00
6	Dual Magnum	*S*-metolachlor	1.33 pt	1.27
7	Outlook	dimethenamid-P	16.0 fl oz	0.75
8	Warrant	acetochlor	2.5 pt	0.94
9	Warrant	acetochlor	5.0 pt	1.87
10	Command	clomazone	20.0 fl oz	0.47

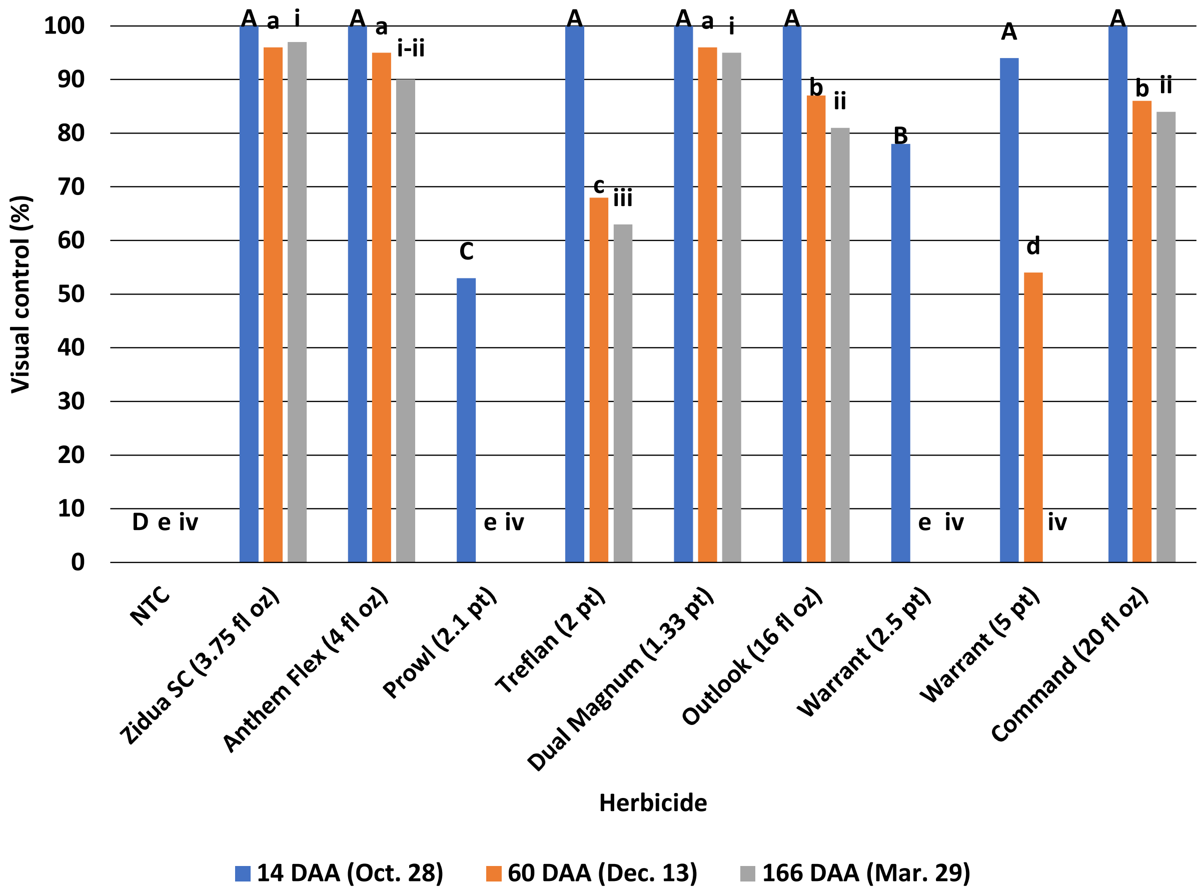

Fig. 1. Visual control of Italian ryegrass [*Lolium perenne* L. ssp. *multiflorum* (Lam.) Husnot] at 14, 60, and 166 days after application (DAA) at the University of Arkansas System Division of Agriculture's Jackson County Extension Center in Newport, Ark. in 2021. Treatments with the same letter or Roman numeral within rating timing are not different according to Tukey's honestly significant difference test at α = 0.05. Abbreviation: NTC = nontreated control.

Effect of Simulated Drift Rates of Reviton® (Tiafenacil) on Soybean

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Abstract

Reviton® (tiafenacil) is a new protoporphyrinogen oxidase (PPO)-inhibiting herbicide labeled for burndown applications. However, as burndown applications can be stretched across a wide range of dates in the mid-South, there is an increased potential for off-target movement onto emerged crops. As a result, research was needed to determine the effects of simulated drift rates of Reviton on soybean [*Glycine max* (L.) Merr.]. In 2022, an experiment was established in Newport, Ark., St. Joseph, La., Alexandria, La., and Milan, Tenn., to assess the tolerance of soybean to simulated drift rates of Reviton herbicide when exposed at the V2 soybean growth stage. Reviton simulated drift rates of 1/8, 1/16, 1/32, 1/64, 1/128, and 1/256 of the labeled rate (1 fl oz./ac) were applied to determine the potential consequences of off-target movement. The higher simulated drift rates of Reviton (1/8x and 1/16x) caused greater visual injury (greater than 60% 2 weeks after application), height reduction (approximately 36% reduction 4 weeks after application), and yield reduction (55% and 26% reduction for the 1/8x and 1/16x rates, respectively) compared to other rates. These results suggest soybean growers should be concerned about Reviton drift onto their soybean crop, and appropriate measures should be taken to reduce off-target movement of Reviton to avoid soybean growth and yield reductions.

Introduction

Mid-South soybean [*Glycine max* (L.) Merr.] growers constantly need new and improved methods to control early-season herbicide-resistant weeds. Reviton® (tiafenacil) is a new protoporphyrinogen oxidase (PPO)-inhibiting herbicide labeled for burndown applications to assist in starting clean ahead of planting the crop. Starting clean is an important first step in establishing effective, season-long weed control (Norsworthy et al., 2012). However, as burndown applications can be stretched out across a wide range of dates in the mid-South, there can be an increased potential for off-target movement to occur onto emerged crops. Previous research has illustrated the severe impacts of spray drift from ground and aerial applications onto soybean (Butts et al., 2022). As a result, it is critical to understand Reviton's impact on soybean if it were to move off-target. The objective of this research was to assess the effects of simulated drift rates of Reviton on soybean.

Procedures

In 2022, an experiment was established to assess the tolerance of soybean to simulated drift rates of Reviton [0.125, 0.0625, 0.03125, 0.01563, 0.00781, and 0.0039 fl oz./ac (1/8th to 1/256th of a label rate)]. The experiments were conducted in Newport, Ark., Milan, Tenn., St. Joseph, La., and Alexandria, La.. Applications were made to V2 soybean with a spray volume of 15 gal/ac and included methylated seed oil (MSO) at 1% v/v. Nontreated control and MSO-only treatments were included for comparison purposes. Data collected consisted of visual injury ratings using a scale of 0% to 100%, where 0% is no visual injury and 100% is complete plant death. Visual injury ratings were recorded 1, 2, and 4 weeks after application (WAA). Soybean heights (average of 5 plants) were also recorded 2 and 4 WAA. Soybean was harvested using a plot combine, and yield was adjusted to 13% moisture. Data were subjected to analysis of variance, and means were separated using Tukey's honestly significant difference test at a 5% significance level.

Results and Discussion

When averaged across locations, the greatest visual injury was observed at 1 WAA (82%) when exposed to the highest rate of Reviton (0.125 fl oz/ac, 1/8x). It remained at 72% visual injury by 4 WAA (Fig. 1). The lowest rate of 0.0039 fl oz/ac (1/256x) resulted in 10% visual soybean injury 1 WAA; however, by 4 WAA resulted in 0% injury. At 4 WAA, less than 16% visual soybean injury was observed from simulated drift rates of 0.03125 fl oz/ac (1/32x) or less. Soybean height and yield reduction were substantial at the 2 highest exposure rates of 0.125 (1/8x) and 0.0625 (1/16x) fl oz/ac (Figs. 2 and 3). Soybean height was reduced by approximately 36% 4 WAA

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for the 2 highest rates compared to all other rates and the nontreated control (Fig. 2). Additionally, the 0.125 (1/8x) and 0.0625 (1/16x) fl oz/ac rates reduced soybean yield by 55% and 26%, respectively, compared to all other simulated drift rates and the nontreated control (Fig. 3). Reviton exposure caused substantial visual injury, height reduction, and yield reduction at the 2 highest simulated drift rates. Yield reduction caused by the highest simulated drift rates would cause a substantial economic impact. These simulated drift rates are highly plausible rates that can occur from a standard herbicide drift event (Butts et al., 2022).

Practical Applications

Our research suggests that soybean growers should be concerned about Reviton's drift onto their soybean crop. The highest rates (1/8x and 1/16x) of Reviton caused substantial visual injury and resulted in both soybean height and yield reduction. As a result, drift mitigation strategies, both from aerial and ground spray equipment, should be implemented to reduce off-target movement of Reviton. Additionally, it should be noted that Reviton is most frequently applied in tank-mixture with other herbicides such as glyphosate, 2,4-D, or dicamba, and depending on the soybean trait technology, these could add additional injury, growth, and yield reduction concerns.

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Literature Cited

Butts, T.R., B.K. Fritz, K.B-J. Kouame, J.K. Norsworthy, L.T. Barber, W.J. Ross, G.M. Lorenz, B.C. Thrash, N.R. Bateman, and J.J. Adamczyk. 2022. Herbicide spray drift from ground and aerial applications: Implications for potential pollinator foraging sources. Sci. Reports, 12, 18017. Accessed 13 June 2023. Available at: https://doi.org/10.1038/s41598-022-22916-4

Norsworthy, J.K., S.M. Ward, D.R. Shaw, R.S. Llewellyn, R.L. Nichols, T.M. Webster, K.W. Bradley, G. Frisvold, S.B. Powles, N.R. Burgos, W.W. Witt, and M. Barrett. 2012. Reducing the Risks of Herbicide Resistance: Best Management Practices and Recommendations. Weed Sci., 60(sp1), 31–62. Accessed 13 June 2023. Available at: https://doi.org/10.1614/WS-D-11-00155.1

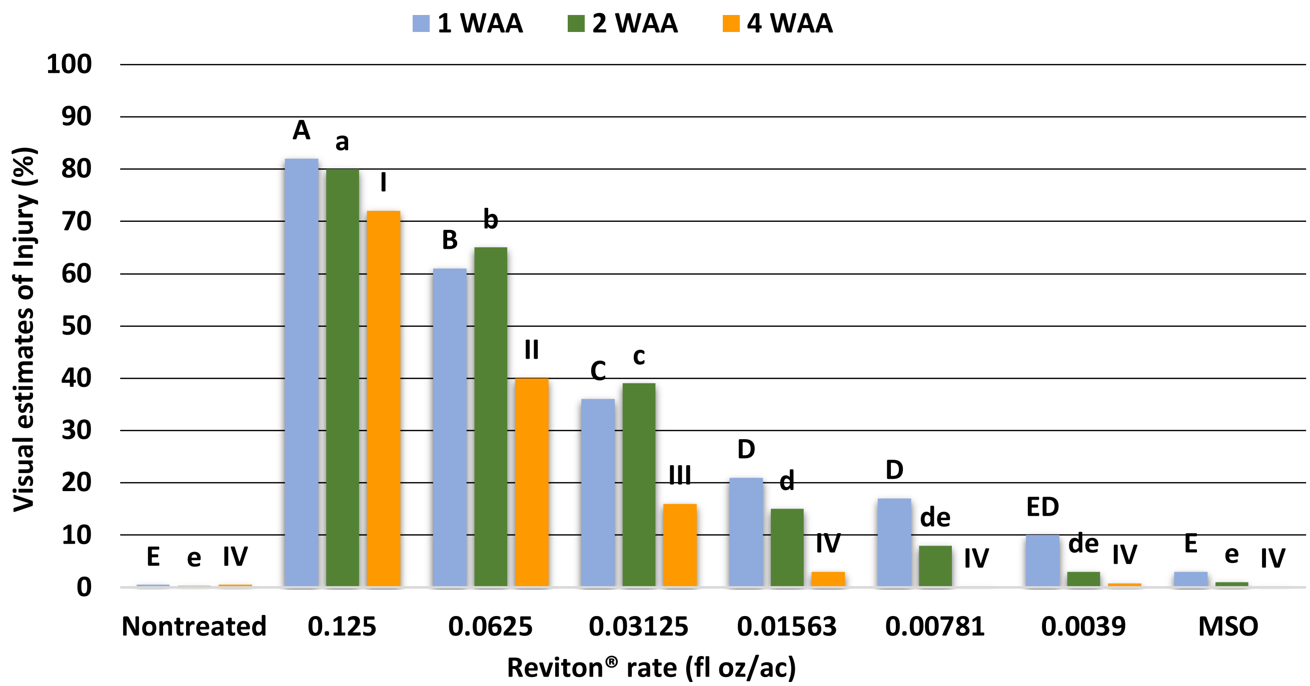

Fig. 1. Soybean visual injury 1, 2, and 4 weeks after application (WAA) of Reviton® simulated drift rates of 1/8, 1/16, 1/32, 1/64, 1/128, 1/256x of the labeled rate (1 fl oz/ac) and methylated seed oil (MSO) alone. Bars with the same letter or Roman numeral within rating timing are not different according to Tukey's honestly significant difference (α = 0.05).

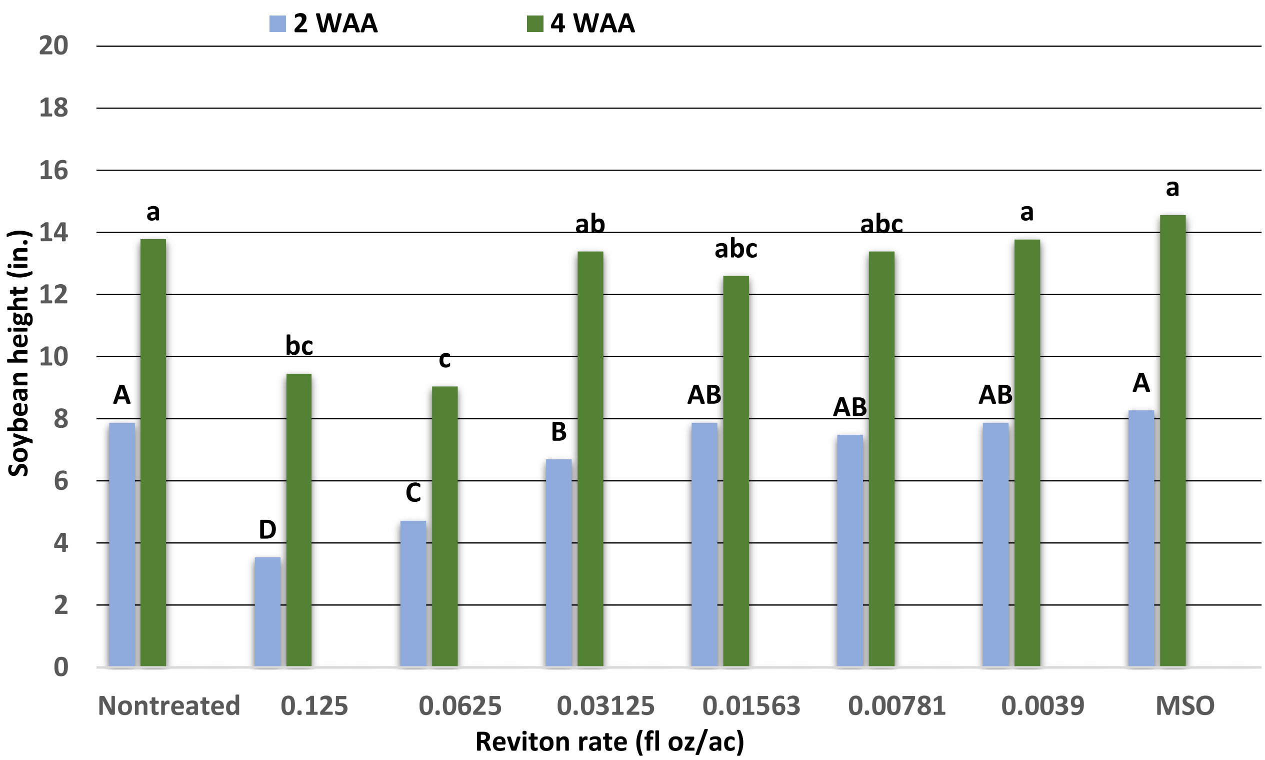

Fig. 2. Soybean heights taken 2 weeks after application (WAA) and 4 WAA of Reviton simulated drift rates of 1/8, 1/16, 1/32, 1/64, 1/128, 1/256x of the labeled rate (1 fl oz/ac) and methylated seed oil (MSO) alone. Bars with the same letter within rating timing are not different according to Tukey's honestly significant difference (α = 0.05).

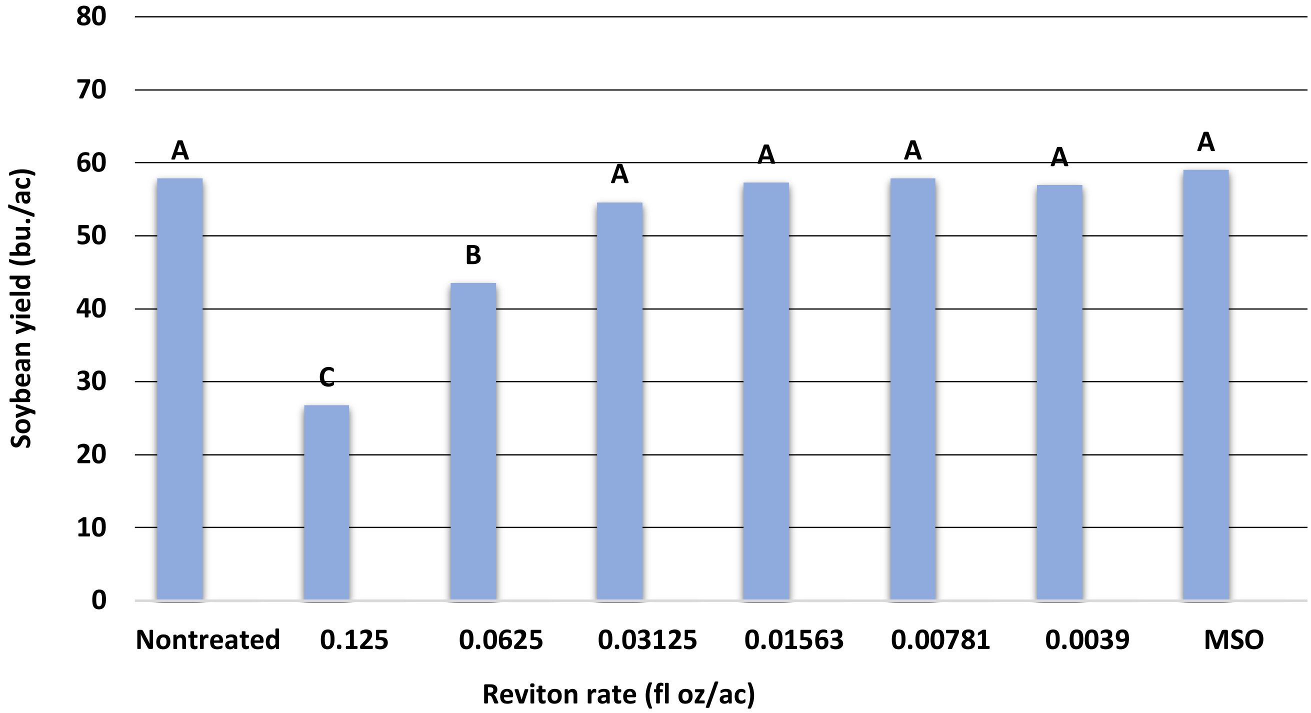

Fig. 3. Soybean yield of Reviton® simulated drift rates of 1/8, 1/16, 1/32, 1/64, 1/128, 1/256x of the labeled rate (1 fl oz/ac) and methylated seed oil (MSO) alone. Bars with the same letter are not different according to Tukey's honestly significant difference (α = 0.05).

Impact of Soybean Exposure to Simulated Drift Rates of Auxin Herbicides on Soybean Pollen and Reproductive Organs Production and Yield

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Abstract

Auxin herbicide drift to susceptible soybean [*Glycine max* (L.) Merr.] and cotton (*Gossypium hirsutum*) cultivars are a significant concern. Additionally, the impact of auxin herbicide drift on pollinators' foraging sources, including soybean, needs to be understood. A field experiment was conducted in 2022 at the University of Arkansas at Pine Bluff Small Farm Outreach Center near Lonoke, Ark., to evaluate the effect of auxin herbicide simulated drift rates on soybean reproductive organs (flowers and pods), pollen grains, and grain yield. A randomized complete block design was implemented with 8 replications. Four herbicides [florpyrauxifen-benzyl (Loyant®), 2,4-D (Enlist® One), dicamba (Engenia®), and quinclorac (Facet®)] were used at 2 rates (1/100x and 1/1000x the labeled rate) except for quinclorac, applied only at 1/100x the labeled rate. Four random soybean plants were collected from each treatment at the R3 growth stage, and reproductive organs were counted. Soybean flowers were also collected for pollen quantification 1 d before anthesis, and soybean was harvested at physiological maturity. Results showed that simulated drift rates of dicamba and florpyrauxifen-benzyl decreased the total number of soybean reproductive organs, pollen grains, and grain yield compared to the untreated control. Dicamba and florpyrauxifen-benzyl applied at 1/100x of the labeled rate reduced the number of reproductive organs by 35% and 39% at R3 compared to the nontreated control. Dicamba and florpyrauxifen-benzyl applied at this rate decreased pollen grains produced per anther by 28% and 18%, respectively, compared to the nontreated control. Applications of dicamba and florpyrauxifen-benzyl at 1/100x of the labeled rate reduced soybean grain yield by 43% and 27%, respectively, compared to the nontreated control. In addition to grain yield reduction, these results show that simulated auxin herbicide drift rates negatively impact pollinators' foraging sources with decreased pollen grain production and reducing the total number of reproductive organs, further illustrating the need for drift mitigation strategies to be developed and implemented.

Introduction

Auxin mimic herbicides are used extensively for selective broadleaf weed management across cropping systems (Barber et al., 2023); they are essential in modern agriculture, with about 366 million hectares treated globally (Busi et al., 2018). In the mid-southern United States, auxin mimic herbicides, such as dicamba and 2,4-D, are critical in XtendFlex® and Enlist® production systems, respectively. At the same time, florpyrauxifen-benzyl and quinclorac are crucial in rice (*Oryza sativa* L.) production systems (Barber et al., 2023). However, their use has raised many environmental concerns, mainly due to their off-target movement to sensitive vegetation and neighboring crops (Butts et al., 2022; Carpenter et al., 2020; Olszyk et al., 2017), with estimates of about 1.5 million hectares of dicamba-injured soybeans [*Glycine max* (L.) Merr.] reported in the United States in 2017 (WSSA, 2018). Also, the off-target movement to soybean by florpyrauxifen-benzyl raised concerns in Arkansas in 2018 (Butts et al., 2022). Because pollinators play a crucial role in food production, the effects of herbicides on their foraging sources and their visitation need to be further investigated. For example, annual pollination services for all crops requiring direct pollination accounted for more than $15 billion in the United States (Calderone, 2012). Unfortunately, the ongoing decline in pollinator populations (Wratten et al., 2012) resulting from various stressors (insecticide use and insufficient forage) (Arathi and Hardin, 2021) requires more studies. Because soybean flowers can be a source of nectar and pollen for different visiting pollinators, and its pollen was found on up to 38% of bees examined by Gill and O'Neal (Gill and O'Neal, 2015), more studies are needed to understand the impact of auxin mimic herbicides on soybean reproduction. Therefore, this research investigated the effect of simulated drift rates

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of various auxin mimic herbicides on soybean pollen grains, number of reproductive organs, and yield.

Procedures

A field experiment was conducted in 2022 at the University of Arkansas at Pine Bluff Small Farm Outreach Center near Lonoke, Ark., to evaluate the impact of auxin herbicide simulated drift rates on soybean reproductive organs, pollen production, and grain yield. A randomized complete block design was implemented with 8 replications of 4-row plots 100-ft long and 30-in. row spacing. A Liberty Link® soybean variety was planted on 21 June 2022. Four herbicides [florpyrauxifen-benzyl (Loyant®), 2,4-D (Enlist® One), dicamba (Engenia®), and quinclorac (Facet®)] were used for the experiment at 2 rates (1/100x and 1/1000x the labeled rate) except quinclorac, applied only at 1/100x the labeled rate at the V3 soybean growth stage. The herbicides and rates used in this experiment can be found in Table 1, and the appropriate adjuvants were included as indicated by the herbicide label. Spray mixtures, prepared with the addition of the labeled rates of the herbicides and their respective adjuvants, were diluted to obtain the desired concentrations for the treatments. A nontreated control was included in the experiment, giving a total number of 8 treatments. The trial was maintained weed-free to assess only the impacts of the herbicide injury. Treatments were applied in a carrier volume of 10 gallons per acre using AI110015 nozzles (TeeJet® Technologies, Spraying Systems Co., Wheaton, Ill., USA). Four random plants were collected from each treatment at the R3 soybean growth stage, and reproductive organs (flowers and pods) were counted. Soybean flowers were collected for pollen quantification on 10 plants randomly selected per replicate (1 flower per plant) 1 d before anthesis. Samples were immediately transported to the laboratory and processed.

Four flowers per treatment were carefully dissected under a microscope to expose the androecium and the pistil. Pollen grains were suspended and counted using a protocol adapted from the previous work of Ohnishi et al. (2010). Briefly, anthers of the flowers were carefully removed from the stamens and transferred into a 2 mL microtube containing 20 µL of water and 50% glycerol (v/v). Twenty µL of lactophenol aniline blue solution were added to the tube, then placed in an ultrasonic cleaner (VWR International LLC, Co.) and ultrasound treated for 15 min to suspend the pollen grains in the solution. Each sample was then mixed using a vortex mixer for 30 s, pollen grains in 10 µL of the solution were loaded into each chamber of a hemocytometer, and pollen grains were counted under a microscope Nikon SMZ745T (Nikon Instruments Inc., N.Y.). Soybean was harvested at physiological maturity, the grain moisture was adjusted to 13%, and the yield was determined. The total number of reproductive organs, pollen grains, and grain yield data were subjected to analysis of variance using the GLIMMIX procedure in SAS v. 9.4 (SAS Institute Inc, Cary, N.C.).

Results and Discussion

The number of soybean reproductive organs (flowers and pods) was decreased by simulated drift rates of auxin herbicides ($P < 0.05$). While 2,4-D and quinclorac did not affect soybean reproduction in this study, dicamba and florpyrauxifen-benzyl applied at 1/100x of the labeled rate reduced the total number of reproductive organs by 35% and 39%, respectively, compared to the nontreated control at the R3 reproductive stage (Fig. 1). This result is consistent with previous research. For example, in their study investigating herbicide spray drift from ground and aerial applications, Butts et al. (2022) reported a severe reduction of soybean reproductive structures after exposure to drift rates of florpyrauxifen-benzyl with a potential negative impact on pollinator foraging sources. According to the same study, soybean reproductive structures were reduced by approximately 25% up to 100 ft downwind and 100% at 200 ft downwind for ground and aerial applications, respectively. Likewise, the reduction of reproductive organs observed in the present research is consistent with the observations made by Carpenter et al. (2020), who reported a delay in peak flowering and a reduction in overall flower production from wild plant species when exposed to various herbicides. Robinson et al. (2013) reported that dicamba reduced the number of soybean seeds, pods, reproductive nodes, and nodes. This research also showed that the number of pollen grains per anther decreased with auxin herbicide exposure. Exposure to dicamba and florpyrauxifen-benzyl at 1/100x of the label rate reduced pollen grains per anther by 28% and 18%, respectively (Fig. 2). Results also revealed that dicamba and florpyrauxifen-benzyl applied at 1/100x of the labeled rate resulted in a 43% and 27% reduction in grain yield, respectively, compared to the nontreated control (Fig. 3). Previous research also reported a decline of soybean yield with the application of sublethal rates of auxin herbicides and a delay in soybean maturity (Solomon and Bradley, 2014). These results illustrate that in addition to grain yield reduction, simulated auxin herbicide drift rates can negatively impact pollinator foraging sources by decreasing pollen production and the total number of reproductive organs.

Practical Applications

This research showed a negative impact of simulated drift rates of auxin herbicides on pollen production, total number of reproductive organs (flowers and pods), and grain yield. Pollen is crucial for pollinators, and the negative impact of herbicide drift rates is a major concern for pollinator foraging. Injury from drift can contribute to a decrease in the pollinator visitation of soybean plants exposed to sublethal rates of auxin herbicides. Previous research reported a diverse community of pollinators visiting soybean fields and foraging on their flowers (Gill and O'Neal, 2015). This research needs to be replicated in time and space to evaluate the impact of environmental conditions on the results. Also, more research is needed to understand the impact of auxin herbicide drift rates on different plant species. Overall, this research emphasizes the importance of developing and implementing effective drift mitigation strategies for continued stewardship of our herbicides.

Acknowledgments

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Literature Cited

Arathi, H.S. and J. Hardin. 2021. Pollinator-friendly flora in rangelands following control of cheatgrass (*Bromus tectorum*): a case study. Invas. Plant Sci. Mana. 14: 270–277.

Barber, L.T., T.R. Butts, J.W. Boyd, H.E. Wright Smith, K. Cunningham, G. Selden, J.K. Norsworthy, N. Burgos, and M.B. Bertucci. 2023. Recommended chemicals for weed and brush control (MP-44). Little Rock, Ark. University of Arkansas System Division of Agriculture's Cooperative Extension Service, Fayetteville, Publication MP44-12M-1-00RV.

Busi, R., D.E. Goggin, I.M. Heap, M.J. Horak, M. Jugulam, R.A. Masters, R.M. Napier, D.S. Riar, N.M. Satchivi, J. Torra, P. Westra, and T.R. Wright. 2018. Weed resistance to synthetic auxin herbicides. Pest Manage. Sci. 74: 2265–2276.

Butts, T.R., B.K. Fritz, K.B. J. Kouame, J.K. Norsworthy, L.T. Barber, W.J. Ross, G.M. Lorenz, B.C. Thrash, N.R. Bateman, and J.J. Adamczyk. 2022. Herbicide spray drift from ground and aerial applications: Implications for potential pollinator foraging sources. Sci. Reports 12:18017.

Calderone, N.W. 2012. Insect pollinated crops, insect pollinators and U.S. agriculture: Trend analysis of aggregate data for the period 1992-2009. Plos One 7.

Carpenter, D.J., S.K. Mathiassen, C. Boutin, B. Strandberg, C.S. Casey, and C. Damgaard. 2020. Effects of herbicides on flowering. Environ. Toxicol. Chem. 39: 1244-1256.

Gill, K.A. and M.E. O'Neal. 2015. Survey of soybean insect pollinators: Community identification and sampling method analysis. Environ. Entomol. 44: 488–498.

Ohnishi, S., T. Miyoshi, and S. Shirai. 2010. Low temperature stress at different flower developmental stages affects pollen development, pollination, and pod set in soybean. Environ. Exp. Bot. 69: 56–62.

Olszyk, D., T. Pfleeger, T. Shiroyama, M. Blakeley-Smith, E.H. Lee, and M. Plocher. 2017. Plant reproduction is altered by simulated herbicide drift to constructed plant communities. Environ. Toxicol. Chem. 36: 2799–2813.

Robinson, A.P., D.M. Simpson, and W.G. Johnson. 2013. Response of Glyphosate-Tolerant Soybean Yield Components to Dicamba Exposure. Weed Sci. 61: 526–536.

Solomon, C.B. and K.W. Bradley. 2014. Influence of application timings and sublethal rates of synthetic auxin herbicides on soybean. Weed Technol. 28: 454–464.

Wratten, S. D., M. Gillespie, A. Decourtye, E. Mader, and N. Desneux. 2012. Pollinator habitat enhancement: Benefits to other ecosystem services. Agric. Ecosyst. Environ. 159: 112-122.

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

Table 1. Herbicides used during a field experiment conducted in 2022 at the University of Arkansas at Pine Bluff Small Farm Outreach Center located near Lonoke, Ark., to evaluate the impact of simulated drift rates of auxin herbicides on soybean reproductive organs (flowers and pods), pollen grains, and yield.

Herbicide	Product and manufacturer	Rates
Florpyrauxifen-benzyl	Loyant®, Corteva Agriscience, Indianapolis, Ind.	1 pt/ac
2,4-D	Enlist® One, Corteva Agriscience, Indianapolis, Ind.	2 pt/ac
Dicamba	Engenia®, BASF, Research Triangle Park, N.C.	12.8 fl oz /ac
Quinclorac	Facet®, BASF, Research Triangle Park, N.C.	43 fl oz

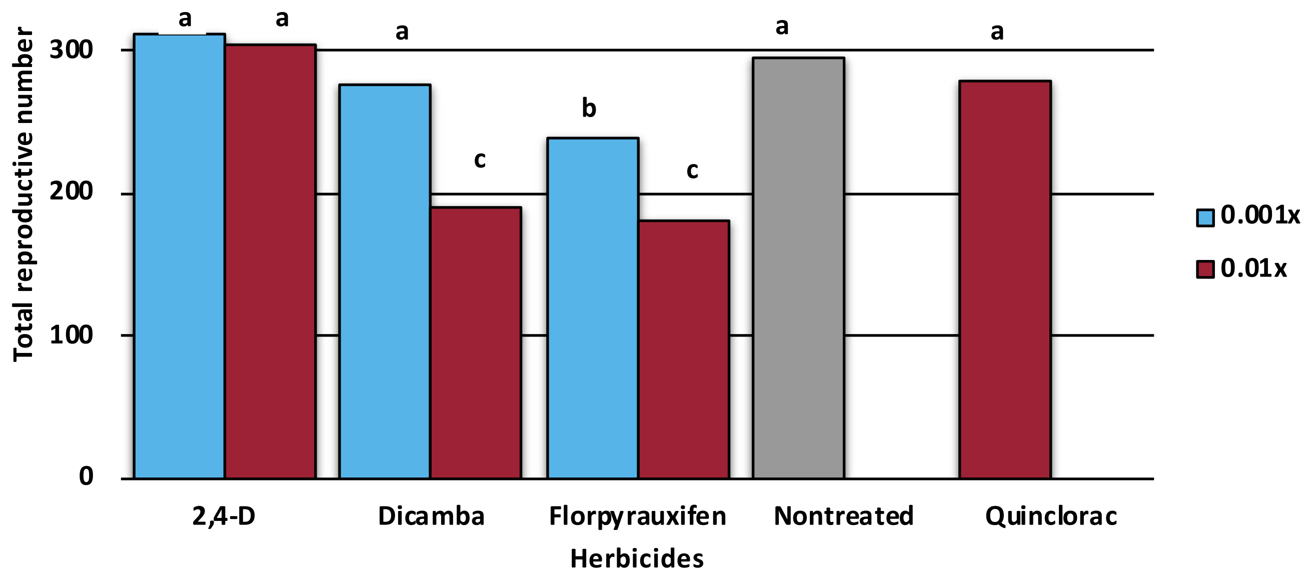

Fig. 1. Number of soybean [*Glycine max* (L.) Merr.] reproductive organs (flowers and pods) at the R3 growth stage obtained during a field experiment conducted in 2022 at the University of Arkansas at Pine Bluff Small Farm Outreach Center located near Lonoke, Ark., impacted by simulated drift rates of auxin herbicides. Treatments with the same lowercase letter are not different according to Fisher's protected least significant difference at α = 0.05.

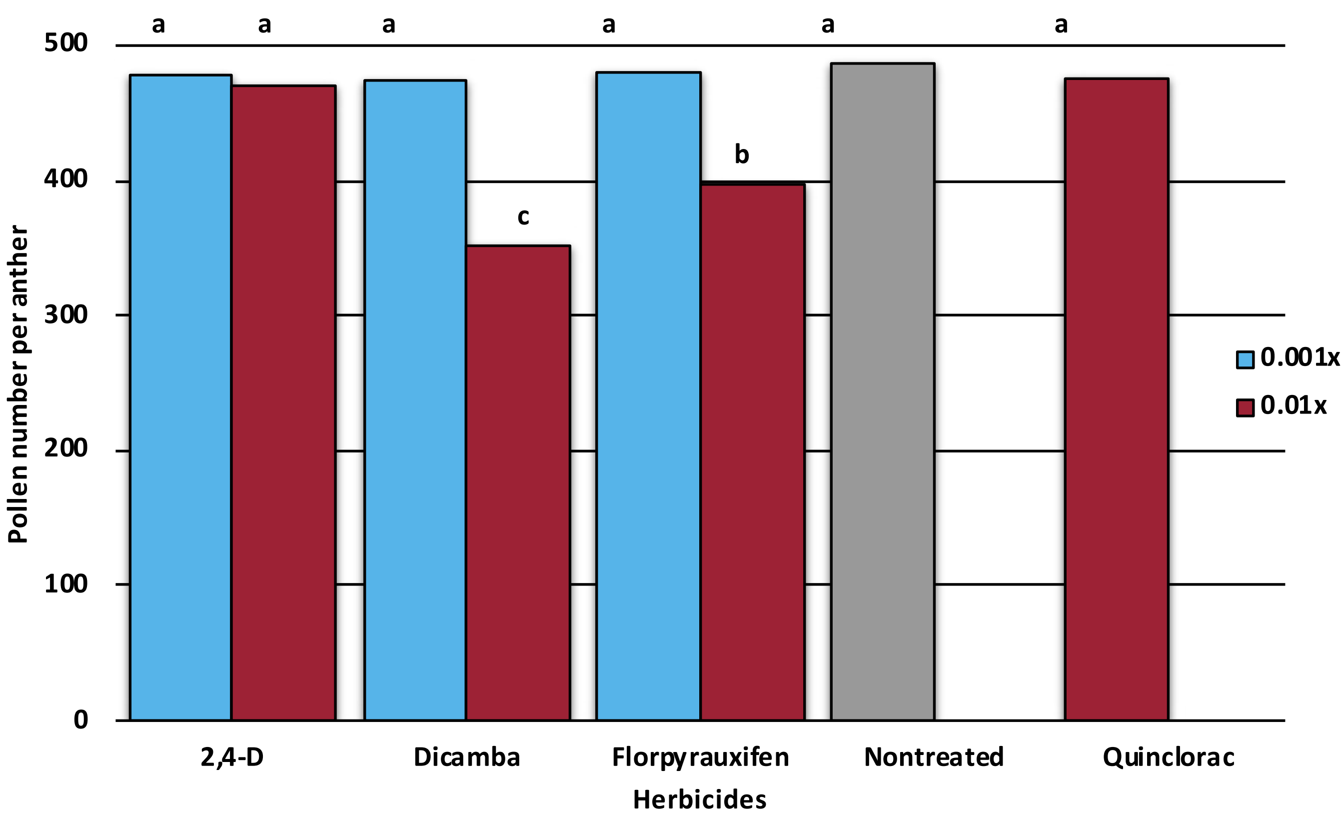

Fig. 2. Number of soybean [*Glycine max* (L.) Merr.] pollen grains per anther obtained during a field experiment conducted in 2022 at the University of Arkansas at Pine Bluff Small Farm Outreach Center located near Lonoke, Ark., impacted by simulated drift rates of auxin herbicides. Treatments with the same lowercase letter are not different according to Fisher's protected least significant difference at α = 0.05.

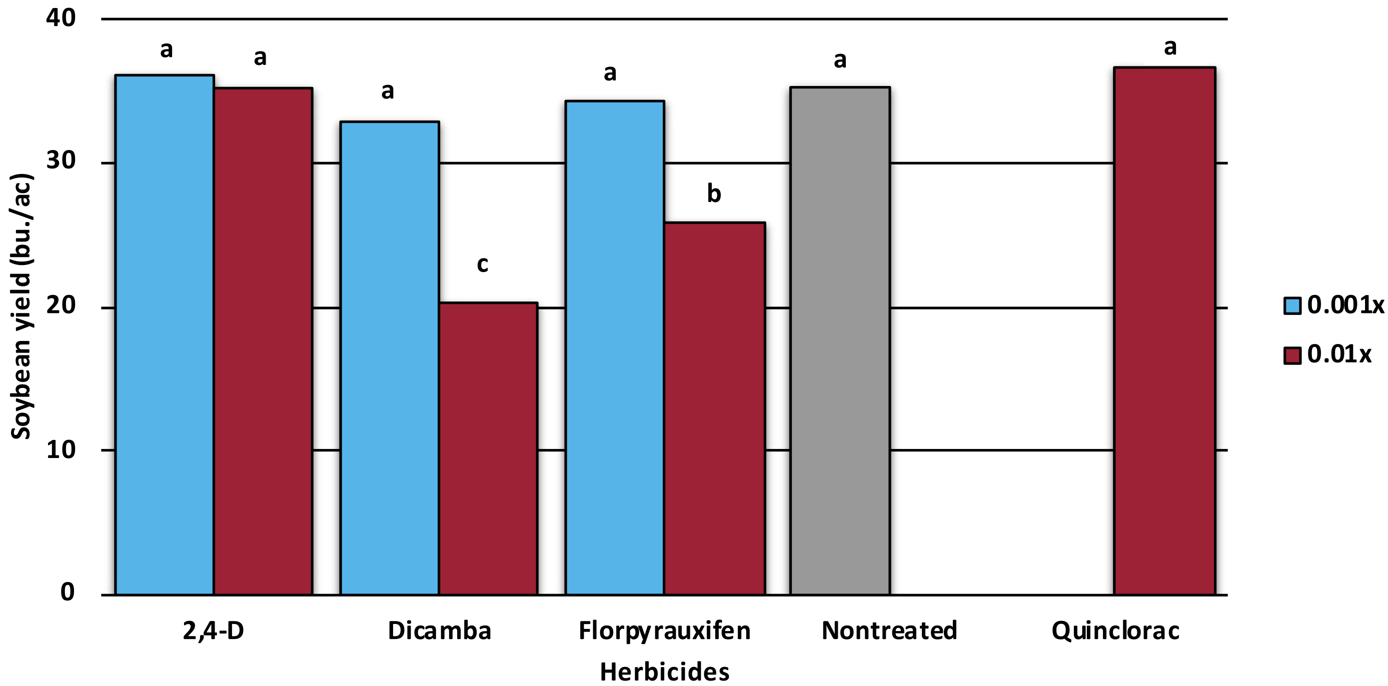

Fig. 3. Soybean [*Glycine max* (L.) Merr.] yield obtained during a field experiment conducted in 2022 at the University of Arkansas at Pine Bluff Small Farm Outreach Center located near Lonoke, Ark., impacted by simulated drift rates of auxin herbicides. Treatments with the same lowercase letter are not different according to Fisher's protected least significant difference at α = 0.05.

Area Sprayed with See and Spray™ Ultimate Compared to Total Weed Area in Soybean

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Abstract

The See and Spray ™ Ultimate is the first commercial precision sprayer for targeted-broadcast applications in row crops. Over the past few years, herbicide prices have drastically increased, and the See and Spray could provide an opportunity for soybean producers to reduce herbicide inputs and mediate the increase in cost. However, no published literature provides or discusses the relationship between total weed area and area treated with the See and Spray Ultimate. Therefore, research was conducted for 2 years in Keiser, Ark., and Greenville, Miss., to determine the relationship between total weed area and area sprayed in XtendFlex® soybean with a Level 4 sensitivity. A Weibull Growth model was fit to predict the percent sprayed area based on the percent weed area with $R^2 \geq 0.883$. Results indicate that preemergence (PRE) applications with the See and Spray have the most significant potential to reduce the area sprayed. A 50% reduction in the sprayed area occurred at 3.4%, 0.5%, and 0.8% of the total weed area for PRE, early-postemergence (EPOST), and mid-postemergence (MPOST) application timings, respectively. These results are likely a function of the nozzle angle and the sensitivity level evaluated. The preemergence timing utilized nozzles with a 40-degree spray angle at a 26-in. boom height from the ground compared to 110- and 100-degree nozzles 20-in. from the crop canopy at the EPOST and MPOST timing. Additionally, the applications occurred with a Level 4 sensitivity, and decreasing to lower levels would reduce the area sprayed with the See and Spray Ultimate; however, weed misses may become more frequent.

Introduction

Precision sprayers in current production systems could reduce herbicide inputs (Cardina et al., 1997; Metcalfe et al., 2019; Wiles et al., 1992). With the commercial release of the See and Spray™ Ultimate, Arkansas soybean [*Glycine max* (L.) Merr.] producers need more insight into the capabilities of this new technology for their production systems. The See and Spray Ultimate is the first precision sprayer to provide in-season targeted herbicide applications capable of distinguishing weeds from crops. The sprayer also has a dual tank and plumbing system, facilitating simultaneous broadcast and See and Spray applications. However, no published literature has determined the relationship between total weed area and area sprayed with the See and Spray Ultimate. With the increasing cost of operating inputs, producers need insight into potential reductions in the area sprayed when utilizing the See and Spray Ultimate technology (USDA-NASS, 2022). Therefore, an experiment was conducted in 2021 and 2022 at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) at Keiser, Ark. and at Stoneville Research and Development (SRD), near Greenville, Miss., to determine the performance of the See and Spray Ultimate in XtendFlex® soybean.

Procedures

The experiment was designed as a randomized complete block with 4 replications. Treatments included a nontreated and a broadcast standard herbicide program, which utilized 10 other variations substituting postemergence residual timings, See and Spray dual tank programs, or See and Spray single tank programs. The standard herbicide program was based on a PRE burndown with residual, dicamba with residual early-postemergence (EPOST), and glufosinate with residual mid-postemergence (MPOST). Herbicide rates remained consistent across application methods (Table 1). Plots were 12.7 ft (4 rows) by 100 ft in length (NEREC) or 90 ft in length (SRD). The PRE through MPOST applications occurred with a scaled-down version of the See and Spray Ultimate attached to a front-end loader of a JD6130M (Deere and Company, Moline, Ill.) at 8 MPH. The following nozzles were utilized for each See and Spray application at a Level 4 sensitivity setting: TDSF4003-30RI (Greenleaf Technologies Inc, Covington, La.), PSLDMQ2004-30RI, and PS3DQ0004 (Deere and Company, Moline, Ill.) for PRE, EPOST, and MPOST application timings, respectively. The See and Spray functionality also allows users to change sensitivity settings, which dictates the weed size treated. The settings range from

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1-5, with 1 detecting fewer weeds and 5 detecting as many weeds as possible. This study used a level 4 sensitivity level at all application timings.

At the time of each application, recordings of each plot were collected and analyzed using John Deere's proprietary software to determine the percent weed area and percent area sprayed. Initially, the presence or absence of residuals and utilization of the See and Spray at each application were tested to determine if the weed area differed at each application timing. This data was subjected to analysis of variance and found insignificant at α = 0.05. Therefore, at each application timing, weed area and area sprayed were pooled when utilizing the See and Spray and regressed using JMP Pro v. 17 (SAS Institute, Inc. Cary, N.C.) with the Fit Curve platform. A Weibull Growth model, equation 1, was the best fitting based on R^2 and AICc (Knezevic et al., 2007). Inverse predictions were used to determine the percent weed area to achieve the specified percent area sprayed (Table 2).

$$Asymptote * \left(1 - EXP\left(-\left(\left(\frac{\%\,Weed\ area}{Inflection\ point}\right)^{Growth\ rate}\right)\right)\right)$$

Eq. 1

Results and Discussion

Across application timings, the models fit well in terms of R^2 with all ≥ 0.883 and the asymptotes containing 100%, meaning that the maximum area sprayed predicted by these models is 100% of the area (Table 2). Inverse predictions also indicate a difference among application timings for the relationship between the area sprayed and the weed area (Table 3). Based on the sensitivity setting evaluated (Level 4), applications at the PRE timing sprayed less area than postemergence applications at similar weed densities. At 1.5% of the weed area, the See and Spray would apply herbicides to 30% of the area for PRE applications and 70% for EPOST and MPOST applications. The reduction in the area sprayed at the PRE timing can also be observed with the rightward shift with the predicted PRE curve compared to the EPOST and MPOST curves (Fig. 1).

Additionally, from 30% to 70% of the area sprayed, MPOST applications could tolerate slightly higher weed areas than EPOST applications for each specified spray area (Table 3). The differences in the area sprayed are likely due to two causes: 1. the nozzle angle at each application timing and 2. the different See and Spray models (fallow or soybean). The more important cause, however, is likely the nozzle angle. At the preemergence application timing, a fallow model applies herbicide to any detected living vegetation. At the postemergence application timings, a soybean crop model was used to distinguish weeds from crops and target applications specifically to weeds. At each timing, from PRE to MPOST, TDSF 4003, PSLDMQ2004-30RI, and PS3DQ2004 nozzles were utilized for the See and Spray applications. Each nozzle has a 40, 110, and 100-degree spray angle, respectively. The See and Spray targeting system is designed to activate any nozzle if it can contribute droplets to a weed (Schwartz-Lazaro and Patzoldt, personal communication); hence, multiple nozzles are often activated to ensure full coverage.

Practical Applications

Though high amounts of the sprayed area were observed with very low weed densities, the See and Spray sensitivity level evaluated was a 4 on a scale of 1–5, with 1 detecting fewer weeds and 5 detecting the most weeds. Based on the results of this analysis, narrower spray angles could reduce the area sprayed with the See and Spray Ultimate. The relationship determined in this study would differ as sensitivity levels are adjusted, and future publications will discuss this relationship. Future research will also determine the relationship between nozzle spray angle, boom height, coverage uniformity, and area sprayed.

Acknowledgments

Blue River Technology and the Soybean Checkoff Research Program, administered by the Arkansas Soybean Promotion Board, provided funding for this research. Additionally, the authors are grateful to Blue River for providing the scaled See and Spray™ Ultimate machine and to the Northeast Research and Extension Center personnel for facilitating this research.

Literature Cited

Cardina, J., G.A. Johnson, and D. H. Sparrow. 1997. The nature and consequence of weed spatial distribution. Weed Sci. 45:364–373.

USDA-NASS. 2022. United States Department of Agriculture. National Agricultural Statistics Service. Statistics by subject results. Accessed 14 Feb. 2023. Available at: https://www.nass.usda.gov/Statistics_by_Subject/result.php?2EB3C821-3F42-329B-B2D7-8CE4D89EEED9&sector=CROPS&group=FIELD%20CROPS&comm=SOYBEANS

Knezevic, S.Z., J.C. Streibig, and C. Ritz. 2007. Utilizing R software package for dose-response studies: the concept and data analysis. Weed Tech. 21:840–848.

Metcalfe H., A.E. Milne, K. Coleman, A.J. Murdoch, and J. Storkey. 2019. Modeling the effect of spatially variable soil properties on the distribution of weeds. Ecological Modelling 396:1–11.

Wiles, L.J., G.W. Oliver, A.C. York, H.J. Gold, and G.G. Wilkerson. 1992. Spatial distribution of broadleaf weeds in North Carolina soybean (*Glycine max*) fields. Weed Sci. 40:554–557.

Table 1. List of treatments for herbicide programs and subsequent herbicide rates.

	Application timing					
	Preemergence		Early-postemergence		Mid-postemergence	
Treatment	Broadcast	See and Spray	Broadcast	See and Spray	Broadcast	See and Spray
Nontreated	-	-	-	-	-	-
BC no res[a] post	Boundary® Gramoxone®		Engenia®[b] SelectMax®		Interline® RUPmax®	
SS no res post	Boundary	Gramoxone		Engenia SelectMax		Interline RUPmax
BC + res EPOST	Boundary Gramoxone		Engenia SelectMax Warrant®		Interline RUPmax	
SS + res EPOST	Boundary	Gramoxone		Engenia SelectMax Warrant		Interline RUPmax
SS + BC res EPOST			Warrant	Engenia SelectMax		Interline RUPmax
BC + res MPOST	Boundary Gramoxone		Engenia SelectMax		Interline RUPmax Warrant®	
SS + res MPOST	Boundary	Gramoxone		Engenia SelectMax		Interline RUPmax Warrant
SS + BC res MPOST				Engenia SelectMax	Warrant	Interline RUPmax
BC + residual	Boundary Gramoxone		Engenia SelectMax Warrant		Interline RUPmax Warrant	
SS + residual	Boundary	Gramoxone		Engenia SelectMax Warrant		Interline RUPmax Warrant
SS + BC residual			Warrant	Engenia SelectMax	Warrant	Interline RUPmax
	Boundary	2.1 pt/ac	Engenia	22 oz/ac	Interline	2 pt/ac
	Gramoxone 3 SL	22 oz/ac	Select Max	12 oz/ac	Roundup PowerMAX 2	22 oz/ac
			Warrant	3 pt/ac	Warrant	3 pt/ac

[a] Abbreviations: BC = broadcast; EPOST = early-postemergence; MPOST = mid-postemergence; res = residual, RUPmax = Roundup PowerMAX 2 or 3; SS = See and Spray.

Table 2. List of model parameters for the Weibull Growth model of percent area sprayed predicted by percent weed area.

	Model Parameters[a,b]				
Application Timing	**Asymptote**	**Inflection point**	**Growth rate**	**n**	**R^2**
Preemergence	1.0110	0.0552	0.7991	112	0.977
Early-postemergence	0.9935	0.0097	0.6074	84	0.888
Mid-postemergence	0.9963	0.0127	0.7740	110	0.883

[a] All model parameters were significant χ^2 (*P* < 0.0001).

[b] Weibull Growth model and parameters determined using JMP Pro 17 with the Fit Curve Platform.

Table 3. Inverse predictions of weed area from specified area sprayed.

	Preemergence			Early-postemergence			Mid-postemergence		
Area Sprayed	**Pred[a]**	**LCL**	**UCL**	**Pred**	**LCL**	**UCL**	**Pred**	**LCL**	**UCL**
(%)	-- Weed area (%) --								
10	0.3	0.3	0.3	0	0	0	0	0	0
20	0.8	0.8	0.8	0.1	0.1	0.1	0.1	0.1	0.1
30	1.5	1.5	1.5	0.2	0.2	0.2	0.3	0.3	0.3
40	2.3	2.2	2.5	0.3	0.3	0.3	0.5	0.5	0.6
50	3.4	3.1	3.8	0.5	0.5	0.6	0.8	0.7	0.8
60	4.8	4.2	5.5	0.9	0.8	1	1.1	1.1	1.2
70	6.8	5.8	7.8	1.3	1.2	1.5	1.6	1.5	1.7
80	9.7	8.3	11.1	2.2	2.0	2.4	2.4	2.2	2.6
90	14.9	12.9	16.9	4.0	3.7	4.3	3.8	3.4	4.2

[a] Abbreviations: LCL = lower 95% confidence level; Pred = predicted weed area; UCL = upper 95% confidence level.

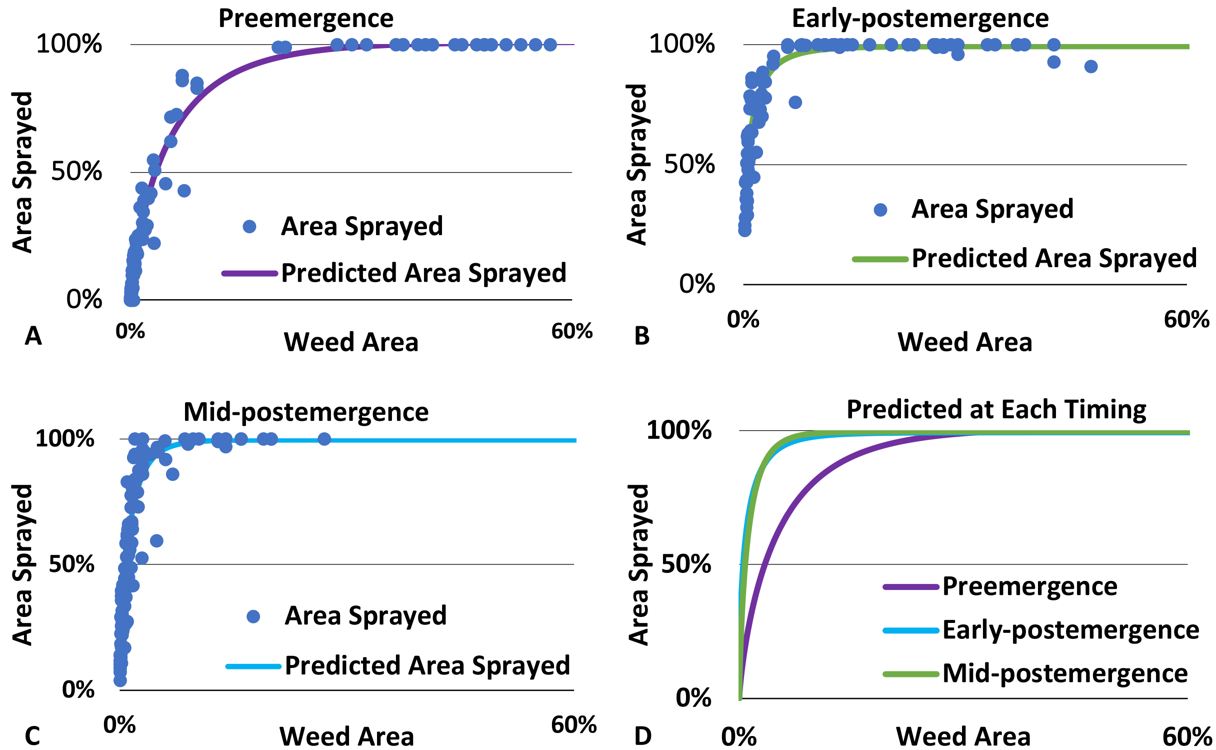

Fig 1. The relationship between the area sprayed with See and Spray™ Ultimate and the weed area. The predicted area sprayed based on the Weibull Growth model with R^2 = 0.977 (A), 0.888 (B), and 0.833 (C). Area sprayed points are data recorded at each application timing with the fallow and soybean See and Spray model. Figure 1D displays the predicted lines for the three application timings.

Does the Timing of a Soil-Applied Diflufenican Mixture Impact Soybean Tolerance and Palmer Amaranth Control?

M.C. Woolard,[1] J.K. Norsworthy,[1] C.T. Arnold,[1] L.B. Piveta,[1] T.H. Avent,[1] and T.R. Butts[2]

Abstract

Diflufenican is a new herbicide to be labeled, potentially, for soybean [*Glycine Max* (L.) Merr] production in the United States. Diflufenican is an Herbicide Resistance Action Committee/Weed Science Society of America group 12 herbicide, the first group 12 herbicide labeled for use in soybean production. Soybean producers need new chemistries to help control Palmer amaranth (*Amaranthus palmeri* S. Wats.). Palmer amaranth has evolved resistance to 9 modes of action; therefore, diflufenican is being evaluated for its control. Two field experiments were conducted at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Arkansas, to evaluate the tolerance of soybean and associated weed control with various rates and application timings of the diflufenican mixture. For the tolerance trial, the diflufenican mixture was applied at 1 and 2 times the anticipated 1X labeled rates at 14- and 7-day preplant, preemergence, and 3 days after planting (DAP). The diflufenican mixture was applied 14- and 7-day preplant, preemergence, and 3 DAP at a 1X labeled rate for the weed control trial. Injury 14 DAP ranged from 2% to 20% for the 1X rate of the herbicide and 6% to 32% for the 2X rate. By 28 DAP, injury decreased for both herbicide rates, with the most injury being observed at the 3 DAP application timing for both rates. Grain yield was collected at maturity, and no difference was observed between application timings and herbicide rates. Palmer amaranth and common lambsquarters (*Chenopodium album* L.) control was greater than 97% for all application timings, except the 14-day preplant timing 21 DAP. By 42 DAP, the application timing of preemergence and 3 DAP provided greater than or equal to 90% control of the 2 weeds. Grain yield increased the closer the herbicide application was made to planting and soybean emergence due to improved weed control.

Introduction

Diflufenican is a group 12 herbicide to be labeled for use in soybean [*Glycine Max* (L.) Merr] production. Diflufenican would add a new mode of action to help control weeds in soybean production and thus has the potential to slow the evolution of herbicide resistance by diversifying herbicide programs (Norsworthy et al. 2012). While diflufenican is new to the United States, the herbicide has been used for several years in European crop production (Anonymous 2021). Diflufenican has been used in crops such as lentils and winter cereals (Anonymous 2021) and has shown excellent activity on broadleaf weed species (Hu et al., 2020). According to Weed Science Society of America surveys in 2022, Palmer amaranth (*Amaranthus palmeri* S. Wats.) is the most problematic weed in soybean production (Van Wychen 2022). Palmer amaranth has resistance to 9 modes of action (Heap 2023), leaving producers with limited herbicide options. Therefore, experiments were conducted to evaluate application timings of a diflufenican mixture for Palmer amaranth control and soybean tolerance.

Procedures

Two field experiments were conducted in 2022 at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Arkansas, to determine soybean tolerance and Palmer amaranth control with different application timings of a diflufenican mixture. Both trials were planted with the cultivar AG45XFO (Bayer CropScience, St Louis, MO 63167) drill-seeded at 144,000 seeds/ac into 4-row plots measuring 12-ft wide, 25-ft long, with 36-inch spacing. The soybean tolerance trial was a randomized complete block with 2 factors (diflufenican rate and application timing) and 4 replications. The diflufenican mixture rates included 1 and 2 times the anticipated labeled (1X) rate, and application timings included 14-day preplant, 7-day preplant, preemergence, and 3 days after planting (DAP). In this trial, weeds were controlled throughout the growing season using standard soybean herbicides to maintain a weed-free environment. The weed control trial was a randomized complete block with 1 factor (application timing) and 4 replications. Application timings

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included 14-day preplant, 7-day preplant, preemergence, and 3 DAP with a 1X rate of the diflufenican mixture. All applications were made at 3 miles per hour with a CO_2-pressurized backpack sprayer calibrated to deliver 15 gal/ac using AIXR 110015 nozzles. Visible injury ratings were evaluated 2 to 6 weeks after planting, and weed control ratings were assessed 2, 3, 4, and 6 weeks after planting. Visible injury and weed control were rated on a scale from 0% to 100%, with 0 being no crop injury or weed control and 100 being crop death or complete weed control. Soybean grain yield was collected at maturity for both trials. Data were subjected to an analysis of variance, and means were separated using Fisher's protected least significant difference with an alpha value of 0.05.

Results and Discussion

By 2 weeks after planting in the tolerance trial, soybean injury ranged from 1%–20% for the 1X rate and 6%–33% for the 2X rate of the diflufenican mixture (Table 1). As application timing neared soybean emergence, injury increased for both herbicide rates, with the highest injury observed being 3 DAP. Additionally, there was an increase in injury between herbicide rates at each application timing. Four weeks after planting, soybean injury decreased from 0% to 13% for the 1X and 1% to 23% for the 2X rate of the diflufenican mixture (Table 1). The injury was <15% for all treatments except for the 2X rate applied at 3 DAP. Also, there was an increase in injury between herbicide rates except for at the 14-day preplant timing. Soybean grain yields were collected and reported relative to the nontreated control (55 bu/ac). Overall percentages ranged from 92% to 117% for the 1X rate and 85% to 114% for the 2X rate of the diflufenican mixture at each application timing (Table 1). While there were no differences in soybean yield among herbicide rates and application timings, there was a slight numerical decrease in soybean yield for both rates for the 3 DAP timing.

The 2 broadleaf weeds evaluated for the weed control trial included Palmer amaranth and common lambsquarters. By 3 weeks after planting, Palmer amaranth visual control ranged from 88% to 100%, and common lambsquarters (*Chenopodium album*) visual control ranged from 93% to 100%, respectively (Table 2). As the application timing of the diflufenican mixture neared soybean emergence, better weed control was obtained. By 6 weeks after planting, Palmer amaranth control ranged from 65% to 91%, and common lambsquarters control ranged from 74% to 96%, respectively (Table 2). At this evaluation timing, the 14-day preplant application timing was no longer providing adequate control of the 2 weed species evaluated. Soybean grain yield was collected at maturity, ranging from 6 to 42 bushels per acre (Table 2). Overall, there was no difference in grain yield observed between the 7-day preplant, preemergence, and 3 DAP application timings.

Practical Applications

If labeled, diflufenican adds a new mode of action to help diversify our herbicide programs in soybean production and has the potential to control herbicide-resistant Palmer amaranth. The diflufenican mixture can be applied 7 days preplant up to planting to maximize weed control and reduce the potential of soybean injury. However, additional research is needed to evaluate the length of residual control diflufenican provides compared to commonly used residual herbicides in soybean production.

Acknowledgments

The authors thank the University of Arkansas System Division of Agriculture, the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, the Arkansas Soybean Research and Promotion Board, and Bayer CropScience for funding this research.

Literature Cited

Anonymous. 2021. Bayer further commits to crop protection innovation with planned introduction of diflufenican. Accessed 13 Feb. 2023. Available at: https://www.agrinews-pubs.com/news/science/2021/07/29/bayer-further-commits-to-crop-protection-innovation-with-planned-introduction-of-diflufenican/

Heap, I. 2023. The international herbicide-resistant weed database. Accessed 13 Feb. 2023. Available at: https://www.weedscience.org/Home.aspx

Hu, Z., J. Li., Y. Zhang, and Y. Shi. 2020. Determination of residue of diflufenican in wheat and soil by spectrometry conditions. J. Sci. Food Agric. 101:215–219.

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

Van Wychen, L. 2022. 2022 survey of the most common and troublesome weeds in broadleaf crops, fruits, and vegetables in the United States and Canada. Accessed 13 Feb. 2023. Available at: https://wssa.net/wp-content/uploads/2022-Weed-Survey-Broadleaf-crops.xlsx

Table 1. Soybean injury (%) at 2 and 4 weeks after emergence (WAE) and relative grain yield collected at maturity from 2022 at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark.

Timing	Diflufenican mixture rate	Injury 2 WAE[†]		Injury 4 WAE		Relative soybean grain yield
		--------	--------	%	--------	--------
Nontreated	0X	--		--		100[§]
14-day preplant	1X	1	f[‡]	0	d	114
14-day preplant	2X	6	e	1	cd	114
7-day preplant	1X	8	de	3	cd	111
7-day preplant	2X	16	bc	14	b	112
Preemergence	1X	13	cd	6	c	117
Preemergence	2X	20	b	14	b	112
3 days after planting	1X	20	b	13	b	92
3 days after planting	2X	33	a	23	a	85

[†] Abbreviations: WAE = weeks after emergence.

[‡] Means within a column not containing the same letter differ according to Fisher's protected least significant difference (α = 0.05).

[§] Nontreated grain yield averaged 55 bushels per acre.

Table 2. Palmer amaranth (*Amaranthus palmeri* S. Wats.) and common lambsquarters (*Chenopodium album*) percent control from 2022 at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark.

Timing	Diflufenican mixture rate	Control: Palmer amaranth 3 WAP[†]		Palmer amaranth 6 WAP		Common lambsquarters 3 WAP		Common lambsquarters 6 WAP		Soybean grain yield	
		--------		--------	%	--------		--------		bu./ac	
Nontreated	0X	--		--		--		--		6	c
14-day preplant	1X	88	b[‡]	65	b	93	b	74	b	26	b
7-day preplant	1X	97	a	87	a	99	a	90	a	34	ab
Preemergence	1X	100	a	90	a	100	a	92	a	35	ab
3 days after planting	1X	100	a	91	a	100	a	96	a	42	a

[†] Abbreviations: WAP = weeks after planting.

[‡] Means within a column not containing the same letter differ according to Fisher's protected least significant difference (α = 0.05).

ECONOMICS

Economic Analysis of the 2022 Soybean Research Verification Program

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Abstract

Economic and agronomic results of a statewide soybean research verification program can be a useful tool for producers making production management decisions before and within a crop-growing season. The 2022 season results provide additional economic relationship insights among seasonal, herbicide, and irrigation production systems as producers received record-high soybean market prices. Full-season production system fields exceeded early-season yields by 7.43 bu./ac and they exceeded late-season yields by 17.13 bu./ac. Full-season returns to land and management were $353.72 per acre higher than early-season returns and $242.91 per acre higher than late-season system fields. Roundup Ready 2 Xtend® (RRX) herbicide production system fields had a 6.37 bushel per acre yield advantage over Roundup Ready 2 Xtend Flex® (RRF) fields and a 26.20 bushel per acre advantage over Enlist E3® system fields, leading to a $31.15 or more per acre advantage in returns to land and management across all program fields. Irrigated systems were far superior to non-irrigated in both yields and returns. Total cost savings of $214.28 per acre associated with the non-irrigated system field could not overcome the 29.62 bushel per acre yield and associated $239.81 per acre returns to land and management disadvantages.

Introduction

The Arkansas Soybean Research Verification Program (SRVP) originated in 1983 with the 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, such as herbicide use rates, have also been identified using the SRVP database (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 and state extension specialists as needed. Economic analysis has been a primary focus of the program from the start. The SRVP coordinators record input rates and production practices throughout the growing season, including official yield measures at harvest. A CES state extension economist compiles the data into the spreadsheet used for the annual cost of production budget development. Measures of profitability and production efficiency are calculated for each cooperator's field and then grouped by soybean production system.

Results are stated for discussion use only. Readers should note that the standard statistical design and analysis used in plot research cannot be applied to the program data due to limited observation numbers and lack of replication. Variety herbicide classifications are consistent with Arkansas Soybean Performance Test designations or commercial seed company descriptions (Carlin et al., 2022; Carlin et al., 2021; Carlin et al., 2019; Syngenta; Mississippi State University, 2022; Becks Hybrids). Herbicide classification titles correspond with the 2022 season Arkansas soybean crop enterprise budgets published by Watkins (2022).

Procedures

Seventeen cooperating soybean producers across Arkansas provided input quantities and production practices utilized in the 2022 growing season. A state average soybean market price was estimated by compiling daily forward booking and cash market prices for the 2022 crop. The collection period was from 1 January through 31 October 2022. These prices are the same used for the weekly soybean market reports published on the Arkansas Row Crops Blog (Deaton, 2023). Data was entered into each respective production system's 2022 Arkansas soybean enterprise budgets (Watkins, 2022). The budget values primarily estimated input prices and production practice charges. Missing values were estimated using a combination of both industry representative quotes and values taken from the Mississippi State Budget Generator program for 2022 (Laughlin and Spurlock, 2016).

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Summary reports, by field, were generated and compiled to generate system results.

Results and Discussion

The 17 fields included in the 2022 Arkansas Soybean Research Verification Program report (Norton et al., 2022) had an average yield of 65.18 bushels per acre, generating an average revenue of $999.16 per acre. Producers required $336.10 per acre of variable costs, $99.26 per acre of fixed costs, or a total cost per acre of $435.36, resulting in a return to land and management of $563.79 per acre. The fields spanned 7 different production systems based on combinations of seasonal, herbicide, and irrigation characteristics (Table 1). The system combination utilizing Full Season, Roundup Ready 2 Xtend Flex® (RRF) technology seed, and Furrow Irrigation was most common with 7 fields. Five fields used a Full Season, Roundup Ready 2 Xtend® seed, and Furrow Irrigation system. The remaining 5 combinations each occurred on only 1 field. All economic comparisons were developed from soybean forward book and cash market prices for the 2022 crop reported by Deaton in weekly market reports (Deaton, 2023). The soybean forward book and cash market price for the 2022 crop averaged $15.33 per bushel from 1 January to 31 October 2022.

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 the numbers within groups of fields represented in this study do not permit standard statistical analysis. Yield and economic results are presented by grouping only for discussion purposes. Economic comparisons are drawn across seasonal, herbicide, and irrigation characteristics (Tables 2, 3, and 4). The values for yield, revenue, total variable cost, total fixed cost, total cost, and return to land and management are discussed by characteristics. Variable costs include fuel, seed, fertilizer, chemicals, and hired labor. Fixed costs include estimates of capital recovery values for all field equipment and irrigation systems used. No land rent was charged. Returns may be regarded as the return to management and operator labor.

Season Comparisons

The 17 fields spanned 1 early-season, 14 full-season, and 2 late-season systems. Full-season plantings had a 7.43 bu./ac yield advantage over the early-season plantings and a 17.13 bu./ac yield advantage over late-season systems (Table 2). Revenue for the full-season fields was much higher than for early- or late-season fields ($1036.75 vs. $922.87 and $774.17, respectively). Early-season fields had much higher total costs than full- or late-season fields. The high total costs were primarily due to much higher variable costs, but fixed costs were also higher for early-season fields. Returns to land and management for full-season fields were by far the highest: $ 241.91 per acre higher than late-season fields and $353.72 per acre higher than early-season fields.

Herbicide Comparisons

The Roundup Ready 2 Xtend Flex® (RRF) herbicide system was most frequently used with 8 of the 17 fields (Table 3). The Roundup Ready 2 Xtend® (RRX) system followed closely with 6 fields. Three fields used the Enlist E3® system. Yield comparisons by herbicide showed the RRX fields had a 6.37 bu./ac advantage over the RRF fields. RRX fields had higher total costs than the other two systems ($66.58/ac or higher), but they also had the highest returns to land and management ($31.15/ac or higher). The Enlist E3® system had the lowest total costs ($123.30/ac lower than RRX), but it also had the lowest yield (26.6 bu./ac lower than RRX) and the lowest returns to land and management ($278.34/ac lower than RRX).

Irrigation Comparisons

Sixteen fields in the 2022 program were irrigated, with only 1 non-irrigated field. Fifteen fields were furrow irrigated, and a center pivot irrigated 1 field. The irrigated fields had a huge yield (29.62 bu./ac higher) and returns ($239.8/ac higher) advantage over the non-irrigated field. The total costs of the non-irrigated field were much lower ($214.24/ac lower) than the irrigated fields.

Overall Comparisons

The 2022 Arkansas Soybean Research Verification Program fields had a 65.18 bu./ac statewide average yield. This yield was 2.28 bushels more than in 2021 and more than 13 bushels above the 2022 Arkansas state average yield of 52 bushels/ac (USDA, 2023). Revenue averaged $999.16 from this production and historically high market price. The revenue mark represents an increase of more than $195/ac compared to 2021. Total variable costs averaged $336.10, a $98.08 increase, and total fixed costs averaged $99.26, an $18.97 increase, for an average total cost per acre of $435.36, a $78.73 increase over 2021. These revenue and cost averages left producers with an average per acre return to land and management of $563.79 across all production systems, an increase per acre of $78.73 compared to 2021.

Practical Applications

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

Acknowledgments

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Literature Cited

Becks Hybrids. Becks 5005XF Variety Specifications Sheet. Accessed 21 September 2023. Available at: https://www.beckshybrids.com/products/soybeans

Carlin, J.F., R.B. Morgan, and R.D. Bond (2022). Arkansas Soybean Performance Tests 2021. Arkansas Agricultural Experiment Station Research Series 682. Accessed 2 Oct 2023. Available at: https://scholarworks.uark.edu/aaesser/206

Carlin, J.F., R.D. Bond, and R.B. Morgan (2021). Arkansas Soybean Performance Tests 2020. Arkansas Agricultural Experiment Station Research Series 673. Accessed 2 Oct 2023. Available at: https://scholarworks.uark.edu/aaesser/196

Carlin, J.F., R.D. Bond, and J.A. Still (2019). Arkansas Soybean Performance Tests 2019. Arkansas Agricultural Experiment Station Research Series 664. Accessed 2 Oct 2023. Available at: https://scholarworks.uark.edu/aaesser/158

Deaton, B.D. 2023. Arkansas Soybean Market Reports (various dates). Arkansas Row Crops Blog. Accessed 31 March 2023. Available at: http://www.arkansas-crops.com/

Laughlin, D.H. and S.R. Spurlock. 2016. "User's Guide for the Mississippi State Budget Generator." Version 6.0 for Windows. Accessed 31 March 2023. Available at: https://www.agecon.msstate.edu/whatwedo/budgets/generator/docs/userguide6.pdf

Mississippi State University. 2022 Soybean Variety Demonstration Program. Accessed 21 September 2023. Available at: https://www.mssoy.org/uploads/files/miss-on-farm-var-demo-2022.pdf

Norton, C., C. Elkins, J. Ross, B. Deaton, and B. Stark. 2022. University of Arkansas System Division of Agriculture Soybean Research Verification Program Report. 2023. Accessed 31 March 2023. Available at: https://www.uaex.uada.edu/farm-ranch/crops-commercial-horticulture/verification/2020%20SRVP%20Final%20Report.pdf

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.

Syngenta. NK48-H3XFS Variety Specifications Sheet. Accessed 21 September 2023. Available at: https://assets.syngenta-us.com/pdf/techsheets/NK48-H3XFS_230425.pdf

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 January 2008, Dumas, Arkansas.

USDA- NASS. 2023. United States Department of Agriculture, National Agricultural Statistics Service. QuickStats. Accessed 31 March 2023. Available at: https://www.nass.usda.gov/Quick_Stats/Lite/index.php

Watkins, B. 2022. Crop Enterprise Budgets for Arkansas Field Crops Planted in 2022. University of Arkansas System Division of Agriculture, Research and Extension, October, 2021. Accessed 31 March 2023. Available at: https://www.uaex.uada.edu/farm-ranch/economics-marketing/farm-planning/budgets/crop-budgets.aspx

Table 1. Production System Combinations of the seventeen fields participating in the 2022 University of Arkansas System Division of Agriculture's Soybean Research Verification Program.

Production System	Early	Full	Full	Full	Full	Late	Late
Herbicide	RRX	E3	E3	RRF	RRX	E3	RRF
Irrigation	Fur	CP	Dry	Fur	Fur	Fur	Fur
Number of Fields	1	1	1	7	5	1	1

Production Systems: Early = Early-Season; Full = Full-Season; Late = Late-Season
Herbicide: E3 = Enlist E3®; RRF = Roundup Ready 2 Xtend Flex®; RRX = Roundup Ready 2 Xtend®
Irrigation: CP = Center Pivot Irrigation; Dry = Non-Irrigation; Fur = Furrow Irrigation
Source: 2022 Arkansas Soybean Research Verification Program Report.

Table 2. Economic Results by Seasonal Production System for the 2021 University of Arkansas System Division of Agriculture's Soybean Research Verification Program.

Production System	Early Season	Full Season	Late Season	All Fields
Number of Fields	1	14	2	17
Yield (bu./ac)	60.20	67.63	50.50	65.18
Revenue ($/ac)	922.87	1036.75	774.17	999.16
Total Variable Costs ($/ac)	516.25	329.60	291.53	336.10
Total Fixed Costs ($/ac)	147.28	94.08	111.50	99.26
Total Costs ($/ac)	663.53	423.68	403.02	435.36
Returns to Land and Management ($/ac)	259.34	613.06	371.15	563.79

Source*:* 2022 Arkansas Soybean Research Verification Program Report.

Table 3. Economic Results by Herbicide System for the 2022 University of Arkansas System Division of Agriculture's Soybean Research Verification Program.

Herbicide System	Enlist E3®	Roundup Ready 2 Xtend Flex®	Roundup Ready 2 Xtend®	All Fields
Number of Fields	3	8	6	17
Yield (bu./ac)	46.60	66.43	72.80	65.18
Revenue ($/ac)	714.38	1018.30	1116.02	999.16
Total Variable Costs ($/ac)	267.59	326.95	382.56	336.10
Total Fixed Costs ($/ac)	97.55	94.92	105.90	99.26
Total Costs ($/ac)	365.15	421.87	488.45	435.36
Returns to Land and Management ($/ac)	349.23	596.42	627.57	563.79

Source: 2022 Arkansas Soybean Research Verification Program Report.

Table 4. Economic Results by Irrigation System for the 2022 University of Arkansas System Division of Agriculture's Soybean Research Verification Program.

Irrigation Production System	Irrigated	Non-Irrigated	All Fields
Number of Fields	16	1	17
Yields (bu./ac)	66.92	37.30	65.18
Revenue ($/ac)	1025.86	571.81	999.16
Total Variable Costs ($/ac)	346.38	171.69	336.10
Total Fixed Costs ($/ac)	101.59	62.03	99.26
Total Costs ($/ac)	447.96	233.72	435.36
Returns to Land and Management ($/ac)	577.90	338.09	563.79

Source: 2022 Arkansas Soybean Research Verification Program Report.

Soybean Yield as a Function of Annual Total Plant Water Use Using the Sap Flow Method

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Abstract

Sap flow was measured in Arkansas irrigated soybeans [*Glycine max* (L.) Merr.] and was summarized by growth stage across a wide range of maturity groups, planting dates, and yields. Data was collected on small plots and a high-yielding commercial field. A linear model between soybean yield and sap flow was y = 5.429 + 0.1662x where x is yield in bushels per acre and y is sap flow (total plant water use) in inches. The goodness of fit was 0.81 between 30–90 bushels per acre. The practical application of this research is that this relationship can be used to manage irrigation because water use can be estimated from an expected yield goal.

Introduction

Predicting soybean [*Glycine max* (L.) Merr.] yield response to water is required for assessing irrigation management strategies. Studies have identified the period from flowering to grain fill as the most sensitive to water stress (Karam et al., 2005; Payero et al., 2005). Soybean yield was predicted and compared with different yield models based on soil water balance and actual transpiration by Gimenez et al. (2017). The results of the Gimenez study show that irrigated soybean yield predictions have fewer errors than water-stressed or rainfed soybeans. Ismanov et al. (2020) reported plant water use by growth stage and a relationship between yield and sap flow. Soil moisture, solar radiation, air temperature, air relative humidity, transpiration, and vapor pressure deficit all influence sap flow in agricultural crops (Zhao et al., 2017; Ismanov et al., 2019).

Procedures

Soil moisture, fertility, and weather all contribute to the amount of sap flow in soybean plants. Field studies in 2017–2022 were conducted at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station at Marianna, Ark., using heat balance flow gauges to determine the relationship between plant sap flow and soybean crop yield. Twenty-three different maturity group soybean varieties were planted during the multiple-year sap flow experiments (Table 1). Seeds were planted early season (late April and beginning of May), middle season (late May and beginning of June), and late season (late June) planting dates based on current planting window recommendations. Field preparation, fertilization, planting, herbicide, and pesticide treatments were fulfilled according to the University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations. Soybean were planted with a single-row, 38-in. wide row spacing.

The Flow 32 1-K (http://dynamax.com) system with SGA5-WS 5 mm diameter and SGB9-WS 9-mm diameter sap flow sensors were used to measure soybean plant sap flow from R1 until R8 growth stages. The measurements continued with 10-minute logging intervals from June in the early season planted early maturity group of soybeans to the end of October in the late-planted late maturity group of soybean varieties. Model-E electronic pulse output digital ET-gage (www.etgage.com) and WatchDog2900 ET weather stations (www.specmeters.com) are used to record the evapotranspiration (ET) and other weather parameters.

Each variety was planted in 12 rows, then divided into 3 4-row plots with 3 middle irrigation rows, allowing 2 control rows irrigated from 2 sides and 2 alley rows irrigated with 1 side. A randomized block design was created by segregating the strip plots into 3 or 12 replications with final plot lengths of 30 ft long.

Irrigation, fertilization, and soil processing treatments were applied, but this paper did not report the fertilization and soil processing. The following irrigation timings were applied to each variety: calendar-based, evapotranspiration-based (ET), sensor-based, and rainfed-only treatment. The calendar-based treatment followed the irrigation frequency of neighboring farmers' irrigations based on weekly irrigation if there was no rainfall. The evapotranspiration-based (ET-based) irrigation plots were monitored using an alfalfa reference canvas atmometer and crop coefficients published by the Division of Agriculture (Henry et al., 2018).

A 2-in. water deficit interval was used to initiate irrigation, corresponding to the characteristics of a silt loam soil with a pan. Sensor-based irrigation was irrigated using the soil sensor calculator mobile application (https://apkpure.

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com/arkansas-watermark-tool-soil-sensor-calculator/com.rire.calculator/download) from the University of Arkansas System Division of Agriculture's Irrigation Water Management Team which uses a 30 in. effective rooting depth, 4 sensors at 6, 12, 18, and 30 inches, an allowable depletion of 50%, a 12-hour irrigation time, and the settings for a silt loam soil with a pan.

Watermark soil moisture sensors installed at 6-, 12-, 18-, and 30-inch depths of the seedbed and connected to 900M Watermark data logger (www.irrometer.com) are used to record the centibars (cb) every hour. Soil temperature was measured at 1-in. and 6-in. depths by an iBWetLand temperature data logger (https://alphamach.com/) and Watermark temperature sensors.

Data was analyzed with JMP (Cary, N.C.) using analysis of variance (ANOVA), linear model, multiple comparison test, and the Tukey-Kramer honestly significant difference method where $\alpha = 0.05$. Linear relationships were determined using JMP or Microsoft Excel (Microsoft, Redman, Wash).

Results and Discussion

Soybean planted during the early, middle, and late-season timings emerged in 9, 7, and 5 days with 143, 144, and 156 growing degree-day heat units (GDD), respectively. Plant growth depends on ET and gets slower when the daily ET is less than 0.15 inches. The highest plant sap flow and growth rates occur around 0.2 – 0.25 inches of ET.

On average, early, middle, and late season planted soybeans received 3253, 3139, and 2668 GDD, respectively, until the R8 growth stage. Solar radiation at 29.5, 27.5, and 24.1 kWh/m^2 was measured for the early, middle, and late-season planted plots, respectively. Alfalfa reference evapotranspiration was 20.7, 19.2, and 15.7-in. from planting until R8. The cumulative GDD, solar radiation, and ET in early and middle-season treatment soybeans are nearly the same, while the late-season soybeans are 70% – 85% less than the early and late-season treatments.

Irrigation in most years was initiated in the middle of June in the early-season planted soybeans. Calendar-based irrigation treatments were irrigated 1 or 2 times more than the ET and sensor-based treatments. The middle-season planted soybeans received irrigation 1–3 times more than early and late-season. Early season planted soybean water use was 3.0, 2.6, and 2.2 in. during the R5 growth stage, respectively, in calendar-based, ET-based, and dryland-rainfed irrigation treatments. Dry conditions delayed soybean plant development by 5–7 days at the R6 and R8 growth stages in dryland plots compared to the irrigated treatments. Wet periods that occurred after heavy rainfalls also delayed soybean development.

Sap flow and ET from the 2022 high yield (90 bu./ac) soybean farm field is shown in Fig. 1. The total water received in this field was 31 in., including 16 in. of irrigation water and 15 in. of rainfall from soybean planting to harvesting dates. Sap flow data for this site was 19 in. during the season. Over the 5-year study period, vegetative growth stages average water demand was summarized. As estimated by sap flow, about 2 in. or 5 % of the total plant water demand occurs in the vegetative period. Early reproductive stages from R1 to R4 needed 7 in. or about 38 % of the total plant water demand. About 55 % or 8 in. of plant water demand was used in the seed fill reproductive stages of R5–R6.5. The final reproductive stages from R6.5 to R8 needed 2 % or 2.6 in. of the total plant water demand. During the irrigation season stages from R3 to R6.5, soybean plants transpired 13.3 in. or 69 % of the total plant water demand.

Early planted soybean yields were significantly different for some varieties, but later planted yields were not significantly different (Table 2). A lower yield of a maturity group 2.5 may be explained because less solar radiation is received and less GDD accumulated than later maturity groups. Thus, there was likely less photosynthetic opportunity for yield potential. Higher yields of the later maturity groups in early planted soybeans were found in previous years and explained by higher sap flows during these periods.

Data from 6 soybean varieties in the early, middle, and late season planting dates in 2022 was analyzed to determine the goodness of fit between soybean yields, ET, and solar radiation (Table 1). A goodness of fit of 0.51 was observed between the soybean yield of all 56 calendar-based irrigation plots and cumulative solar radiation received during the VC–R6.9 growth stages (Fig. 2). No reliable goodness of fit model was found between yield and solar radiation received in all 39 rain-fed dryland plots. The goodness of fit between soybean yield and cumulative ET during the VC–R6.9 growth stages for the early and middle season planted soybeans were found to be 0.53 and 0.64, respectively.

The results indicate that sap flow is likely a better predictor of yield than ET or solar radiation. A yield versus total sap flow (water use) model was developed by combining all of the data from the sap flow plot studies between 2017 and 2022. The data from the study is shown in Fig. 3. The model of $y = 5.092 + 0.1544x$ is yield in bushels per acre, and sap flow (total plant water use) in inches was determined using a quadratic equation. The goodness of fit was found to be 0.538, between 40 – 90 bushels per acre.

Several outliers appear in the data, reducing the slope slightly from very low water use but similar yield to other data points. These three data points were removed, and a linear model was developed. This model, $y = 5.429 + 0.166x$, had a much-improved goodness of fit of 0.811. It also resulted in a 0.6 to 1.5 in. higher prediction of sap flow for the same yield as the first model. For application in irrigation, a more conservative model is preferred. Thus, the more conservative model that would predict a higher water use for a given yield and had a better fit is reported in Fig. 4.

Such a model is helpful in irrigation management because the total water use between 60 and 100 bushels per acre is nearly 4 in. Thus, 2 fewer irrigations may be needed for lower yield potential soybeans while also ensuring high-yielding soybeans have sufficient water for yield potential.

Additionally, as yield potential increases, additional data and modeling are warranted to predict water use from yield better.

Practical Applications

Growth degree-day heat units increased with soil temperature in middle and late-season planted soybeans. It was found that middle and late-season plants emerged 2–4 days earlier than the early-season planted ones. Soybean plants produced higher yields with higher accumulated sap flow during the vegetative and reproductive stages. The relationship of y = 5.429 + 0.1662x, where y is the yield and x is the sap flow in inches, is a useful tool in estimating the total crop water demand for irrigation. When used with soil water availability, such a tool can be used to better match irrigation needs based on yield rather than a single book value.

The relationship between sap flow water use and yield is helpful in irrigation management. The total water use between soybean crops that yield 60 and 100 bushels per acre is nearly 5 inches or about 2 irrigations. Thus, two irrigations could be saved for low-yield potential soybeans while also ensuring high-yielding soybeans have sufficient water for yield potential.

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Literature Cited

Giménez, L., P. Paredes, and L.S. Pereira. 2017. Water Use and Yield of Soybean under Various Irrigation Regimes and Severe Water Stress. Water. 9(6), 393. Accessed 19 June 2023. Available at: https://doi.org/10.3390/w9060393

Henry, C.G., L. Espinoza, M. Ismanov, P. Francis and J. Ross. 2018. ET-Gage-Sheet-Soybean. https://www.uaex.uada.edu/environment-nature/water/docs/irrig-ET-Gage-Sheet-Soybean.pdf

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. Ag. Sci. Vol.10, No.3. Accessed 19 June 2023. 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. Arkansas Agricultural Experiment Station Research Series 680:185-189.

Karam, F., R. Masaad, T. Sfeir, O. Mounzer, and Y. Rouphael. 2005. Evapotranspiration and seed yield of field grown soybean under deficit irrigation conditions. Agric. Water Manag. 75, 226–244.

Payero, J.O., S.R. Melvin, and S. Irmak. 2005. Response of soybean to deficit irrigation in the semi-arid environment of West-Central Nebraska. Trans. ASAE. 48, 2189–2203.

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 Reg. 82, 353-362. Accessed 8 July 2022. Available at: https://doi.org/10.1007/s10725-017-0263-6

Table 1. Soybean varieties and planting dates in multiple years for sap flow experiment at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, at Marianna, Ark.

Year	Planting date	Variety	Year	Planting date	Variety
2017	19 April	Dyna-Gro 39RY43	2021	25 May	P31A06L
2017	20 April	AV38E8LLDU	2021	25 May	P40A03L
2017	16 May	AV49H9LLST	2021	25 May	49A41L
2017	2 June	AV52C2DU23	2021	25 May	P38A49L
2017	16 June	AV52C2DU23	2021	25 May	P47A76L
2018	2 May	P55A49X	2021	24 June	P31A06L
2018	2 May	P4247 LL	2021	14 July	P31A06L
2018	4 May	P35T75X	2021	14 July	P40A03L
2018	28 May	P40A47X	2021	14 July	P49A41L
2018	30 June	P48A60X	2021	14 July	P38A49L
2019	1 May	P31A06L	2022	5 May	P46A20L
2019	28 May	P40A03L	2022	5 May	P40 A20L
2019	30 June	P40A03L	2022	5 May	P52A14S
2020	6 May	P31A06L	2022	5 May	P25A16S
2020	6 May	P37T09L	2022	31 May	P46A20L
2020	3 June	P37T09L	2022	31 May	P40A20L
2020	3 June	P48A99L	2022	31 May	P25A16S
2020	30 June	P37T09L	2022	31 May	AG55XF
2021	26 April	P31A06L	2022	31 May	AG26XF
2021	26 April	P40A03L	2022	28 June	P40A20L
2021	26 April	P49A41L	2022	28 June	P25A16SE
2021	26 April	P38A49L	2022	28 June	AG26XF1
2021	26 April	P47A76L	2022	28 June	AG55XF0
			2022	28 June	P46A20LX

Table 2. Yields of selected soybean varieties and maturity groups planted on different dates.

Variety	P52A14SE	P46A20LX	P40A20LX	AG55XF0	AG26XF1	P25A16SE
			Planting Date 5 May 2022			
Average Yield, bu./ac	76.2 ab†	78.8 a	72.4 b			31.2 c
			Planting Date 31 May 2022			
Average Yield, bu./ac		70.4 a	70.8 a	74.5 a	67.3 a	74.6 a
			Planting Date 28 June 2022			
Average Yield, bu./ac		53.6 a	53.7 a	54.7 a	57.4 a	40.2 a

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

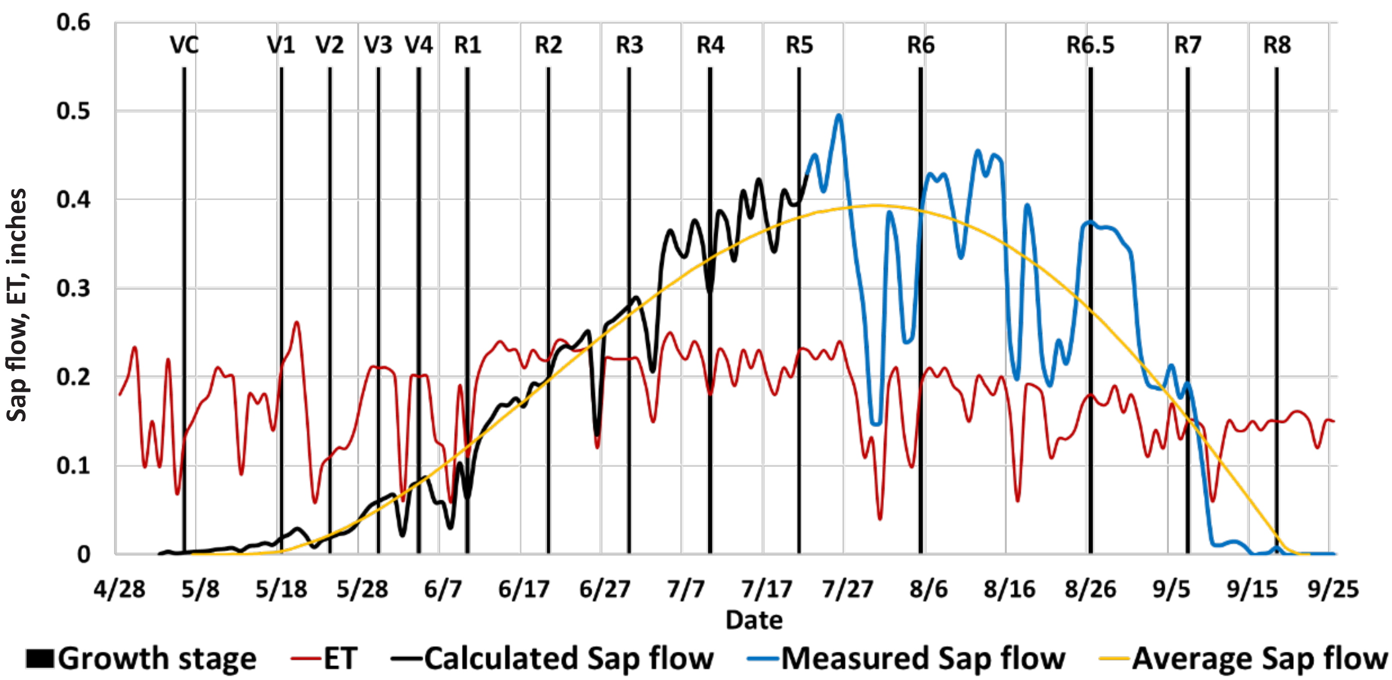

Fig. 1. High yield expecting soybean farm field sap flow and evapotranspiration (ET) during the vegetative and reproductive stages of the whole growing season (2022).

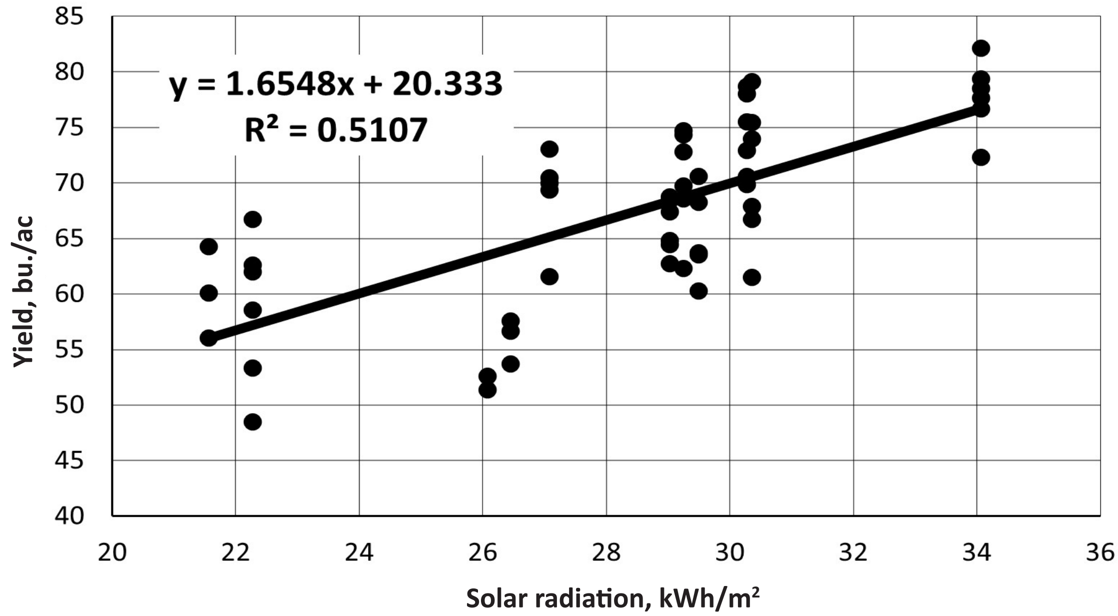

Fig. 2. Relationship between yield and cumulative solar radiation during VC-R6.9 growth stages for the 192 soybean plots with different irrigation treatments and soybean varieties at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station at Marianna, Ark. (2022).

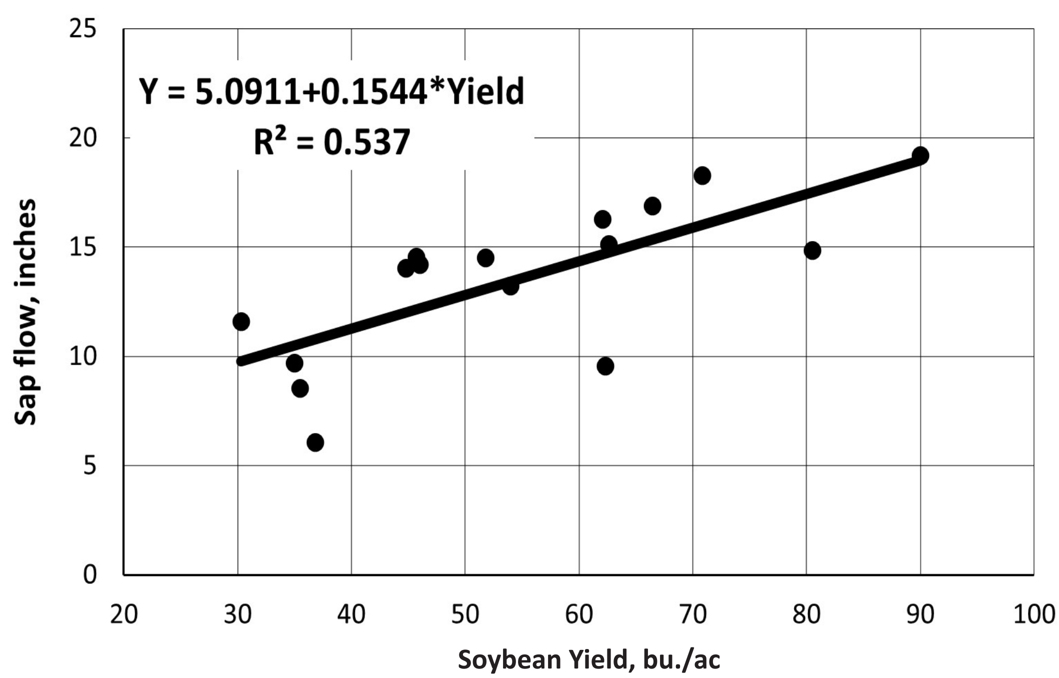

Fig. 3. Soybean sap flow versus yield (bu./ac) with outliers.

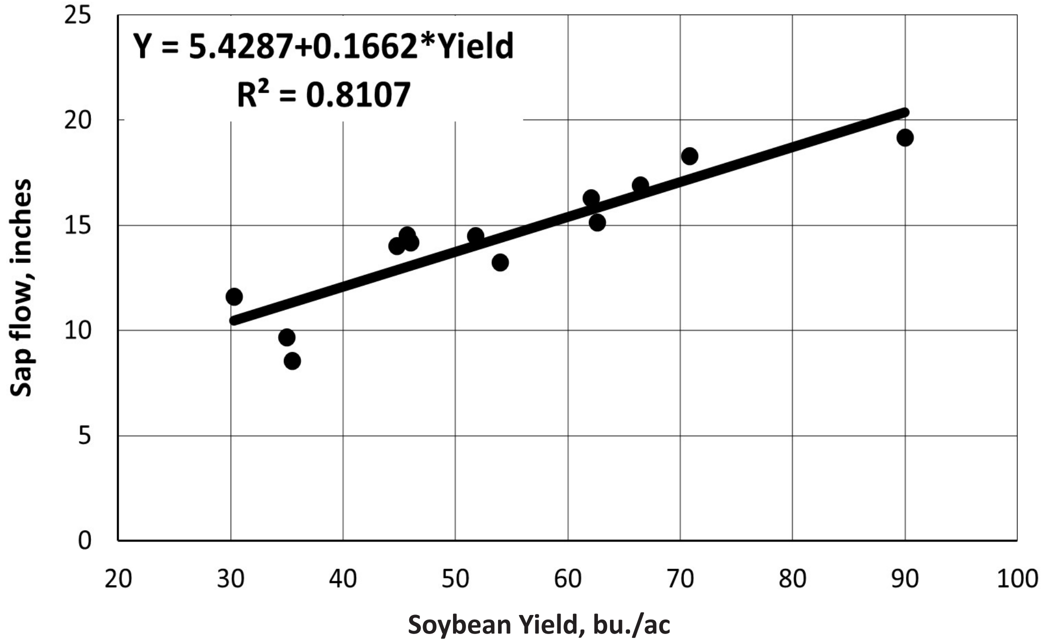

Fig. 4. Soybean sap flow versus yield (bu./ac) with outliers removed.

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

C.G. Henry,[1] T. Clark,[1] R. Parker,[1] and J.P. Pimentel[2]

Abstract

The University of Arkansas System Division of Agriculture's Irrigation Yield Contest was conducted in 2018, 2019, 2020, 2021, and 2022. The contest was designed to promote better use of irrigation water and record data on water use and water use efficiency for various crops. Unlike yield contests, where winners are decided by yield alone, the irrigation contest results are decided by the highest calculated total water use efficiency (WUE) achieved by a producer. The contest consists of 3 categories: corn, rice, and soybeans. All fields entered were required to show a history of irrigation and production on the field. Irrigation water was recorded using 6-in., 8-in., and 10-in. portable mechanical flow meters. Rainfall totals were calculated using Farmlogs™. The contest average water use efficiency of 2018–2022 for soybean was 3.23 bu./in. The winning WUE was 4.25 bu./in. for 2022, 5.23 bu./in. for 2021, 4.34 bu./in. for 2020, 4.31 for 2019, and 3.92 bu./in. for 2018. Adoption of IWM practices by participants such as CHS, Surge irrigation, and soil moisture sensors are increasing. Soybean contest participants from 2018–2022 reported using, on average, 9.5 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). One study of the aquifer found that 29% of the wells in the aquifer, that were tested, had lower water levels between 2009 and 2019 (Arkansas Department of Agriculture Natural Resource Division, 2019).

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

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

Materials and Methods

Rules for the irrigation yield contest were developed in 2018. The influence was from existing yield contests (Arkansas Soybean Association, 2014; National Corn Growers Association, 2015; National Wheat Foundation, 2018; University of California Cooperative Extension, 2018). The rules were designed to be as unobtrusive as possible to normal planting and harvesting operations. Fields 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™, an online software that provides rainfall data for a given location. Rainfall amounts were totaled from the emergence date to the physiological maturity date. Emergence was assumed as 7 days after the planting date provided on the entry form. For physiological maturity, the seed companies published 'days to maturity' was used. Rainfall was adjusted for extreme events.

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

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

Results and Discussion

For each contest year, detailed results are published on the contest website (www.uaex.uada.edu/irrigation). Over the 5 years that the competition has been conducted, 68 fields have been entered for soybean. The average WUE over the 5 years was 3.23 bu./in. By year, the average WUE was 3.16 bu./in. for 2022 with 8 contestants, 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 4.25 bu./in. for 2022, 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 can be 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 exists. There is no discernable relationship between yield and WUE in the soybean dataset. Another commonly held belief by contestants is that a higher amount of rainfall will help to increase WUE. By plotting rainfall against WUE, linear regression was used to determine if there was a linear relationship. The coefficient of determination was determined to be $R^2 = 0.15$. There is no discernable relationship between WUE and precipitation. The lack of relationships suggests that neither precipitation nor yield is a factor in achieving high WUE, and achieving high WUE is due to irrigation management.

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

Contestants are asked about adopting IWM tools when they enter the contest. In total, 64% of the participants across all 3 categories included responses in their entry form. The IWM tool that was most widely adopted was CHS. The average use among respondents was 82.7% across all 5 years, with 88% in 2018, 72% in 2019, 100% in 2020, 97.5% in 2021, and 79% in 2022. Sixty percent of respondents from all 5 years said they used soil moisture sensors on their farm, with 50% in 2018, 40% in 2019, 42% in 2020, 87% in 2021, and 81% in 2022. Surge valves were the least used IWM tool, with a 5-year average use rate of 25%. Those that reported using surge irrigation over the 5 years of the contest were 44% in 2018, 28% in 2019, 16% in 2020, 35% in 2021, and 12% in 2022 (Table 2).

Practical Applications

Irrigation water use efficiency of working farms is not a common metric available in the literature and is not a metric familiar to soybean farmers. The data recorded from the Arkansas Irrigation Yield Contest provides direct feedback to irrigators about their irrigation performance in maintaining high yields and low irrigation water used. Direct feedback from Arkansas soybean farmers will likely give many a competitive advantage when water resources become scarce. 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 5 years averaged 9.4 ac-in./ac applied and a total water use of 24.6 in. for soybean.

Acknowledgments

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Literature Cited

Arkansas Department of Agriculture Natural Resource Division. 2020. Arkansas Groundwater Protection and Management Report for 2019. Accessed 22 February, 2021. Available at: https://www.agriculture.arkansas.gov/wp-content/uploads/2020/06/27-2019_Report_Final_Draft.pdf

Arkansas Soybean Association. 2014. Grow for the Green Soybean Yield Challenge Rules and Entry Form. Accessed 14 January 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, 65 p., Accessed 21 June 2023. Available at: https://doi.org/10.3133/cir1441

Irmak, S., L.O. Odhiambo, W.L. Kranz, and D.E. Eisenhauer. 2011. Irrigation Efficiency and Uniformity and Crop Water Use Efficiency. Biological Systems Engineering: Papers and Publications, 1-8.

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 14 January 2023. Available at: http://dx.doi.org/10.3133/sir20145149

National Corn Growers Association. 2015. National Corn Yield Contest. Accessed 14 January 2021. Available at: https://www.ncga.com/get-involved/national-corn-yield-contest

National Wheat Foundation. 2018. National Wheat Yield Contest Rules. Accessed 14 January 2021. 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 14 January 2023. Available at: https://doi.org/10.2134/cftm2018.12.0100

United States Department of Agriculture National Agricultural Statistics Service. 2017. Quick Stats. Accessed 22 February, 2021. Available at: https://quickstats.nass.usda.gov/results/4754F465-950B-35AB-A192-B4699B526B66

University of California Cooperative Extension. 2018. UCCE Rice Yield Contest Entry and Harvest Rules. Accessed 14 January, 2021. Available at: https://ucanr.edu/sites/RiceTestSite/files/328524.pdf

Table 1. Maximum, average, and minimum for 2018, 2019, 2020, 2021, and 2022 of various 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.)
2022	Maximum	4.25	100	17.8	16.7	29.16
	Average	3.16	82	14.3	11.9	26.2
	Minimum	2.33	68	10.4	8.0	23.6
2021	Maximum	5.23	101	21.4	19	32
	Average	3.53	84	14.5	9.9	24.5
	Minimum	2.45	72	10.4	5.1	18.9
2020	Maximum	4.34	105	15.9	20.8	34.1
	Average	3.48	80	13.4	10.2	23.7
	Minimum	1.81	44	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
5 Yr.	Average	3.23	78	15.2	9.5	24.9

Table 2. Technology adoption from the Arkansas Irrigation Yield Contest (% by respondents).

	Computerized Hole Selection	Moisture Sensors	Surge Valve
	-----------------	%	-----------------
2022	79	81	12
2021	97.5	87	35
2020	100	100	25
2019	72	40	28
2018	88	50	44

SOIL FERTILITY

Fertilizer Rates to Correct In-Season Potassium Deficiencies During Early Reproductive Growth in Arkansas Soybean

C.C. Ortel,[1] T.L. Roberts,[1] K.A. Hoegenauer,[1] W.J. Ross,[2] N.A. Slaton,[3] and C.A. Followell[1]

Abstract

Potassium (K) deficiencies in irrigated soybean [*Glycine max* (L.) Merr.] are common in irrigated mid-South production systems that can limit soybean yield potential. A study was conducted to correlate the relative soybean grain yield to the leaf-K concentration at 15 days after first flower (DAR1) and calibrate the fertilizer-K rate needed to correct in-season K deficiencies and maximize grain yield at 15 DAR1 based on the trifoliolate leaf-K concentration. Research was conducted in 2021 and 2022 at 8 site-years across Arkansas on silt loam soils planted with maturity group 4 or 5 cultivars. One treatment received 160 lb K_2O/ac as granular muriate of potash (MOP) at preplant, and all other treatments received no preplant fertilizer-K followed by multiple rates of granular MOP ranging from 0 to 160 lb K_2O/ac at 15 DAR1. The trifoliolate leaf-K concentration was measured in the upper-most fully expanded leaf at 15 DAR1 and was confirmed to be positively correlated with relative grain yield. Soybean leaf-K concentrations ranged from 0.96% to 1.93% K at 15 DAR1. Soybean with leaf-K concentrations at or less than 1.76% K at 15 DAR1 responded significantly to in-season fertilizer-K applications. Quadratic models were used to predict the fertilizer-K rate needed to reach 95% relative grain yield or the highest relative grain yield achieved for the responsive sites, which ranged from 20 to 120 lb K_2O/ac depending on the leaf-K concentrations. Calibrated fertilizer-K rates based on tissue-K concentrations in early reproductive growth will enable producers to correct deficiencies in season with the appropriate fertilizer rate to maximize yield.

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 upper-most fully expanded trifoliolate leaf (no petiole) should occur before any signs of K deficiency appear. Unrecoverable yield loss can occur by the time a soybean plant shows visible K deficiency symptoms. Slaton et al. (2021) recently established a dynamic tissue-K critical concentration curve to diagnose in-season K deficiencies in soybean at any time during reproductive growth. If a deficiency or hidden hunger is confirmed, a timely application of fertilizer-K is required to prevent the potential yield loss. More specifically, Slaton et al. (2020) found a window of opportunity for in-season K applications in relation to the R1 growth stage, or first flower, to restore yield potential, assuming fertilizer can be incorporated and adequate soil moisture for plant uptake of K exists. When soil test K levels are "very low," and no preplant fertilizer-K is applied, or visible K deficiencies are observed, maximum soybean yield can be recovered up to 20 days after R1 (DAR1) with a timely potash fertilizer application that is incorporated via irrigation or rainfall. When soil test K levels are "low to medium," and no preplant fertilizer-K is applied, or plants are experiencing hidden hunger (yield loss with no visual K deficiency symptoms present), maximum soybean yield can be recovered up to 45 DAR1 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 rate of fertilizer-K needed to correct in-season K deficiencies during early reproductive growth and maximize soybean yield potential.

Procedures

Field trials were conducted in 2021 and 2022 at multiple research stations across the state on silt loam soils (Table 1). One composite soil sample consisting of an average of 8 subsamples was taken from each replicate just before 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 mix-

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ture), Mehlich-3 extractable nutrients (Helmke and Sparks, 1996), and LOI (Zhang and Wang, 2014). Means (n = 4) of the selected soil properties are listed in Table 1. Experiments were designed as a randomized complete block design with 4 replications of each treatment. Individual plots ranged from 10- to 12.6-ft. wide and 30-ft. long with 30- to 38-in. row spacings. One 160 lb K_2O/ac treatment was applied as muriate of potash (0-0-60) at preplant and incorporated. All other treatments were applied in-season at 15 DAR1 at rates of 0, 40, 80, 120, and 160 lb K_2O/ac as MOP following no preplant K fertilizer. In-season applications were broadcasted across the plot and the field was irrigated within 24 hours to incorporate the treatments. To ensure that P was not limiting in sites that measured less than "optimum" soil test P, 40 lb P_2O_5/ac was applied as triple super phosphate (0-46-0) and incorporated prior to planting. A maturity group 4 or 5 cultivar was planted between 19 May and 17 June at a seeding rate of approximately 130,000 seed/ac (Table 2). General crop management and furrow irrigation followed the current University of Arkansas System Division of Agriculture's Cooperative Extension Service production recommendations for stand establishment and pest control in soybean (Ross, 2000).

At 15 DAR1 for the scheduled in-season fertilizer application time, all site years were in the R2 (full bloom) growth stage. A composite sample of 12 trifoliolate leaves was taken from the upper-most fully expanded trifoliate leaves within the middle 2 rows of each plot, as well as 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 the University of Arkansas System Division of Agriculture's Agricultural Diagnostic Lab in Fayetteville. At maturity, the middle 2 rows were harvested using a small plot combine, 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 was capped at a value of 100%. Any value that exceeded 1.5 times the interquartile range (IQR) and was greater than the third quartile or less than the first quartile was designated as an outlier and excluded from the analysis. The relative grain yield was correlated to the trifoliolate-K concentrations measured at 15 DAR1 for each site year individually using Pearson's correlation coefficient. A quadratic equation was used to model the relative grain yield response to the in-season fertilizer-K applications at each site. For the sites that had significant yield responses to in-season fertilizer applications, the regression equation was used to predict the fertilizer-K rate needed to achieve 95% relative grain yield or the highest relative grain yield achieved if the 95% relative grain yield threshold was not reached. The sites that did not respond significantly to the in-season applications at 15 DAR1 were recorded to have a recommended rate of 0 lb K2O/ac. All analysis was completed in R v. 4.0.2 (R Core Team, 2021) using the dplyr (Wickham et al., 2022), ggplot2 (Wickham, 2016), lme4 (Bates et al., 2015), lmerTest (Kuznetsova et al., 2017), and pbkrtest (Halekoh and Hojsgaard, 2014) packages and yield responses were interpreted as significant at $P < 0.10$.

Results and Discussion

Leaf-K concentrations are a valuable tool in assessing the crop nutrient status and predicting the expected yield loss if no corrective fertilizer application is made (Parvej et al., 2016). At 15 DAR1, the average trifoliolate-K concentration of untreated plots measured from 0.96% to 1.93% K depending on the site year and the plant available K in the soil (Table 3). These tissue-K concentrations confirm that 7 of the 8 site-years were deficient in K compared to the critical tissue-K concentration value of 1.89% at 15 DAR1 required to achieve 95% relative grain yield (Slaton et al., 2021). Correlation values ranged from 0.22 to 0.85 across the different site years between the measured trifoliolate leaf-K concentrations at 15 DAR1 and the relative grain yield. The positive correlation relationships confirm the expected increase in soybean relative grain yield associated with an increasing trifoliolate leaf-K concentration.

Only the 2022 Jonesboro site-year expressed any visual K deficiency symptoms at 15 DAR1, which had a leaf-K of 0.96% and may have been exacerbated by dry field conditions and "low" soil test K. The other 6 site-years identified as deficient resulted in leaf-K concentrations of 1.28% to 1.82% K and showed no visual symptoms of K deficiency at 15 DAR1 and, therefore, could be classified as hidden hunger (Table 3). However, only 4 of the 7 deficient site years resulted in a significant yield response to applying fertilizer-K at 15 DAR1. These responsive sites measured 1.67% K or less leaf-K, indicating a moderate to severe deficiency during sampling and fertilizer application. Only 2 of these sites, 2021 Marianna and 2022 Fayetteville, A1A, reached the full yield goal of 95% relative grain yield with an in-season application of fertilizer-K. While the other 2 sites did respond to the in-season fertilizer-K applications, it only reached 83.7% and 92.4% of the relative grain yield in 2022 Pine Tree 1 and 2022 Jonesboro, respectively.

Within each of the responsive sites, the significant quadratic model was used to predict the exact fertilizer-K rate needed to reach the yield goal of 95% relative grain yield or in sites that did not reach the full 95% relative grain yield goal. The model was used to predict the rate needed to reach the highest yield that was achieved. The resulting rates were plotted against the leaf-K concentration measured at each site to create Fig. 1, providing a linear plateau regression model for rate recommendations to maximize grain yield based on the leaf-K concentration at 15 DAR1. The linear plateau equation can be used to provide a fertilizer-K rate recommendation for any leaf-K concentration within the range of the data (0.96% to 1.93% K), showing the lower levels of leaf-K required higher rates of fertilizer-K to minimize yield loss (Fig. 1).

Practical Applications

The ability to calibrate the rate of an in-season fertilizer application to the crop nutrient status for a site-specific rate needed to maximize yield is novel across all crops and nutrients. The resulting rate recommendations for corrective in-season fertilizer-K applications to soybean at 15 DAR1 complement additional research recently conducted to provide Arkansas soybean producers with the ability to manage K in-season effectively. Effective K management begins with a leaf sampling protocol to monitor soybean K nutrition (Ortel et al., 2022) and comparing the mineral element tissue-K concentration to the dynamic critical tissue-K concentration curve to accurately diagnose in-season deficiencies (Slaton et al., 2021). If a deficiency is confirmed, the leaf-K concentration from the collected sample can be used to delineate the site-specific fertilizer-K rate needed to minimize yield loss (Fig. 1). These corrective fertilizer applications should be applied as a broadcast application of a granular source of fertilizer-K to effectively provide the relatively high rates (0 to 120 lb K_2O/ac.) needed to correct the deficiency. The window of opportunity to apply these corrective applications, incorporate the fertilizer through irrigation, and minimize yield loss ranges from 20 to 44 DAR1, depending on the severity of the deficiency (Slaton et al., 2020). While the current research considered the appropriate rate for applications at 15 DAR1, ongoing research intends to determine the rate needed for delayed corrective applications at 30 and 45 DAR1, and how these rates may impact producer profitability. Ultimately, the resulting fertilizer rate recommendations combined with previous research intend to provide Arkansas producers with the ability to monitor soybean fields for deficiencies, diagnose a deficiency at any point during reproductive growth, and correct the deficiency with the right rate, time, source, and place for in-season fertilizer-K applications to minimize yield loss.

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Literature Cited

Bates, D., M. Maechler, B. Bolker, and S. Walker, 2015. Fitting Linear Mixed-Effects Models Using lme4. J. Stat. Software. Accessed 22 March 2023. Available at: https://doi:10.18637/jss.v067.i01

Halekoh, U., and S. Højsgaard, 2014. A Kenward-Roger Approximation and Parametric Bootstrap Methods for Tests in Linear Mixed Models - The R Package pbkrtest. J. Stat. Software. Accessed 22 March 2023. Available at: https://www.jstatsoft.org/v59/i09/

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, Wisc.

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.

Kuznetsova A., P.B. Brockhoff, and R.H.B. Christensen, 2017. lmerTest Package: Tests in Linear Mixed Effects Models. J. Stat. Software. Accessed 22 March 2023. Available at: https://doi.org/10.18637/jss.v082.i13

Ortel, C.C., T.L. Roberts, A.M. Poncet, K.A. Hoegenauer, M.V. Pessotto, and W.J. Ross, 2022. Understanding Spatial Variability of Soybean Leaf Potassium to Establish a Sampling Protocol. *In*: J. Ross (ed.) Arkansas Soybean Research Studies 2021. Arkansas Agricultural Experiment Station Research Series 689:172-176. Fayetteville. Accessed 21 March 2023. Available at: https://scholarworks.uark.edu/cgi/viewcontent.cgi?article=1211&context=aaesser

Parvej, R., N.A. Slaton, L.C. Purcell, and T.L. Roberts, 2016. Critical trifoliolate leaf and petiole potassium concentrations during the reproductive stages of soybean. Agron. J., Accessed 22 March 2023. Available at: https://doi.org/10.2134/agronj2016.04.0234

Slaton, N.A., G.L. Drescher, T.L. Roberts, and R. Parvej, 2021. Dynamic critical potassium concentrations in soybean leaves and petioles for monitoring potassium nutrition. Agron. J., Accessed 21 March 2023. 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 21 March 2023. Available at: https://doi.org/10.1002/agj2.20342

Ross, 2000. Soybean Production Handbook MP 197. University of Arkansas System Division of Agriculture. Accessed 21 March 2023. Available at: https://www.uaex.uada.edu/publications/mp-197.aspx

Wickham, H. (2016). ggplot2: Elegant Graphics for Data Analysis. Springer-Verlag New York, 2016. ISBN: 978-3-319-24277-4

Wickham, H., R. François, L. Henry, and K. Müller, 2022. dplyr: A Grammar of Data Manipulation. R package version 1.0.10. Accessed 22 March 2023. Available at: https://CRAN.R-project.org/package=dplyr

Zhang, H. and J.J. Wang, 2014. Loss on Ignition Method. In F.J. Sikora and K.P. Moore (Eds.) Soil test methods from the southeastern United States. Southern Coop. Ser. Bull. 419. Univ. of Georgia. p. 155-157.

Table 1. Selected soil physical and chemical characteristics for each site-year.

Year	Site	Coordinates	Primary soil series	Primary soil texture	Primary taxonomic class	pH	LOI[a]	P	K	Ca	Mg
							(%)	----------------(ppm)----------------			
2021	Fayetteville D4	36.096718, -94.171635	Pembroke	Silt loam	Fine-silty, mixed, active, mesic Mollic Paleudalfs	6.0	1.0	40	79	528	31
2021	Kibler	35.378892, -94.232618	Roxana	Silt loam	Coarse-silty, mixed, superactive, nonacid, thermic Typic Udifluvents	7.3	0.6	63	105	959	173
2021	Marianna	34.729512, -90.734227	Convent	Silt loam	Coarse-silty, mixed, superactive, nonacid, thermic Fluvaquentic Endoaquepts	6.4	1.4	29	40	1145	293
2022	Fayetteville A1A	36.098444, -94.174728	Captina	Silt loam	Fine-silty, siliceous, active, mesic Typic Fragiudults	7.3	1.3	48	70	963	55
2022	Fayetteville HC	36.100122, -94.166433	Captina	Silt loam	Fine-silty, siliceous, active, mesic Typic Fragiudults	6.5	1.2	45	149	732	57
2022	Jonesboro	35.661846, -90.712054	Henry	Silt loam	Coarse-silty, mixed, active, thermic Typic Fragiaqualfs	5.4	1.8	35	44	688	148
2022	Pine Tree 1	35.135344, -90.939141	Calhoun	Silt loam	Fine-silty, mixed, active, thermic Typic Glossaqualfs	7.4	2.4	34	85	1791	255
2022	Pine Tree 2	35.135667, -90.940178	Calloway	Silt loam	Fine-silty, mixed, active, thermic Aquic Fraglossudalfs	7.3	2.5	40	164	1599	270

[a] LOI = Loss on Ignition.

Table 2. Individual management and sampling schedule for each site-year.

Year	Site	Previous Crop	Cultivar	Maturity Group	Row Spacing	Planting Date	R1 Date	Sampling Date	Visual K Deficiency Symptoms
					(in.)	---------------(Day Month)---------------			
2021	Fayetteville D4	Soybean	P44A37L	4.4	36	31 May	08 July	23 July	No
2021	Kibler	Corn (*Zea mays*)	P44A37L	4.4	36	04 June	08 July	22 July	No
2021	Marianna	Corn	DG47E80	4.7	38	17 June	24 July	09 Aug.	No
2022	Fayetteville A1A	Summer Fallow, Cereal Rye (*Secale cereale*) Cover Crop	P44A21X	4.4	36	31 May	11 July	26 July	No
2022	Fayetteville HC	Soybean	P44A21X	4.4	36	31 May	11 July	26 July	No
2022	Jonesboro	Soybean	DG49XF22	4.9	30	18 May	03 July	18 July	Yes
2022	Pine Tree 1	Soybean	DG46E10	4.6	30	11 June	15 July	28 July	No
2022	Pine Tree 2	Soybean	P52A14SE	5.2	30	19 May	19 July	03 Aug.	No

Table 3. Statistical results for 15 days after R1 (DAR1) leaf sampling and fertilizer application time by site-year. The critical leaf-K concentration is 1.89% K for 95% relative grain yield (RGY), 1.32% K for 85% RGY, and 0.96% K for 75% RGY.

Year	Site	Mean Leaf K	Pearson's Correlation Coefficient (R)	Quadratic Model Significance (*P*)	Maximum RGY achieved	Achieved ≥95% RGY?	Predicted Fertilizer-K Rate
		(%)			(%)		(lb K_2O/ac)
2021	Fayetteville D4	1.68	0.38	0.4617	81.7	No	0
2021	Kibler	1.82	0.59	0.1081	65.9	No	0
2021	Marianna	1.28	0.76	0.0005*	96.5	Yes	88.6
2022	Fayetteville A1A	1.52	0.22	0.0030*	96.6	Yes	74.2
2022	Fayetteville HC	1.93	0.41	0.1149	93.6	No	0
2022	Jonesboro	0.96	0.85	0.0000*	92.4	No	119.7
2022	Pine Tree 1	1.67	0.70	0.0538*	83.7	No	19.9
2022	Pine Tree 2	1.62	0.57	0.7184	89.8	No	0

* Indicates significance at the $\alpha < 0.10$ level.

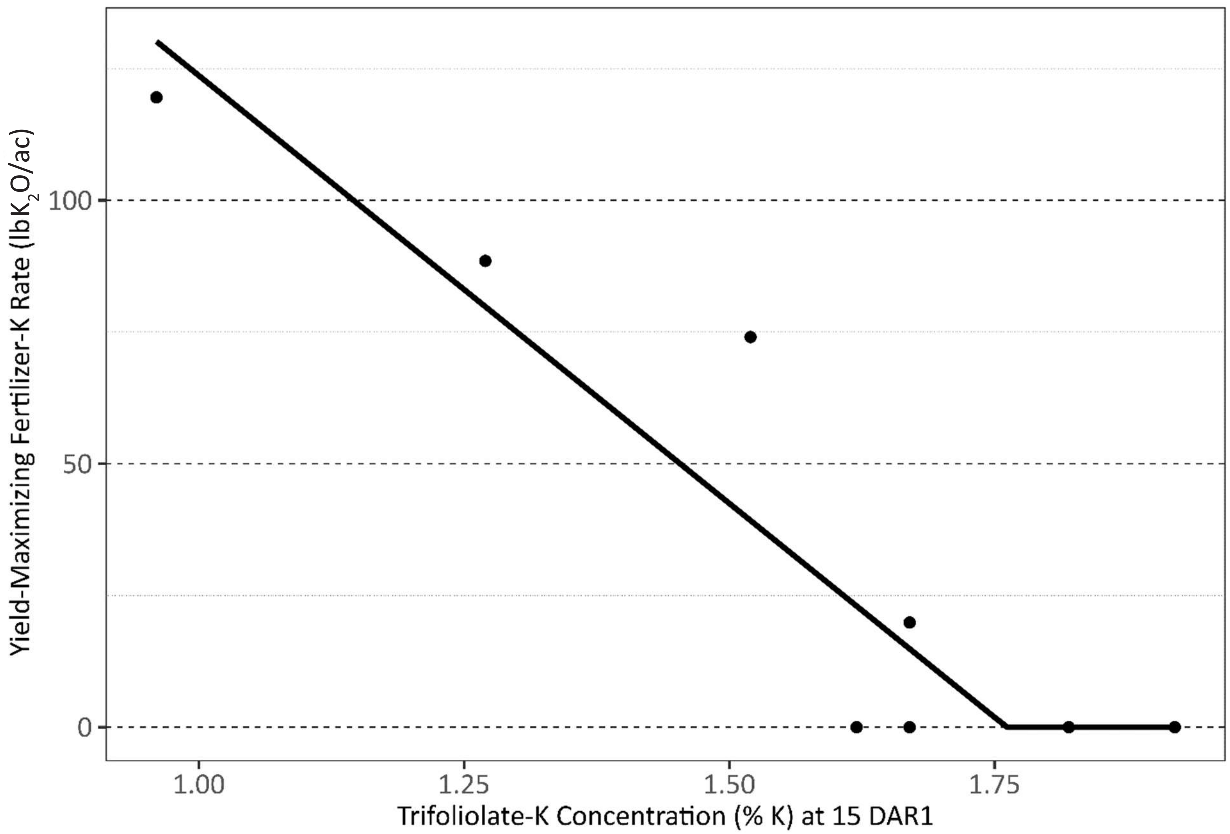

Fig. 1. Calibration of in-season K-fertilizer rates with trifoliolate leaf-K concentrations using a linear-plateau regression model. The linear plateau join point is 1.76% leaf-K concentration, indicating the value at which no additional K-fertilizer is recommended at 15 days after R1 (DAR1).

Effect of Diets Containing Soybean Co-Products Formulated for High-Risk Stocker Cattle on Growth Performance, Morbidity, and Mortality Associated with Respiratory Disease

K.A. Midkiff,[1] E.B. Kegley,[1] R.A. Cheek,[1] D.L. Galloway,[1] J.L. Reynolds,[1] B.P. Shoulders,[1] and J.G. Powell[1]

Abstract

The objectives of this study were to determine the effect of including soybean co-products on growth performance and respiratory disease incidence in high-risk stocker cattle. Crossbred beef bulls and steers (n = 272; initial body weight 508 ± 43 lb) were purchased from local auction markets at 3 time points. On day 0, cattle were processed, stratified by body weight, and allocated randomly to 1 of 8 pens (1.1 ac). Pens were assigned randomly to 1 of 3 dietary treatments: 1. a control supplement containing no soy co-products (CON); 2. a supplement containing soybean meal (SBM); or 3. a supplement containing soybean oil (SBO). All supplements were isonitrogenous and isoenergetic. Cattle were fed supplements (6 lb/day) and offered bermudagrass hay for ad libitum intake for a 42-day trial. Weights were taken on days 14, 28, 41, and 42 of the trial. If presenting with respiratory disease symptoms and rectal temperature exceeding 104 °F, calves were treated according to a standard protocol. Cattle were chronic if they received 3 antibiotic treatments and overall average daily gain was less than 1 lb/day. Body weight and average daily gain were not affected by treatment ($P = 0.86$), with body weight increasing throughout the trial ($P < 0.0001$). Overall morbidity and mortality were 71% and 1%, respectively, and were not affected by treatment ($P = 0.62$ and $P = 0.99$, respectively). Treatments did not affect relapse rates ($P = 0.52$), chronics ($P = 0.51$), or total cost of antibiotic treatments ($P = 0.8$). Actual costs for supplements were lower for the SBM supplement ($415.19/ton) and were most expensive for the SBO supplement ($647.79/ton), with the CON supplement costing $538.47/ton. Including soybean co-products did not affect growth or respiratory disease incidence in these high-risk stocker cattle.

Introduction

Soybean co-products, particularly soybean meal, are a primary staple for poultry diets, but the beef cattle industry accounted for only 6.8% of soybean meal use in 2019 and 2020 (ASA, 2021). Additionally, the market for soybean oil in livestock production is small, with 68% used for human consumption, 25% for biodiesel and bioheat, and 7% for industrial uses (Stowe, 2022). Soybean products are high in omega-3 and omega-6 fatty acids, which can have an important role in the inflammatory response. Specifically, omega-6 fatty acids are more pro-inflammatory, promoting inflammation and aiding in the development of pro-inflammatory compounds (Patterson et al., 2012; Jandacek, 2017), while omega-3 fatty acids have anti-inflammatory properties.

The stocker and feedlot sector of the livestock industry places huge importance on the health of cattle. Respiratory disease alone represents a large economic loss in the beef industry, with $907.8 million in losses associated with cattle succumbing to the disease complex in 2015. Because of the significance of health in these high-risk cattle, the inflammatory response is a topic of increased discussion, as cattle health directly affects growth performance due to the inflammatory response to infection (Richeson, 2018). While chronic inflammation can cause long-term tissue damage, an inflammatory response in moderation enhances an animal's ability to respond quickly to viral and bacterial infections (Broom and Kogut, 2018). In turn, this creates the possibility of activating the immune response and pre-disposing these high-risk cattle to a faster defense against respiratory disease. We hypothesized that supplementing stocker cattle with soybean co-products would modulate the inflammatory response and affect the overall health and growth of stocker calves at high risk for respiratory disease. Our objectives were to determine the effect of supplementing soybean co-products on the inflammatory response, the morbidity, and the mortality associated with respiratory disease, growth performance, and economic viability of stocker cattle feeding systems.

Procedures

This experiment was conducted according to ethical policies and procedures approved by the Division of Agriculture Institutional Animal Care and Use Committee (Ag-IACUC).

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Crossbred bulls and steers (n = 272; initial body weight 508 ± 43 lb) were purchased from local auction markets and transported to the University of Arkansas System Division of Agriculture's Stocker and Receiving Unit. Loads of cattle were purchased at 3 time points (load 1: n = 93 cattle; load 2: n = 91 cattle; load 3: n = 88 cattle). On arrival, cattle were processed (ear tagged, vaccinated, dewormed, ear notched for identification of cattle persistently infected with bovine viral diarrhea virus, castrated intact bulls) and sorted randomly into 1 of 8 pens on each delivery date (n = 11 to 12 cattle/1.1 ac pen). Pens were assigned randomly to 1 of 3 supplemental treatment groups: 1. diet formulated with no soybean product (CON), 2. diet formulated with soybean meal (SBM; 0.23% of body weight, or 10% of total diet dry matter intake), and 3. diet formulated with soybean oil (SBO; 0.05% of body weight, or 2% of total diet dry matter intake). Supplements were formulated to be isonitrogenous and isocaloric (Table 1). Corn gluten meal and urea were used to balance for protein, and choice white grease was used to balance for energy. Body weights were taken on days 14, 28, 41, and 42 of the trial.

Cattle were assessed daily for bovine respiratory disease (BRD) symptoms. If an animal showed signs of sickness, it was pulled from the pen, and a rectal temperature was taken. If the rectal temperature was ≥104 °F, cattle were treated with antibiotics according to a standard protocol (first treatment: Nuflor;® second treatment: Bayril;® third treatment: Excenel®). The antibiotic cost was determined by multiplying the amount of antibiotic given to an animal and the cost per milliliter ($/mL) for each antibiotic given. The actual cost of supplements was also recorded.

Statistical Analysis

Statistical analyses were performed using SAS 9.4,® with PROC MIXED used for body weight, average daily gain (ADG), and antibiotic cost analysis. Body weights were analyzed with the repeated measure of day and for treatment, day, and treatment-by-day interaction. The GLIMMIX procedure was used for morbidity and mortality analyses. Statistical significance was declared at $P \leq 0.05$, and tendencies were reported at $0.05 < P \leq 0.1$.

Results and Discussion

Initial body weight (Table 2) did not differ across treatments ($P > 0.20$). There was no treatment-by-day interaction ($P = 0.99$) or main effect of treatment ($P = 0.86$), but there was a day effect ($P < 0.0001$) with body weight increasing throughout the trial. Average daily gain (Table 2) was not affected by treatment ($P \geq 0.42$). Past research in growing cattle has shown that supplementing seed oils (soybean or linseed oil) increases body weight compared to a control diet (Rosa et al., 2013). Additionally, a study on lambs found that diets containing sunflower cake and sunflower seed had less weight gain compared to diets containing soybean meal (Alves et al., 2016). Even though growth parameters were not different in this study, soybean meal and oil have improved weight gains compared to other seed co-products fed to ruminant animals.

Overall morbidity and mortality (Table 3) were 71% and 1%, respectively, and were not affected by treatment ($P = 0.62$ and $P = 0.99$, respectively). Sickness associated with BRD was 66%, 75%, and 71% for CON, SBM, and SBO-supplemented groups, respectively. Also, a calf died from BRD in each treatment group. Treatment did not affect relapse rates and percentage of chronics ($P = 0.52$ and $P = 0.51$, respectively). A smaller study performed in 2007 found that there were fewer diseased animals in groups of dairy cattle fed flaxseed than those cattle that were fed control diets (Petit et al., 2007), and another large-scale study found that supplementing extruded flaxseed decreased the incidence of ketosis and severe mastitis, as well as markedly decreased mortality. Compared to flaxseed co-products, soybeans are higher in pro-inflammatory fatty acids. Still, in high-risk stocker cattle, the additional pro-inflammatory fatty acids in soybean co-products did not show beneficial or harmful effects on sickness and death compared to a diet without soybean co-products.

The total cost of antibiotic treatments (Table 3) was not different between the diets with or without soybean co-products ($P = 0.8$). However, the actual cost of the supplement fed to the cattle was the lowest for SBM-supplemented cattle ($415.19/ton) compared to both CON-supplemented cattle ($538.47/ton) and SBO-supplemented cattle with the most expensive supplement ($647.79/ton). Additionally, the cost of gain based on supplement costs for SBM-supplemented cattle was cheaper ($1.36/lb of gain) compared to both CON ($1.85/lb of gain) and SBO ($2.36/lb of gain) supplemented cattle. These differences can be attributed to the CON supplement containing corn gluten meal, urea, and choice white grease, the SBM supplement formulated to contain soybean meal and choice white grease, and the SBO supplement containing corn gluten meal, urea, and soybean oil. Market fluctuations have an impact on the feed ingredients used to supplement cattle.

Practical Applications

There were no differences in growth, morbidity, and mortality rates due to respiratory disease or the total cost of antibiotic treatments given to cattle. However, the stark difference in the actual cost of the supplements given to cattle should be noted. The choice for including soybean co-products in supplemental diets given to high-risk stocker cattle is based on many factors, and one of the most important factors for stocker cattle operations is the cost. While the costs of individual feed ingredients are variable, in this study, the supplement, including soybean meal, was the more cost-effective. Soybean co-products did not have a negative effect on cattle performance; still, more research is needed to determine the effects of soybean co-products on inflammation and stress markers in high-risk stocker cattle.

Acknowledgments

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Literature Cited

Alves, F.J.L., M. de Andrade Ferreira, S.A. Urbano, R. de Paula Xavier de Andrade, A.E.M. da Silva, M.C.B. De Siqueira, J.P.F. de Oliveira, and J. De Lima Silva. 2016. Performance of lambs fed alternative protein sources to soybean meal. R. Bras. Zootec. 45:145-150.

ASA. American Soybean Association. 2021. USB Soybean Meal Demand Assessment Reports.

Broom, L.J., and M.H. Kogut. 2018. Inflammation: friend or foe for animal production? Poultry Science. 97:510-514.

Jandacek, R.J. 2017. Linoleic Acid: A Nutritional Quandry. Healthcare. 5:25.

Patterson, E., R. Wall, G.F. Fitzgerald, R.P. Ross, and C. Stanton. 2012. Health implications of high dietary omega-6 polyunsaturated fatty acids. J. Nutri. Meta. 12:1-16.

Petit, H.V., M.F. Palin, and L. Doepel. 2007. Hepatic lipid metabolism in transition dairy cows fed flaxseed. J. Dairy Sci. 90:4780-4792.

Richeson, J.T. 2018. Effect of cattle health on performance during the stocker and feedlot periods. 67th Annual Florida Beef Cattle Short Course Manual. Alto and Patricia Straughn IFAS Extension Development Center, Gainesville, Fla.

Rosa, B.L., A.A.M. Sampaio, W. Henrique, E.A. de Oliveira, T.M. Pivaro, A.T. de Andrade, and A.R. Mendes Fernandes. 2013. Performance and carcass characteristics of Nellore young bulls fed different sources of oils, protected or not from rumen degradation. R. Bras. Zootec. 42:109-116.

Stowe, K.D. 2022. Soybean Facts. N.C. State Extension: North Carolina Soybean Production Guide. AG-835.

Table 1. Ingredient composition of supplements fed at 6 lb/day.

Ingredient	Control	SBM[a]	SBO[b]
	------------(%)------------		
Corn	77.7	66.2	77.7
Corn gluten meal	14.57	--	14.6
Soybean meal	--	26.6	--
Urea	0.94	--	0.94
Salt, white	0.58	0.58	0.58
Limestone	1.5	1.7	1.54
Vitamin A, D, E[c]	0.065	0.065	0.065
Vitamin E[d]	0.035	0.035	0.035
Corn and Rumensin premix[e]	0.267	0.267	0.267
Trace mineral premix[f]	0.056	0.056	0.056
Choice white grease	3.74	3.99	--
Soybean oil	--	--	3.74
Molasses	0.86	0.86	0.86

[a] SBM = supplement containing soybean meal.

[b] SBO = supplement containing soybean oil.

[c] ADE premix contains 4,000,000 IU/lb Vitamin A, 800,000 IU/lb Vitamin D, and 500 IU/lb Vitamin E.

[d] Vitamin E premix contains 20,000 IU/lb.

[e] 6 lb of finished supplement provided 160 mg monensin/day.

[f] Trace mineral premix contains 12% zinc, 8% manganese, 4% copper, 1% iron, 500 ppm cobalt, 2,000 ppm iodine, and 66 ppm selenium.

Table 2. Effect of soybean co-product inclusion in grain supplements for newly received cattle on growth performance.

	Dietary treatments				*P*-Value		
	Control	SBM[a]	SBO[b]	SE[c]	Trt[d]	Day	Trt × day
Body weight, lb					0.86	< 0.0001	0.99
Day 0	512	507	506	42			
Day 14	527	526	525	49			
Day 28	556	552	552	55			
Day 42	583	581	579	55			
Average daily gain, lb							
Days 0 to 14	1.1	1.4	1.5	0.18	0.42		
Days 14 to 28	2.1	1.9	2	0.09	0.87		
Days 28 to 42	1.9	2.1	1.9	0.39	0.91		
Overall, days 0 to 42	1.7	1.8	1.8	0.13	0.91		

[a] SBM = supplement containing soybean meal.
[b] SBO = supplement containing soybean oil.
[c] SE = standard error.
[d] Trt = treatment.

Table 3. Effect of soybean co-product inclusion in grain supplements for newly received cattle on morbidity and antibiotic usage.

	Dietary treatments			*P*-Value
	Control	SBM[a]	SBO[b]	Trt[c]
Sickness and death from BRD[d]				
Morbidity, %	66	75	71	0.62
Given 2nd antibiotic, %	23	27	28	0.79
Relapse, %	23	27	28	0.52
Given 3rd antibiotic, %	10	11	14	0.64
Dead, %	1	1	1	0.99
Chronic, %	4.4	5.5	6.7	0.51
Day of antibiotic treatments				
1st antibiotic	4	4	5	0.73
2nd antibiotic	17	16	14	0.52
3rd antibiotic	24	20	22	0.78
Cost of antibiotic treatments				
1st antibiotic treatment, $/calf	20.42	20.09	20.33	0.78
2nd antibiotic treatment, $/calf	17.53	16.82	16.81	0.58
3rd antibiotic treatment, $/calf	17.53	17.23	16.81	0.57
Total antibiotic cost, $/calf	29.11	28.56	30.31	0.8

[a] SBM = supplement containing soybean meal.
[b] SBO = supplement containing soybean oil.
[c] Trt = treatment.
[d] BRD = bovine respiratory disease.

APPENDIX

2022-2023 Soybean Research Proposals

Principal Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
B. Bluhm		Optimization of Fungal Pathogens AF22 and AF24 as Bioherbicides for Palmer Amaranth (Pigweed)	1 of 3	40,000
T. Butts	T. Barber, J. Norsworthy, and N. Burgos	A Team Approach to Weed Management in Soybean	1 of 3	244,986
J. Carlin		Arkansas Soybean Performance Trials	1 of 3	52,320
M. Daniels		The Arkansas Discovery Farm Program	2 of 3	23,544
B. Deaton		Economic Analysis of Soybean Production and Marketing Practices	2 of 3	7,249
T. Faske	T. Spurlock and J. Kud	Comprehensive Disease Screening of Soybean Varieties in Arkansas	3 of 3	131,427
T. Faske	J. Kud	Integrated Management of Soybean Nematodes in Arkansas	1 of 3	67,092
T. Faske	A. Rojas	Monitoring and Management of Fungicide-Resistant Soybean Diseases in Arkansas	2 of 3	49,402
C. Henry		Irrigation Water Management for Soybeans: Moving the Needle	1 of 3	205,639
C. Henry		The Arkansas Irrigation Yield Contest (Year 6)	Year 6	10,000
R. Kariyat	N. Joshi, G. Studebaker, and B. Thrash	Developing Scouting, Threshold, and Management Practices for Stinkbug in Arkansas Soybean	1 of 3	51,585
B. Kegley		The Effects of the Inclusion of Soybean Oil in Beef Cow Diets on Reproductive and Calf Performance	1 of 3	48,804
M. Kidd		Assessment of Broiler Dietary Least Cost Protein Supply Via Soybean Genotype Amino Acid Selection	1 of 3	46,826
B.P. Littlejohn		Use of Gossypol to Inhibit Reproduction in Domestic Hogs as a Model for Feral Hog Control	1 of 3	30,014
J. Norsworthy		Screening for Soybean Tolerance to Metribuzin	2 of 3	15,876
A. Poncet	C. Henry	Characterizing Top-to-Bottom Soybean Yield Variability in Furrow Irrigated Fields	3 of 3	64,000
T. Roberts	G. Drescher	Fertilization of Soybean	1 of 3	79,463
T. Roberts		Influence of Cover Crops and Soil Health on Soybean	1 of 3	59,238
T. Roberts	J. Ross and J. Carlin	Field-Based Determination of Chloride Tolerance in Soybean	1 of 3	50,395
T. Roberts	J. Ross	Monitoring the Extent of Potassium Deficiency and Chloride Toxicity in Arkansas Soybean Fields	1 of 3	36,418

Continued

2022-2023 Soybean Research Proposals, continued.

Principal Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
J. Robinson		Arkansas Future Ag Leaders Tour	2 of 3	5,000
J. Robinson		Soybean Science Challenge	3 of 3	85,875
J. Ross	B. Thrash	Investigating Emerging Production Recommendations for Sustainable Soybean Production	1 of 3	211,785
J. Ross	J. Norsworthy	Improving Technology Transfer for Profitable and Sustainable Soybean Production	1 of 3	75,012
J. Ross	A. Poncet	On Farm Variable Soybean Seeding Rate Study	3 of 3	76,680
J. Ross		Science for Success	1 of 3	114,023
J. Ross		Soybean Research Verification Program	1 of 3	210,273
T. Spurlock		Developing a Satellite-Based Field Scouting Tool	1 of 3	14,860
T. Spurlock	J. Davis	Determining the Value of Fungicide Applications on Regional, Whole-Farm, Field Level, and Within-Field Scales	1 of 3	52,686
T. Spurlock	N. Bateman and A. Rojas	Determining Factors Associated with Poor Grain Quality in Soybean and Management Options	2 of 3	67,000
T. Spurlock	A. Rojas	Understanding Taproot Decline; A Soybean Disease of Increasing Importance in Arkansas	1 of 3	39,438
B. Thrash	N. Bateman and G. Studebaker	Refining Insect Thresholds in Arkansas Soybean	2 of 3	70,700
B. Thrash		Impact of Water Quality on Insects	3 of 3	20,000
A. Ubeyitogullari		An Innovative Approach to Generate Porous Soy Proteins with Enhanced Flavor for the Plant-Based Food Industry	1 of 3	43,955
C.C. Vieira		Development of High Yielding Soybean Cultivars with Broad Resilience to Stressors	1 of 3	184,844
C.C. Vieira		Utilization of Winter Nursery for Soybean Line Development through Back-Crossing	2 of 3	29,540
C.C. Vieira	T. Faske	Fast Tracking MG 4 and Early MG 5 Cultivars with Southern Root-Knot Nematode Resistance	3 of 3	51,008
C.C. Vieira		Soybean Germplasm Enhancement Using Genetic Diversity	1 of 3	193,121
C.C. Vieira	S. Fernandes	Genomic Prediction to Enhance the Efficiency of Soybean Breeding	1 of 3	101,900
B. Watkins		Soybean Enterprise Budgets	1 of 3	10,000
			Total:	**2,971,978**

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