Arkansas Soybean Research Studies 2023

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Cover photo: Soybean test plot at the Northeast Research and Extension Center in Keiser. (U of A System Division of Agriculture photo by Ryan McGeeney).

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Preface

The 2023 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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Introduction

Arkansas is the leading soybean-producing state in the mid-southern United States. Arkansas ranked 11th in soybean production in 2023 when compared to the other soybean-producing states in the U.S. The state represented 3.8% (159,300,000 bu) of the total U.S. soybean production and 3.6% (2,980,000 acres) of the total acres planted in soybean in 2023 The 2023 state soybean average yield was 54.0 bushels per acre, setting a new state yield record and surpassing the previous record of 52.0 bushels per acre set in 2022. The top five Arkansas soybean-producing counties in 2023 were Mississippi, Phillips, Crittenden, Poinsett, and Arkansas Counties (Table 1). These five counties accounted for over 35.0% of the soybean production in Arkansas in 2023.

Weather events during the early portion of the 2023 growing season were much improved compared to those during 2022. Dry weather conditions during the fall of 2022 allowed soybean producers to prepare fields for planting in 2023. Soybean planting during 2023 was much ahead of the 5-year average. For the entire planting window, planting progress during 2023 on a weekly basis was 11% to 25% ahead of the 5-year average. According to the 4 June 2023 USDA-NASS Arkansas Crop Progress and Condition Report (USDA-NASS, 2023), 94% of the soybean acreage had been planted as of the first of June compared to 85% and 78% for the 2022 and the 5-year average planting progress, respectively. With higher commodity prices, Arkansas soybean producers planted 2.98 million acres in 2023. This was a decrease in acreage compared to 2022, and back to under 3 million acres planted compared to the last three years. The most significant event to occur in Arkansas during the 2023 growing season was the exceptional weather conditions for soybean growth and development observed during the entire year.

Overall, disease and insect issues were at typical levels in 2023. 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 decreased to cause no problems at 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 2023 growing season was the seventh 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, 2022-2023[a]

	Acres Planted		Acres Harvested		Yield		Production	
	2022	2023	2022	2023	2022	2023	2022	2023
County	------------ac------------		-------------ac-------------		---- bu./ac ----		------------- bu. -------------	
Arkansas	171,500	163,000	171,300	161,800	56	57.1	9,585,000	9,239,000
Ashley	52,800	46,600	52,400	46,200	59.7	58.9	3,128,000	2,721,000
Chicot	171,000	154,500	170,700	153,100	54.1	54.3	9,227,000	8,313,000
Clark	*	3,400	*	3,380	*	48.5	*	164,000
Clay	112,500	101,000	111,000	100,200	54.7	47.3	6,072,000	4,739,000
Conway	16,300	15,700	15,900	15,300	32	40.9	509,000	626,000
Craighead	96,800	89,600	94,100	88,600	46.5	58	4,376,000	5,139,000
Crittenden	218,500	213,000	218,000	211,500	53.2	54.7	11,591,000	11,569,000
Cross	162,500	140,000	161,800	138,800	51.9	63.7	8,397,000	8,842,000
Desha	158,500	148,000	158,200	146,800	58.8	59.2	9,295,000	8,691,000
Drew	29,300	26,200	29,300	25,900	61.9	55	1,814,000	1,425,000
Franklin	*	2,100	*	2,080	*	39.4	*	82,000
Faulkner	6,900	*	6,590	*	39.9	*	263,000	*
Greene	74,200	76,200	72,800	75,500	52	53	3,785,000	4,002,000
Independence	23,700	*	22,700	*	42.9	*	974,000	*
Jackson	111,000	108,000	106,300	106,300	38.4	42.6	4,081,000	4,528,000
Jefferson	106,000	96,200	104,100	95,300	57.6	54.6	5,994,000	5,203,000
Lawrence	67,400	*	65,400	*	48.7	*	3,185,000	*
Lee	132,500	119,000	131,200	117,900	57.7	57.9	7,570,000	6,826,000
Lincoln	65,300	55,800	64,600	55,400	60.8	53.3	3,928,000	2,953,000
Little River	12,900	*	10,300	*	31.3	*	322,000	*
Lonoke	89,200	93,900	88,500	92,900	49.6	50.9	4,390,000	4,729,000
Mississippi	279,000	*	278,000	*	59.3	*	16,475,000	*
Monroe	90,300	88,500	89,500	87,600	44.2	48.7	3,956,000	4,266,000
Phillips	202,000	196,500	201,000	194,600	55.4	62.7	11,126,000	12,201,000
Poinsett	197,500	176,500	196,400	175,000	49.2	55	9,658,000	9,625,000
Pope	8,100	*	8,100	*	43.8	*	355,000	*
Prairie	100,500	101,000	99,800	100,200	50.6	56.8	5,050,000	5,691,000
Pulaski	18,700	20,500	17,000	18,100	35.6	38.5	605,000	697,000
Saint Francis	148,500	141,500	147,800	140,200	52	58.8	7,685,000	8,244,000
Sebastian	*	3,800	*	3,770	*	31.8	*	120,000
Washington	*	400	*	400	*	30	*	12,000
White	31,200	29,900	30,400	29,600	36.4	38.1	1,106,000	1,128,000
Woodruff	122,000	110,500	119,200	109,600	40.1	50.7	4,780,000	5,557,000
Yell	7,000	7,000	6,680	6,950	34.6	44.6	231,000	310,000
Other Counties	96,400	451,700	90,930	447,020	41.4	48.4	3,767,000	21,658,000
State Totals	3,180,000	2,980,000	3,140,000	2,950,000	52	54	163,280,000	159,300,000

[a] Data obtained from USDA-NASS;2023

*Included in "Other Counties".

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2023 Soybean Research Verification Program

C.R. Elkins,[1] M.C. Norton,[2] B.D. Deaton,[3] and W.J. Ross[4]

Abstract

The 2023 Soybean Research Verification Program (SRVP) was conducted on 15 commercial soybean fields across the state. Counties participating in the program included Arkansas, Chicot, Cross, Drew, Greene, Jackson, Jefferson, Lawrence, Lonoke, Mississippi, Poinsett, Randolph, St. Francis, White, and Yell for a total of 765 acres. Grain yield in the 2023 SRVP averaged 62.5 bu./ac, ranging from 36.0 to 81.9 bu./ac. The 2023 SRVP average yield was 8.5 bu./ac greater than the estimated Arkansas state average of 54 bu./ac. The highest-yielding field was in Jackson County, with a grain yield of 81.9 bu./ac. The lowest yielding field was in Arkansas County and produced 36.0 bu./ac.

Introduction

In 1983, the University of Arkansas System Division of Agriculture's (UADA) Cooperative Extension Service (CES) established an interdisciplinary soybean educational program that stresses management intensity and integrated pest management to maximize net returns. The purpose of the Soybean Research Verification Program (SRVP) is to verify the profitability of CES recommendations in fields with less than optimum yields or returns. The goals of SRVP are to 1) educate producers on the benefits of utilizing CES recommendations to improve yields and/or net returns, 2) conduct on-farm field trials to verify researched-based recommendations, 3) aid researchers in identifying areas of production that require further study, 4) improve or refine existing recommendations which contribute to more profitable production, and 5) incorporate data from SRVP into CES educational programs at the county and state level. Since 1983, the SRVP has been conducted on 710 commercial soybean fields in 41 soybean-producing counties in Arkansas. SRVP has typically averaged 10 bu./ac better than the state average yield. This increased yield can mainly be attributed to intensive cultural management and integrated pest management.

Procedures

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

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

In 2023, the following counties participated in the SRVP: Arkansas, Chicot, Cross, Drew, Greene, Jackson, Jefferson, Lawrence, Lonoke, Mississippi, Poinsett, Randolph, St. Francis, White, and Yell. The 15 SRVP fields totaled 765 acres. Four Roundup Ready 2 Xtend® varieties (Asgrow AG46X0, Asgrow AG46X6, Becks 4991X2, and Pioneer P46A36X.), 3 Roundup Ready 2 XtendFlex® varieties (Asgrow AG46XF3, Pioneer P45A40LX, Pioneer P46A20LX), 5 Enlist E3® varieties (Armor 46-E50, Innvictis B48A41E, Pioneer P48A14E, Pioneer P52A14SE, and Stine 46EE20), and 1 conventional (Virtue 4520S) were planted and CES recommendations were used to manage the SRVP Fields (Table 1). Agronomic and pest management decisions were based on field history, soil test results, variety, and data collected from individual fields during the growing season. An integrated pest management philosophy was utilized based on CES recommendations. Data collected included components such as stand density, weed populations, disease infestation levels, insect populations, rainfall amounts, irrigation amounts, and dates for specific growth stages (Tables 1 and 2).

Results and Discussion

Yield

The average 2023 SRVP grain yield was 62.5 bu./ac, ranging from 36.0 to 81.9 bu./ac (Table 2). The SRVP average yield was 8.5 bu./ac higher than the estimated 2023 state average yield of 54 bu./ac (USDA, 2024). The difference has been attained many times since the program began and can

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be attributed in part to intensive management practices and utilization of CES recommendations. The highest soybean grain yield, 81.9 bu./ac, was planted with Pioneer P48A14E in Jackson County.

Planting and Emergence

Planting was initiated in Arkansas County on 29 March and concluded on 21 June in Poinsett County, with an average planting date of 27 April. The average seeding rate across all SRVP fields was 139,000 seeds/ac, ranging from 120,000 to 160,000 seeds/ac. The average emergence date was 6 May, ranging from 3 April to 27 June. On average, across all SRVP fields, 9 days were required for emergence. Please refer to Tables 1 and 2 for agronomic information for specific locations.

Fertilization

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

Weed Control

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

Disease/Insect Control

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

Irrigation

All irrigated fields were either enrolled in the University of Arkansas System Division of Agriculture's Irrigation Scheduler Program or had moisture sensors placed in the field to determine irrigation timing based on soil moisture deficit. Fourteen of the 15 SRVP fields were furrow irrigated, and 1 was pivot irrigated.

Practical Applications

Data collected from the 2023 SRVP reflected higher soybean yields and maintained above-average returns in the 2023 growing season. Analysis of this data showed that the average yield was higher in the SRVP compared to the state average, and the average cost of production was equal to or less than the CES estimated soybean production budgeted costs (Watkins, 2024).

Acknowledgments

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

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Table 1. Agronomic Information for 2023 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 P45A40LX	64	Soybean	ESI	130K	110K
Chicot	Asgrow AG46X6	62	Soybean	ESI	140K	118K
Cross	Virtue 4520S	70	Soybean	FSI	120K	89K
Drew	Asgrow AG46X0	26	Soybean	ESI	160K	110K
Greene	Innvictis B4841E	65	Corn	FSI	140K	109K
Jackson	Pioneer P48A14E	32	Corn	FSI	140K	129K
Jefferson	Pioneer P46A36X	40	Soybean	ESI	120K	98K
Lawrence	Stine 46EE20	73	Rice	ESI	140K	129K
Lonoke	Asgrow AG46XF3	73	Corn	FSI	136K	118K
Mississippi	Becks 4991X2	74	Soybean	ESI	140K	132K
Poinsett	Asgrow AG46XF3	40	Wheat	LSI	140K	109K
Randolph	Pioneer P52A14SE	39	Soybean	FSI	160K	147K
St. Francis	Pioneer 46A20LX	31	Corn	ESI	135K	108K
White	Armor 46-E50	43	Rice	FSI	140K	122K
Yell	Pioneer P48A14E	33	Soybean	FSI	150K	135K
Average		**51**			**139K**	**118K**

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

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

Table 2. Planting, Emergence, and Harvest Dates and Adjusted Soybean Grain Yield for 2023 Soybean Research Verification Program Fields.

County	Planting	Emergence	Harvest	Yield adj. to 13% moisture[a]
	------------------- (date) -------------------			(bu./ac)
Arkansas	3/29	4/12	8/26	36.0
Chicot	4/16	4/23	8/25	55.7
Cross	5/8	5/16	10/9	41.2
Drew	4/19	5/1	9/26	65.9
Greene	5/8	5/15	10/17	63.7
Jackson	5/17	5/24	10/11	81.9
Jefferson	3/22	4/3	8/30	67.1
Lawrence	4/11	4/24	10/12	78.0
Lonoke	4/27	5/11	10/10	64.5
Mississippi	4/11	4/20	10/2	78.9
Poinsett	6/21	6/27	10/20	59.6
Randolph	5/8	5/17	10/19	64.5
St. Francis	4/1	4/13	9/17	72.3
White	5/15	5/22	10/10	62.0
Yell	5/10	5/15	10/9	46.2
Average	**4/27**	**5/6**	**9/30**	**62.5**

[a] 2023 Arkansas state soybean average yield was 54.0 bu./ac (USDA, 2023).

Table 3. Soil Test Results, Fertilizer Applied and Soil Classification for 2023 Soybean Research Verification Fields.

County	Soil Test Results pH	P	K	Pre-plant applied fertilizer N-P-K	Soil Classification
	---------- (ppm) ----------			(lb/ac)	
Arkansas	6.6	34	91	0-36-72	Herbert and Rilla silt loam
Chicot	7.2	44	101	0-0-75	Calloway and Henry silt loam
Cross	6.4	31	133	0-30-60	Crowley silt loam
Drew	6.2	9	323	0-70-0	Portland clay
Greene	5.8	49	129	0-0-60	Hillemann silt loam
Jackson	6.0	17	167	0-0-75	Egam silt loam
Jefferson	7.1	36	103	0-0-75	Rilla and Herbert silt loam, Perry clay
Lawrence	6.3	13	88	0-70-120	Bosket fine sandy loam and Crowley silt loam
Lonoke	6.5	48	101	0-0-75	Calloway and Immanuel silt loam
Mississippi	7.1	29	99	0-0-60	Sharkey- Steele complex
Poinsett	6.6	29	106	0-30-56	Calloway silt loam and Henry silt loam
Randolph	6.7	57	102	0-0-100-.3B	Bosket fine sandy loam and Dexter silt loam
St. Francis	7.4	12	74	0-54-108	Calloway silt loam and Henry silt loam
White	6.3	16	62	0-60-120	Roellen silty clay
Yell	6.1	8	244	35-90-0	Calhoun silt loam and Calloway silt loam

Table 4. Herbicide Rates and Timing for 2023 Soybean Research Verification Program Fields.

	Herbicide (rates/ac)	
County	**Burndown/Pre-emergence**	**Post-emergence**
Arkansas	Burndown; 1 qt Cornerstone® Pre-emerge; 1 qt Cornerstone + 1 qt Liberty® + 1 pt Dual Magnum® II	1st; 1 qt Cornerstone + 3.2 oz Zidua® WG 2nd; 22 oz RoundUp PowerMax® III + 1.2 pt Dual Magnum II
Chicot	Pre-emerge; 1 qt paraquat + 1 qt Intimidator®	1st; 12.8 oz Engenia® + 1.25 pt Dual Magnum II Harvest Aid; 1 pt paraquat + 1% NIS
Cross	Pre-emerge: 5 oz Verdict® + 8 oz Outlook®	1st; 2.25 pt Prefix® + 8 oz Select
Drew	Pre-emerge; 24 oz paraquat + 3.25 Anthem Max®	1 qt Cornerstone + 1.25 pt Charger Basic®
Greene	Burndown: 40 oz glyphosate	1st; 1 qt glyphosate + 2 pt Enlist One® + 2.5 pt Warrant® 2nd; 1 qt glyphosate + 2 pt Enlist One + 1.25 pt *S*-metolachlor
Jackson	Pre-emerge: 2 pt Enlist One® + 16 oz Select® + 1.25 pt *S*-metolachlor	1st; 1 qt glyphosate + 2 pt Enlist One 2nd; 1 qt glyphosate + 2 pt Enlist One
Jefferson	Pre-emerge; 1 qt paraquat + 24 oz Boundary®	1st; 56.5 oz Tavium® + 0.3 oz First Rate® Harvest Aid; 1 pt paraquat + 1% NIS
Lawrence	Pre-emerge: 1.5 pt Boundary + 1 qt Gramoxone®	1st; 1 qt glyphosate + 2 pt Enlist One + 1 pt *S*-metolachlor
Lonoke	Burndown; 1 qt Cornerstone Pre-emerge; 1 pt Charger Basic	1 qt Transline® + 1 qt Prefix®
Mississippi	Pre-emerge: 1.5 pt MetalliS MTZ + 1 qt Gramoxone	1st; 12.8 oz Engenia® + 1.25 pt *S*-metolachlor 2nd; 1 qt glyphosate
Poinsett		1st; 1 qt glyphosate + 1 qt Liberty + 1.25 pt *S*-metolachlor 2nd; 1 qt glyphosate + 1 qt Liberty + 3 pt Warrant 3rd; 0.3 oz Firstrate® + 0.12 oz Python® + 0.5% COC
Randolph		1st; 2 pt Enlist One + 22 oz Roundup Power Max 3 + 3.25 oz Zidua 2nd; 2 pt Enlist One + 1 qt Liberty + 1 pt *S*-metolachlor
St. Francis	Pre-emerge: 1.5 pt Boundary + 2 oz Zidua	1st; 12.8 oz Engenia + 14 oz Outlook 2nd; 28 oz Roundup Power Max 3 Harvest Aid: 10.67 oz Gramoxone
White	Pre-emerge: 1.25 pt *S*-metolachlor	1st; 1 qt glyphosate + 2 pt Enlist One + 6 oz clethodim
Yell		1st; 1 qt glyphosate + 2 pt Enlist One 2nd; 1 qt glyphosate + 1.25 pt *S*-metolachlor

Table 5. Fungicide and Insecticide Applications for 2023 Soybean Research Verification Program Fields.

County	Aerial Web Blight	Frogeye Leaf Spot	Bollworms/Defoliators	Stink Bugs
Arkansas	-	-	-	-
Chicot	-	-	-	6.4 oz. bifenthrin + 0.5 lb acephate
Cross	-	-	-	-
Drew	-	-	-	-
Greene	-	-	-	-
Jackson	13.7 oz. Miravis Top®	-	-	-
Jefferson	-	-	-	5.12 oz. bifenthrin
Lawrence	-	-	-	-
Lonoke	-	-	-	-
Mississippi	-	-	-	-
Poinsett	-	-	8 oz. Besiege®	-
Randolph	13.7 oz. Miravis Top	-	-	-
St. Francis	-	-	-	-
White	-	-	-	-
Yell	-	-	-	-

Practical Considerations for Data-Driven Implementation of Variable-Soybean Seeding Rate

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Abstract

Proper soybean seeding rate selection is required to optimize crop development and yield and maximize profitability. While the optimum seeding rate may vary within a field due to spatial changes in soil properties and management history, the current Arkansas soybean recommendations were developed for uniform, whole-field application. In-field adjustments of these recommendations to match site-specific changes in field conditions, and practical implementation of the fine-tuned recommendations using variable-rate seeding (VRS) technology could help increase operation efficiency and optimize crop production. However, no practical implementation guidelines for VRS are available. The project objective was to develop data-driven soybean seeding rate prescriptions from 3 on-farm seeding rate trials. This report describes the project's major findings and discusses practical applications and future development of this methodology. Emphasis is given to seeding rate treatment selection that should bracket the typical range, as well as ground-truthing of planter performance. A method was developed to identify the drivers of in-field soybean yield variability, model crop response to spatial changes in the identified parameters, and create relevant prescription maps for VRS. Findings demonstrated that VRS should only be recommended if in-field soybean yield variability is structured and if crop response to seeding rate depends on site-specific field conditions. Economic analysis should be computed to fine-tune the created agronomic optimum prescriptions for maximized profitability. Future integration into a web-tool will make these findings and the developed algorithms accessible to agricultural stakeholders.

Introduction

The mid-southern agricultural region has unique characteristics (e.g., wide planting window, high solar radiation, numerous options for cultivar selection), allowing for high potential soybean yields (Salmeron et al., 2014). Potential yield is determined at planting and proper seeding rate selection is essential to optimize resource use and maximize profitability (Evans and Fischer, 1999; Chen and Wiatrak, 2011). Current Arkansas soybean seeding rate recommendations target whole-field applications, optimizing agronomic and economic production with a single seeding rate prescription. However, site-specific variability from spatial changes in soil properties, management history, fate and transport of nutrients, and distribution of water substantially affect soybean growth and yield within a field (Cox et al., 2003; Kravchenko and Bullock, 2000). Such variability may affect yields and could be managed using precision technologies (Pierce and Nowak, 1999). For instance, variable-rate seeding (VRS) could be used to account for finer-scale variability and optimize resource use beyond whole-field recommendations (Šarauskis et al., 2022).

While previous research has been conducted to identify manageable variability and delineate management zones within modern crop production systems, no practical implementation guidelines for seeding-rate technology are available (Hamman et al., 2021; Maestrini and Basso, 2018). Development of such recommendations could help maximize the benefits of technology adoption (Correndo et al., 2022; Paz et al., 2001). Moreover, proper characterization of the drivers of in-field variability - defined as the parameters that most strongly affect crop development and yield - and determination of which sources of variability can most effectively be managed by seeding rate selection is necessary to help determine which fields are most likely to benefit from VRS technology, and generate relevant, data-driven prescriptions (Paccioretti et al., 2021; Andrade et al., 2022). This information will allow producers to make informed decisions regarding VRS technology acquisition and application (Huang and Brown, 2019; Hegedus et al., 2023). A methodology was developed to provide practical, data-driven soybean seeding rate prescriptions that optimize in-field variability management using VRS. The objective of this report is to describe the project's major findings and discuss practical applications and future development of this methodology.

Procedures

Site Description and Experimental Design

A seeding rate trial was established in 2 production soybean fields located in Lincoln County, Arkansas. Field A was used in 2021 (Fig. 1). Soil development took place on loamy

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and clayey alluvium (NRCS USDA, 2023), and a field size of 80 acres. The dominant soil series was Perry, which accounted for 67% of the field area. Other soil series represented in field A included Portland and Rilla, which accounted for 20% and 13% of the field area, respectively. The previous crop was rice. Field B was used in 2022 (Fig. 2). Soil development took place on loamy, silty, and clayey alluvium (NRCS USDA, 2023), and the field size was 40 acres. The dominant soil series was also Perry, which accounted for 50% of the field area. Other soil series represented in field B included Rilla and Herbert, each accounting for 25% of the field area. The previous crop was soybean. In both fields, 5 seeding rate treatments were selected to bracket the typical range and established within a randomized complete block strip design with four replicates. The seeding rate treatments were 75, 100, 125, 150, and 175 thousand seeds per acre.

Field A was planted on 6 June 2021 and harvested on 8 November 2021. Field B was planted on 21 May 2022 and harvested on 4 October 2022. Planting was performed using a 12-row planter equipped with auto-guidance technology, variable-rate seeding capabilities, and real-time kinematic positioning accuracy. The soybean variety was AG48X9. Row-spacing was 36 in. Each seeding rate treatment strip was created from 2 consecutive planter passes so that the total treatment strip width was 72 ft. Both fields were furrow-irrigated, and the treatment strips were established from the crown to the bottom of the field, following the irrigation furrows. Therefore, treatment length varied with field shape. A total of 8.7 in. and 6.2 in. of water were delivered in 3 applications between flowering (R2) and full pod (R6) in fields A and B, respectively. Nutrient and pest management was accomplished using current University of Arkansas System Division of Agriculture's Cooperative Extension Service guidelines. The harvest was conducted using a 12-row combine harvester equipped with a yield monitor and real-time kinematic positioning accuracy.

Data Collection and Analysis

The planter as-applied maps and yield monitor data were processed to remove outliers caused by changes in travel speed on the edge of the field. The collected wet yield data were adjusted at 13.3% moisture. Soil mapping unit information was gathered from the Web Soil Survey (Soil Survey Staff et al., 2023). Soil samples and stand counts were collected in 91 locations in field A and 80 locations in field B (Figs. 1 and 2). The sampling locations were selected using stratified random sampling. All sampling locations were found in the middle of a treatment strip, all locations were dispersed across the field to capture as much variability as possible, and approximately the same number of locations were found within each seeding rate treatment strip. The soil samples were collected before the growing season and submitted to the University of Arkansas System Division of Agriculture Fayetteville Soil Test Laboratory (Fayetteville, Ark.) for routine soil testing and soil texture analysis. The stand counts were collected at V3 (3 expanded trifoliate leaves) along 2 7.2-ft row sections (representing 0.001 acre) and used to quantify final plant population. Digital elevation models (DEMs) providing field elevation data were downloaded from the United States Geological Survey public data repository (USGS, 2023). The downloaded data were less than 3 years old, and the spatial resolution was approximately 3.3 ft.

The plant population and as-applied seeding rate data were used to assess planter performance. The distribution of yield data was compared between treatments and fields. Soil mapping units, soil pH, soil potassium, soil phosphorus, field elevation, percent clay, percent sand, and soil textural class were all considered as possible drivers of in-field soybean yield variability. All possible drivers of variability and yield were estimated at 3,586 and 2,153 square grid points in fields A and B, respectively (Figs. 1 and 2). The distance between 2 consecutive grid points in a row or column was 36 ft., which corresponded to the planter width. Therefore, there was a total of 5 seeding rate treatments × 4 replicates × 2 planter passes = 40 rows used to build the square grid in both fields. Yield was estimated as the median clean yield monitor data found within 15 ft. from each square grid point. Soil pH, nutrient availability, and texture were estimated from the soil test results using Kriging. Soil mapping unit and field elevation were determined using spatial intersection functions.

Linear models with spatial correlation structures (Zuur et al., 2009) were implemented within a cross-validation procedure to identify the parameters that contribute to in-field soybean yield variability and establish the model that best describes soybean yield within each field. The cross-validation was computed using a 10% calibration – 90% validation data split and 100 iterations. Separate statistical analyses were computed per field. The best model found in each field was used to predict soybean yield, assuming a seeding rate of 75, 100, 125, 150, and 175 thousand seeds per acre. The grid points were grouped into management zones that accounted for 2 × 2 = 4 side-by-side grid points within a treatment strip. The 5 seeding rates × 4 points = 20 predicted yield values associated with each grid point were compared using analysis of variance. The lowest site-specific seeding rates that maximized predicted yield (statistically) were used to generate a-posteriori soybean seeding rate prescriptions for each field. The associated predicted yield data were mapped to show how much in-field soybean yield variability is not expected to be accounted for with variable soybean seeding rate.

Results and Discussion

Planter Performance

The planter achieved acceptable plant populations at 100,000, 125,000, and 150,000 seeds/acre seeding rate treatments in fields A and B (Fig. 3). The planter also achieved acceptable plant populations at 75,000 and 175,000 seeds/acre seeding rate treatments in field B. However, the planter tended to overachieve the 75,000 seeds/acre seeding rate treatment in field A. One explanation was that 75,000 seeds/ac was on the lower end of the planter capabilities and the seed plate rotation was likely not sufficient to maintain proper vacuum, ensure proper singulation, and ultimately achieve the targeted seeding rate. This issue could not be identified from the as-applied seeding rate data, emphasizing the importance of ground-truthing planter performance. Moreover, the planter tended to underachieve the higher seeding rate treatments – mostly 175,000 seeds/ac, and to some extent, 150,000 seeds/ac. This issue could have been caused by improper planter calibration before the growing season or excessive planting speeds that did not allow the seed plates to rotate fast enough to apply the targeted rate. Similar issues were previously documented in the published literature (Virk et al., 2020).

Soybean Yield Response to Seeding Rate

The median soybean yield ranged from 62.8 to 69.4 bu./ac at 75,000 and 150,000 seeds/ac in field A, and from 65.0 to 68.6 bu./ac at 75,000 and 100,000 seeds/ac in field B (Fig. 4). The magnitude of within-treatment soybean yield variability ranged from 67.8–39.4 bu./ac at 75,000 seeds/ac, to 86.0–39.0 = 47.0 bu./ac at 175,000 seeds/ac in field A. The magnitude of within-treatment soybean variability ranged from 70.4–61.5 = 8.9 bu./ac at 100,000 seeds/ac, to 72.7–46.9 = 25.8 bu./ac at 125,000 seeds/ac in field B. Overall, greater average yields by treatment and within-treatment variability were observed in field B. Not one treatment resulted in completely different soybean yields than the other – in other words, all boxplots overlapped.

Drivers of Yield Variability and Agronomic Optimum Seeding Rate Prescription

Soil pH and the 2-way interactions between seeding rate and soil fertility metrics were significant drivers of yield variability in field A. Soil mapping unit, soil texture metrics, and the 2-way interactions between seeding rate and soil fertility metrics were significant drivers of yield variability in field B. Therefore, soybean response to site-specific changes in field conditions varied with seeding rate selection, and VRS may be considered to optimize crop management. The 175,000 seeds/ac was expected to maximize yield in 94.3% of field A (Fig. 5). The 150,000 seeds/ac was expected to maximize yield with minimum seed requirements in the rest of field A. That particular area in the field, where the 150,000 seeding rate treatment maximized yield, corresponded to a low draw with poorer drainage than the rest of the field. On the other hand, greater variability in the agronomic optimum seeding rate prescription was found in field B, with 47.0%, 24.6%, 14.0%, 11.6%, and 2.8% of the field area that should be managed with 150,000, 100,000, 75,000, 175,000, and 125,000 seeds/ac seeding rates, respectively (Fig. 6).

Practical Applications

The created method allows for data-driven determination of soybean seeding rate prescriptions for variable-rate applications. Future (and anticipated) integration into a web-tool will fully automate the data analysis steps and make these findings available to agricultural stakeholders. Web-tool utilization will require the producers to establish a seeding rate trial in the fields where VRS is to be implemented. Key field management data (e.g., field boundary, as-applied seeding rate, soil test results) will also need to be uploaded into the web application to execute the algorithm and determine whether and how VRS should be used to optimize crop management. The web-tool recommendation will be limited to the seeding rates used in the field trial, and careful seeding rate treatment selection will be necessary to make sure that the producer is comfortable implementing the computed prescription, and that the selected rates can be successfully applied by the planter according to the manufacturer specifications. Ground-truth assessments of planter performance will be needed to ensure adequate planter performance and proper seeding rate treatment establishment. VRS will only be recommended – and the prescription generated – if structured in-field soybean yield variability is observed in the field (= yield variability that correlates with in-field changes in topography or soil properties), and if crop response to seeding rate depends on site-specific field conditions (= some of the yield variability can be managed with VRS). If a seeding rate prescription is created, management unit size will be equal to twice the planter (or automatic section) width. Economic analysis will also be computed to account for the cost of seeds and crop prices to fine-tune the computed agronomic prescription for maximized profitability. Repeated studies in the same location and spatio-temporal analysis of the collected data across years will be needed to assess the stability and variability of crop response to in-field variability and convert the computed a posteriori prescriptions into true a priori prescription proven to maximize benefits from VRS independently from specific weather conditions.

Acknowledgments

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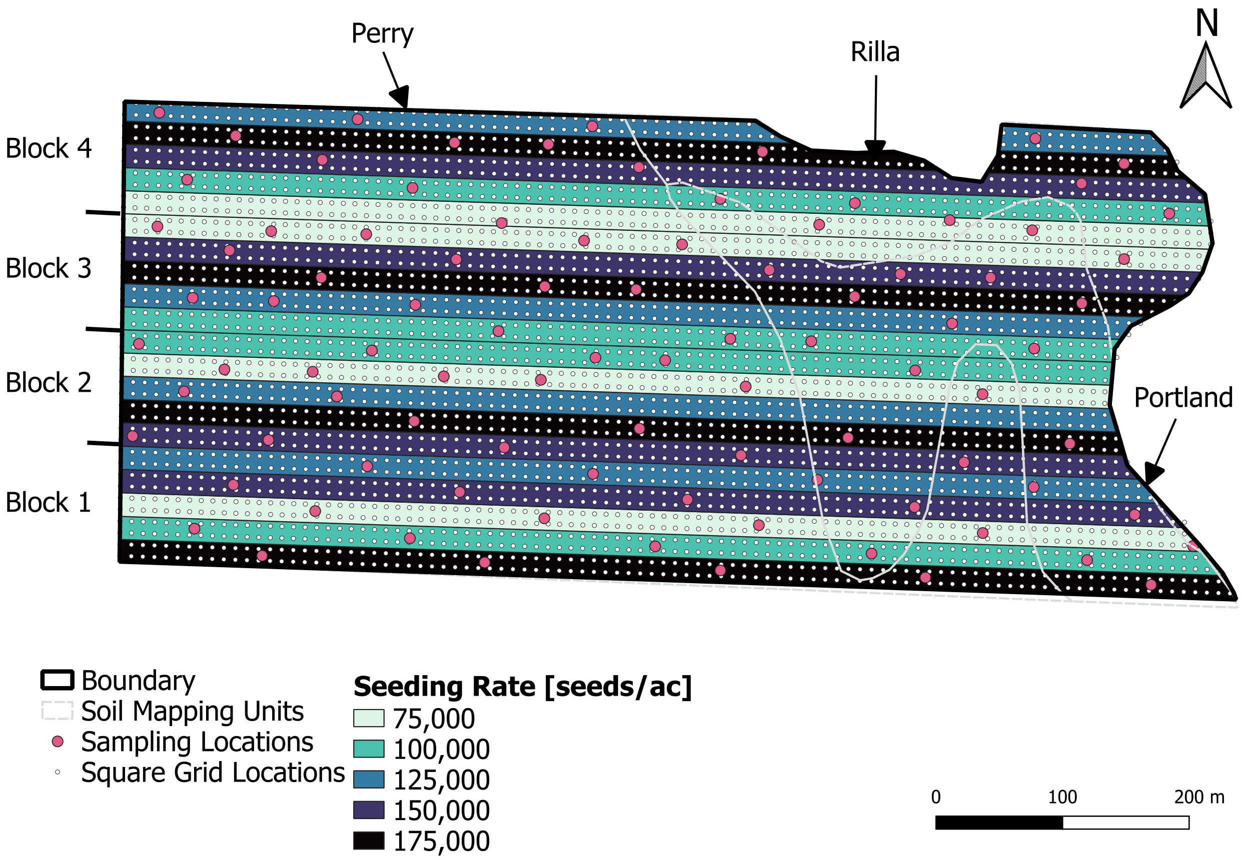

Fig. 1. Seeding rate treatment layout, soil mapping units, and data collection strategy in field A. Soil mapping unit information was downloaded from the Web Soil Survey (Soil Survey Staff et al., 2023). The sampling locations describe where soil samples and stand count data were collected. The square grid locations determine where field parameters such as soil pH, nutrient availability, soil texture, and elevation were estimated in preparation for statistical analysis.

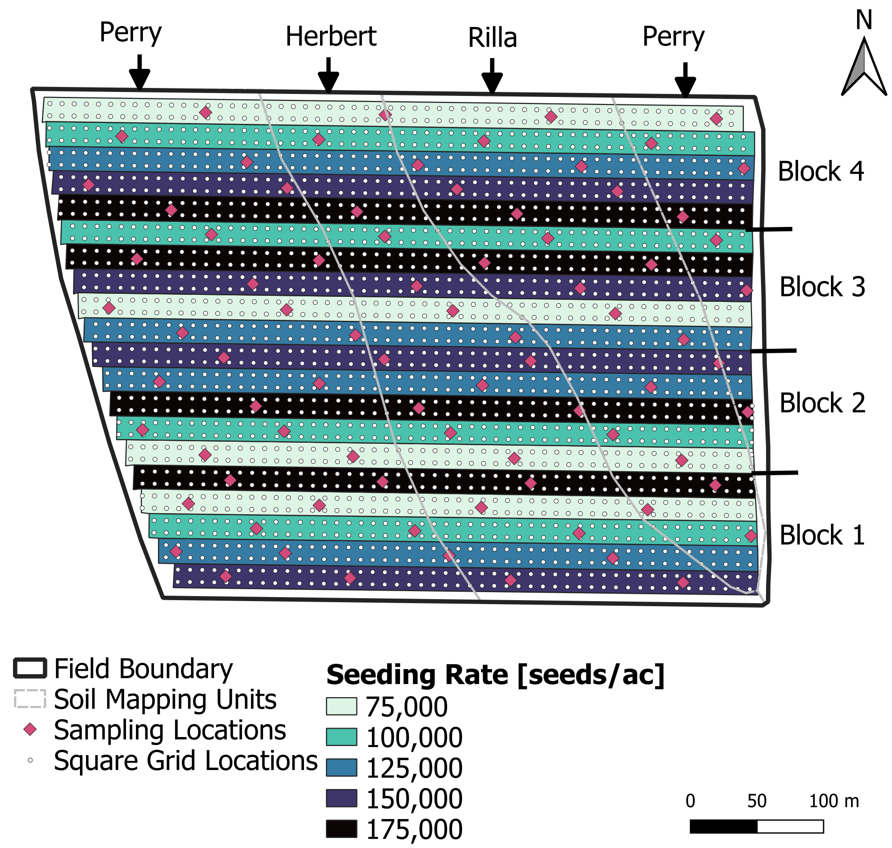

Fig. 2. Seeding rate treatment layout, soil mapping units, and data collection strategy in field B. Soil mapping unit information was downloaded from the Web Soil Survey (Soil Survey Staff et al., 2023). The sampling locations describe where soil samples and stand count data were collected. The square grid locations determine where field parameters such as soil pH, nutrient availability, soil texture, and elevation were estimated in preparation for statistical analysis.

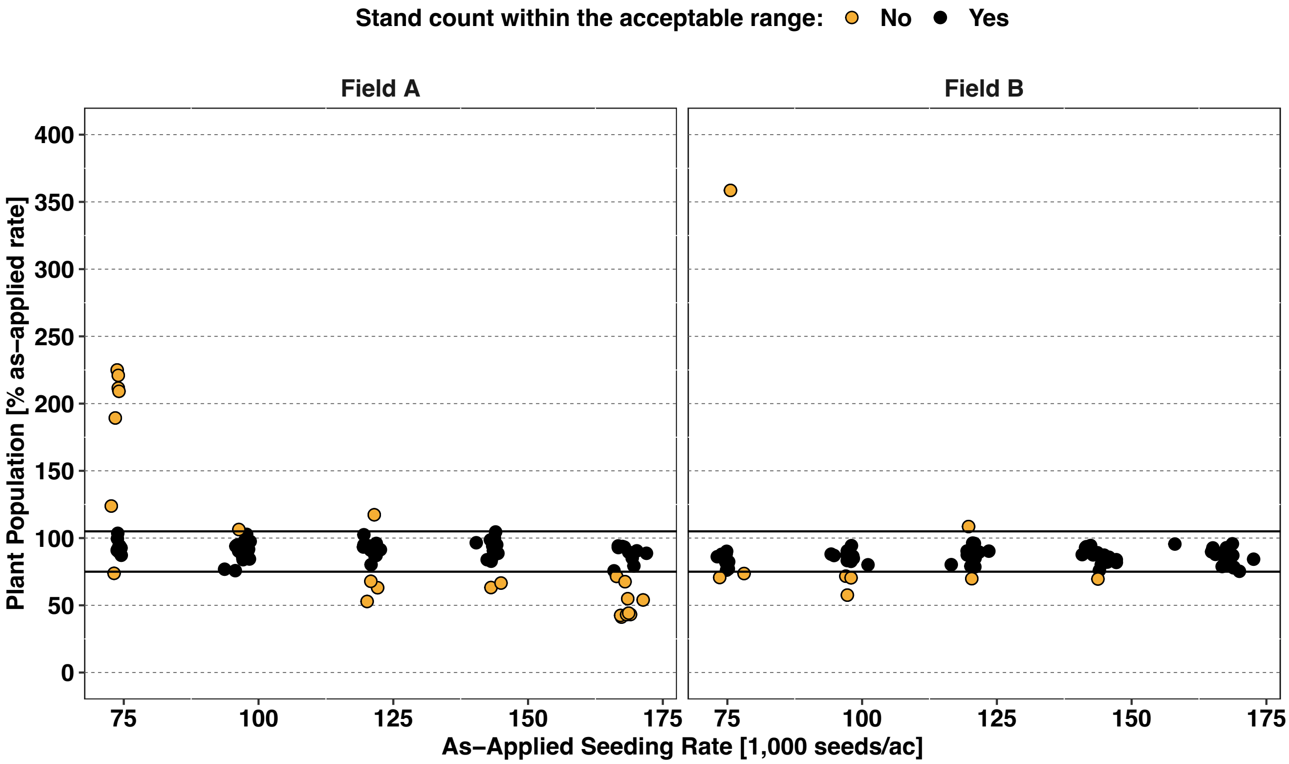

Fig. 3. Plant population response to as-applied soybean seeding rate by field. The acceptable plant population ranged from 75% to 105% of the as-applied seeding rate to account for reasonable metering error (+/- 5%) and seed/seedling loss.

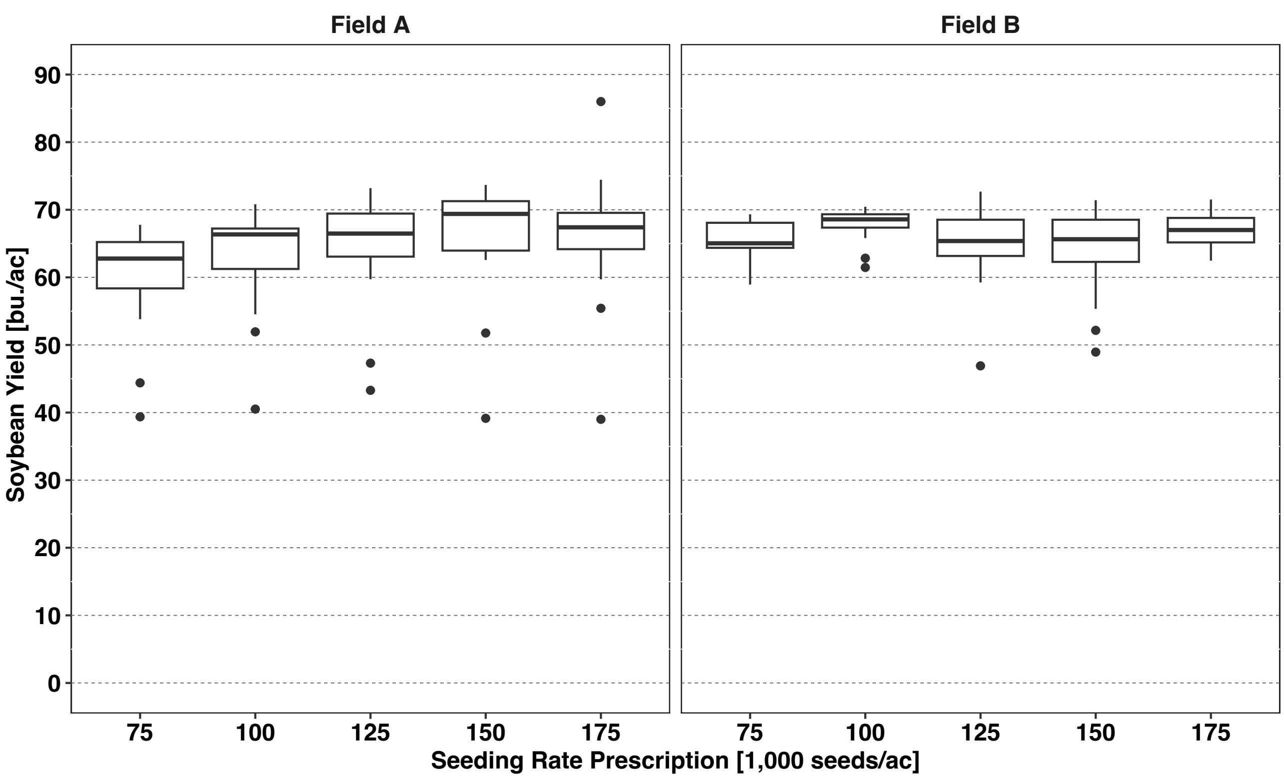

Fig. 4. Distribution of soybean yield response to seeding rate treatment by field.

Fig. 5. Soybean seeding rate prescription for field A.

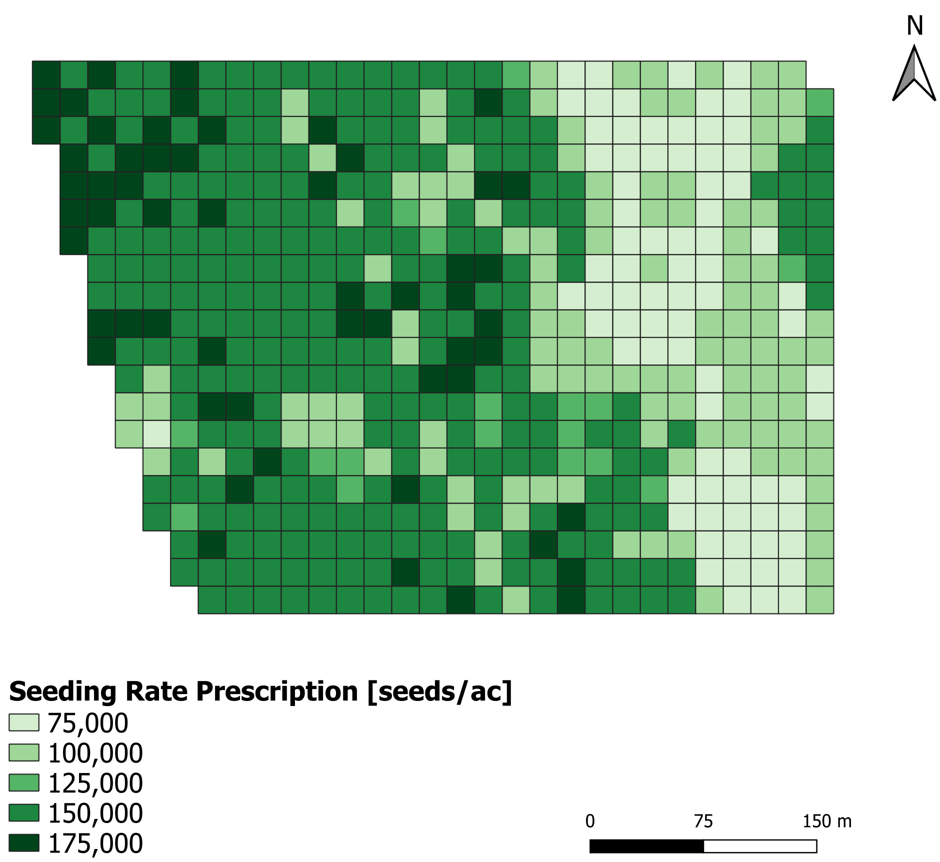

Fig.6. Soybean seeding rate prescription for field B.

AGRONOMY

Assessment of In-Field Variability in Furrow-Irrigated Soybean: Lessons Learned

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Abstract

Soybean accounts for more acreage than any other crop in Arkansas. Furrow-irrigation is preferred, but the water use efficiency is greatly affected by in-field variability. While recent technological advances have equipped producers with new tools and methods that can be used to increase the overall efficiency of furrow-irrigation, there are no guidelines to help producers prioritize efforts and optimize practical implementation. A better understanding of soybean response to in-field variability, identification of the drivers of variability, and in-season monitoring of soybean development and health, and correlations with yield are needed to help develop data-driven recommendations for optimized soybean production. More specifically, accurate yield prediction from satellite imagery is needed to help inform scouting efforts and support the development of data-driven recommendations for optimized soybean management in furrow-irrigated fields. The project objective was to quantify in-field soybean variability and characterize relationships between yield and the normalized difference vegetation index (NDVI) computed from satellite imagery in three fields planted with 5 seeding rates. Results showed that while in-field soybean yield variability and correlations with the computed NDVI values were found in all fields and seeding rates treatments, the magnitude of these correlations varied greatly with location, management, and timing in a growing season. These findings demonstrated that remote sensing imagery could be used to monitor soybean development and predict yield, but a complementary approach that better accounts for the multi-dimensional nature of in-field variability is needed to better capture the complexity of interactions at play, improve model performance, and ultimately inform crop management decisions for increased profitability.

Introduction

Soybean [*Glycine max* (L.) Merr.] is the most cultivated crop in Arkansas with more than 160 million bushels produced annually on approximately 3.3 million acres spread across 41 of 75 counties (NASS, 2023). Most of the production is in the Arkansas River Valley and Mississippi Delta regions, and approximately 85% of the total acreage is irrigated to minimize yield loss from drought stress (Coats and Ashlock, 2000). Furrow-irrigation accounts for more than 80% of the irrigated soybean acreage in Arkansas and allows for quick delivery of irrigation water in large or irregular fields (West et al., 2020). Furrow-irrigated fields require positive and continuous row grades ranging between 0.10% and 0.50%, and precision land-leveling is also widely used to optimize soil topography and improve drainage (Tacker and Vories, 2000). Positive and continuous row grades between 0.15% and 0.30% with effective irrigation lengths of 0.25 mile are particularly desirable to promote greater water application efficiencies.

Furrow-irrigated soybean is planted on elevated beds and water is delivered between the crop rows using inflatable flat-lying polyethylene pipes, referred to as polypipes (Bryant et al., 2017). The polypipes are attached at the field inlet (riser) and deposited perpendicularly to the crop rows along the field crown. Holes are created in the polypipe at the front of each furrow and water flows down the field with gravity. Hole size is determined according to furrow length and head pressure using computerized hole selection software to help regulate and uniformize the water advance pattern (Henry and Krutz, 2016). The whole-farm furrow-irrigation system is designed according to field topography, predicted peak crop water needs, and the producers' operational constraints defined by riser locations and available labor, budget, equipment, and technology. However, site-specific dynamics created by spatial changes in management history (e.g., planting date, seeding rate) cannot easily be accounted for and furrow-irrigation efficiency remains low in comparison to that of other methods (Kebede et al., 2014).

Traditionally, furrow-irrigation is managed as an open, continuous-flow water delivery system and scheduling is determined using non-quantitative methods not proven to maximize water use efficiency and profitability (Bryant et al., 2017). Because of limited labor and riser availability, water is often allowed to flow along the entire furrow even though the effective irrigation length is longer than the recommended 0.25 mile, potentially creating significant deep percolation. Water is also frequently delivered for significant amounts of time beyond the minimum duration for adequate irrigation, creating excessive tailwater runoff. Greater inefficiencies and

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losses may occur at the top and bottom of the field and create top-to-bottom crop development and yield effects along the irrigated furrows. Deep percolation and tailwater runoff are the 2 major sources of inefficiency in furrow-irrigated crop production systems (Bryant et al., 2017). Deep percolation is harmful because it reduces the amount of irrigation water used by the crop and increases nutrient loss by leaching (Mailhol et al., 2007). Fortunately, recent technological advances have provided producers with new tools that can be used to improve furrow-irrigation efficiency. For instance, surge irrigation, cutback irrigation, end-block, or tailwater recovery may be used to mitigate deep percolation and tailwater runoff issues (Kandpal and Henry, 2016). Soil water potential sensors may also be used to ground truth the soil water status and inform irrigation scheduling, and variable-rate seeding may be considered to mitigate top-to-bottom effects (Bryant et al., 2017; University of Arkansas System Division of Agriculture Cooperative Extension Service, 2023).

While the adoption and use of new precision irrigation methods can allow producers to achieve furrow-irrigation efficiencies that are comparable to that of other methods, a more thorough understanding of crop development and yield dynamics in furrow-irrigated systems is needed to develop data-driven recommendations that will help producers prioritize efforts and maximize benefits from their investment. Emphasis should be given to investigating crop response to site-specific changes in soil properties and soil water dynamics, and remote sensing-based vegetation indices have been widely used to assess spatial changes in crop development and yield within agricultural fields and identify the drivers of variability (Yagci et al., 2015; Rogovska and Blackmer, 2009). Application of satellite remote sensing to furrow-irrigated soybean production could help map spatial changes in crop development and yield, model crop response to site-specific soil and water dynamics, determine what percentage of field variability could be managed with greater irrigation efficiency, and allow for the development of data-driven recommendations that will help producers maximize benefits from precision irrigation technologies. For instance, such recommendations could help farmers determine where to install soil water potential sensors and improve irrigation scheduling to reduce crop stress along the furrow, minimize yield loss from suboptimal field conditions, optimize input cost per bushel per acre produced, increase furrow-irrigation water efficiency, and reduce the pressure exerted on depleting groundwater resources. The project objective was to investigate the use of satellite-based vegetation indices to characterize in-field soybean development and yield in three furrow-irrigated fields.

Procedures

Site Information

The experiment was conducted on-farm in Lincoln County, Arkansas. Three furrow-irrigated production soybean fields referred to as fields A, B, and C were used in 2021, 2022, and 2023, respectively. Field sizes were 80, 50, and 85 acres. Soil development took place on loamy and clayey alluvium in field A, loamy, silty, and clayey alluvium in field B, and clayey alluvium in field C. Perry, Portland, and Rilla soil series accounted for 67%, 20%, and 13% of field A. Perry, Rilla, and Herbert soil series accounted for 50%, 25%, and 25% of field B. Perry and Portland soil series accounted for 52% and 48% of field C. The previous crop was rice in fields A and C, and soybean in field B. Five seeding rate treatments were selected to bracket the typical range: 75, 100, 125, 150, and 175 thousand seeds/ac. The treatments were established in strips within each field and randomized within 4 complete blocks (Figs. 1 to 3). Fields A, B, and C were planted on 6 June 2021, 21 May 2022, and 25 May 2023. Planting was performed using a 12-row planter equipped with auto-guidance technology, variable-rate seeding capabilities, and real-time kinematic positioning accuracy. Row spacing was 36 in. The treatment strips were established parallel to the irrigated furrows and extended from the top to the bottom of the field. Each strip was created as 2 consecutive planter passes so that the total treatment strip width was 72 ft. Treatment strip length was equal to the furrow length and varied with field shape. All fields were planted using soybean variety AG48X9. All 3 fields were irrigated using 2 polypipe sets. The 2 sets were established sequentially on the eastern side of field A and water was delivered from east to west (Fig. 1.). The 2 sets were established back-to-back in field B (Fig. 2.). In the western two-thirds of field B, irrigation was delivered from east to west. In the eastern third of field B, irrigation was delivered from west to east. The 2 sets were established parallel to each other in field C and water was delivered from north to south (Fig. 3.). The set was used to irrigate the top half of field C. The second set was used to irrigate the bottom half of field C. PipePlanner software (Revolution/Delta Plastics, Little Rock, Ark.) was used to optimize polypipe hole selection. Furrow-irrigation was delivered three times between flowering (R2) and full pod (R6) in each field, and a total of 8.7, 6.2, and 9.5 in. of water were applied throughout the growing season in fields A, B, and C, respectively. Nutrient and pest management was accomplished using current University of Arkansas System Division of Agriculture's Cooperative Extension guidelines. Fields A, B, and C were harvested on 8 November 2021, 4 October 2022, and 21 October 2023, respectively, using a 12-row combine harvester equipped with a yield monitor and real-time kinematic positioning accuracy.

Data Collection

The yield monitor data were processed to remove outliers resulting from changes in travel speed on the edge of the field. High spatial and temporal resolution satellite images were downloaded from the Planet data repositories and used to characterize in-field changes in crop health throughout the growing season. The satellite image spatial resolution was 5 m, and images were downloaded approximately every 5 days from planting to harvest. The red and near-infrared (NIR) images were used to compute the normalized difference vegetation index (NDVI) using the following equation: NDVI = (NIR - Red)/(NIR + Red). Data collection transects were established in the middle of each treatment strip (Figs. 1 to 3). The distance between 2 consecutive sampling locations within a transect was 80 ft. In each sampling location, yield was estimated as the average value of all clean yield monitor data found within a 15-ft radius. NDVI was determined using a spatial intersection function. Yield response to the seeding rate treatments was evaluated using summary statistics that characterize the central tendency and within-treatment variability of yield. Relationships between the NDVI values computed from available satellite imagery and soybean yield were characterized using Spearman's correlations. Positive Spearman's correlation coefficients indicated positive relationships among variables. The greater the absolute values of the correlation coefficients, the stronger the relationship among variables.

Results and Discussion

Soybean yield and variability varied among fields and seeding rate treatments (Table 1). The lowest median (62.8, 64.8, and 62.4 bu./ac in fields A to C) and average soybean yields (60.6, 63.8, and 60.9 bu./ac in fields A to C) were achieved at 75,000 seeds/ac in all fields. The highest median (67.6, 67.6, and 66.1 bu./ac in fields A to C) and average (65.7, 66.9, and 65.1 bu./ac) soybean yields were achieved at 175,000 seeds/ac in all fields. The lowest within-treatment soybean yield variability (corresponding to CV values of 12.0%, 6.7%, and 8.7% in fields A to C) were also observed at the 175,000 seeds/ac treatments in each field. More within-treatment soybean yield variability, corresponding to CV values of 13.8%, 22.4%, and 12.5%, was found at the 100,000, 150,000, and 75,000 seeds/ac treatment in fields A, B, and C, respectively. For each treatment, the minimum and maximum soybean yield values largely bracketed the between-treatment differences in median and mean soybean yield values found in each field. Overall, greater in-field soybean yield variability was observed in fields A and B. Therefore, in-field soybean yield variability was observed in all fields independently from seeding rate management. However, the magnitude of variability and effect of seeding rate was not consistent across locations. While no seeding rate treatment resulted in a range of soybean yield that was distinct from that of the other treatments, further analysis is needed to characterize the structure of in-field yield variability and ultimately inform crop management.

Moderate to strong positive correlations were identified between the NDVI values and soybean yield in all fields (Fig. 4). In field A, these strong positive correlations were observed between 50 and 115 days after planting. The strongest correlations were observed at 125,000 and 150,000 seeds/ac. In field B, only moderate positive correlations were identified between NDVI and yield. However, these were observed throughout the growing season. The strongest correlations were found at 75,000 and 150,000 seeds/ac. In field C, strong positive correlations between NDVI and yield were identified from 60 days after planting to harvest. The strongest correlations were found at 75,000 and 125,000 seeds/ac. These results demonstrated that in-field soybean yield variability is structured enough to allow for in-season monitoring and prediction using remote-sensing-based vegetation indices such as the NDVI. However, the magnitude of the relationship between NDVI and yield varied between fields, seeding rate treatments, and timing within a growing season.

Practical Applications

The project goal is to increase the profitability of irrigated soybean production with optimized crop management. In order to meet this goal, the following tasks must be completed: 1) characterization of soybean yield response to in-field variability, 2) in-season monitoring of soybean development and health, and correlations with yield, 3. definition of data-driven recommendations for optimized crop production, and 4. decision-support tool development and validation for delivery of data-driven recommendations. The analysis presented in this report addresses the first 2 items. The presented work was conducted under the assumption that most yield variability in furrow-irrigated soybean fields occurs parallel to the irrigation furrows, and that the remote-sensing-based vegetation indices collected at key crop development stages correlate with yield. The presented work also assumed that the assumptions above were valid independently from seeding rate selection. The results demonstrated that, as expected, in-field soybean yield variability occurs in commercial soybean fields independently from the seeding rate selection. However, the magnitude of variability, spatial distribution of yields, and patterns of correlations between remote-sensing-based NDVI were not consistent across site-years and seeding rate treatments, making it difficult to generalize findings. These results supported the idea that remote sensing imagery can be used to monitor soybean development in production fields, but the initial assumptions and approach should be revised to better account for the multi-dimensional nature of in-field variability and the complexity of interactions at play. Future research will use a complementary approach to that of the presented work that will help improve model performance by accounting for two-dimensional spatial effects. The research scope will also be expanded to other irrigation strategies including overhead and flood irrigation. Moreover, the site-specific temporal changes in remote sensing-based vegetation indices will be accounted for so that yield is no longer correlated to in-field changes in remote sensing-based vegetation indices at any given time, but rather how the remote sensing-based indices have varied in time.

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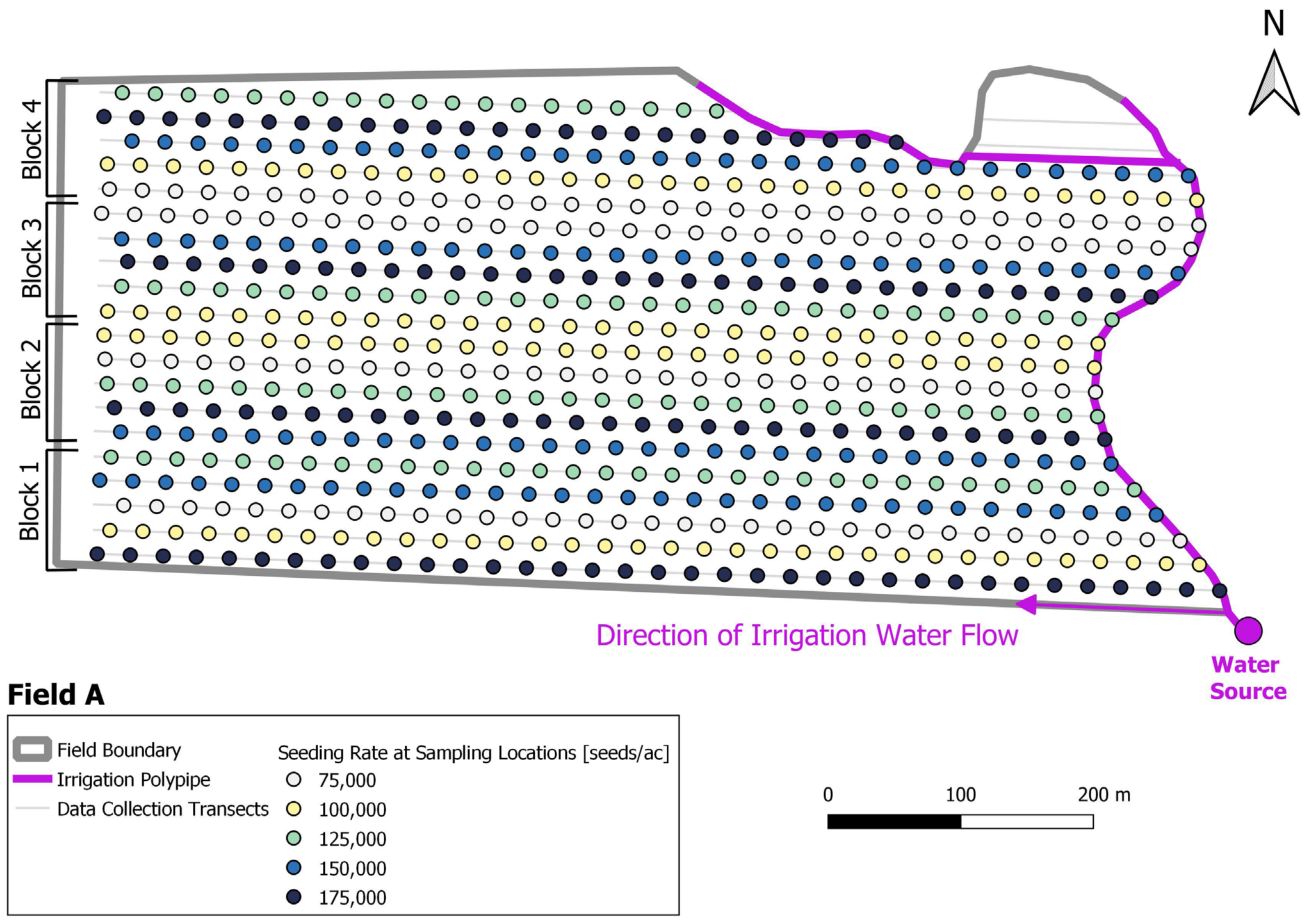

Fig. 1. Soybean seeding rate treatment layout, irrigation setup, and data collection strategy for field A.

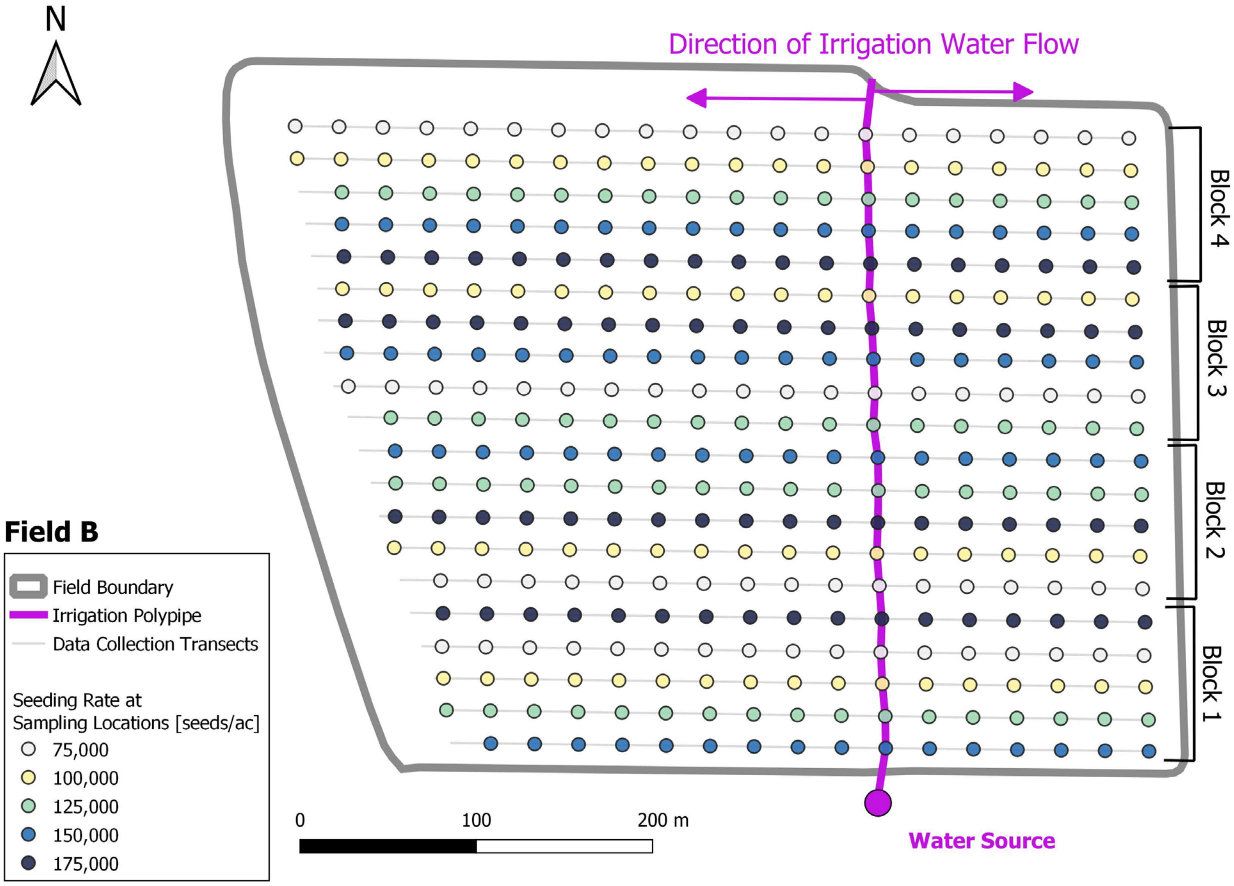

Fig. 2. Seeding rate treatment layout, irrigation setup, and data collection strategy for Field B.

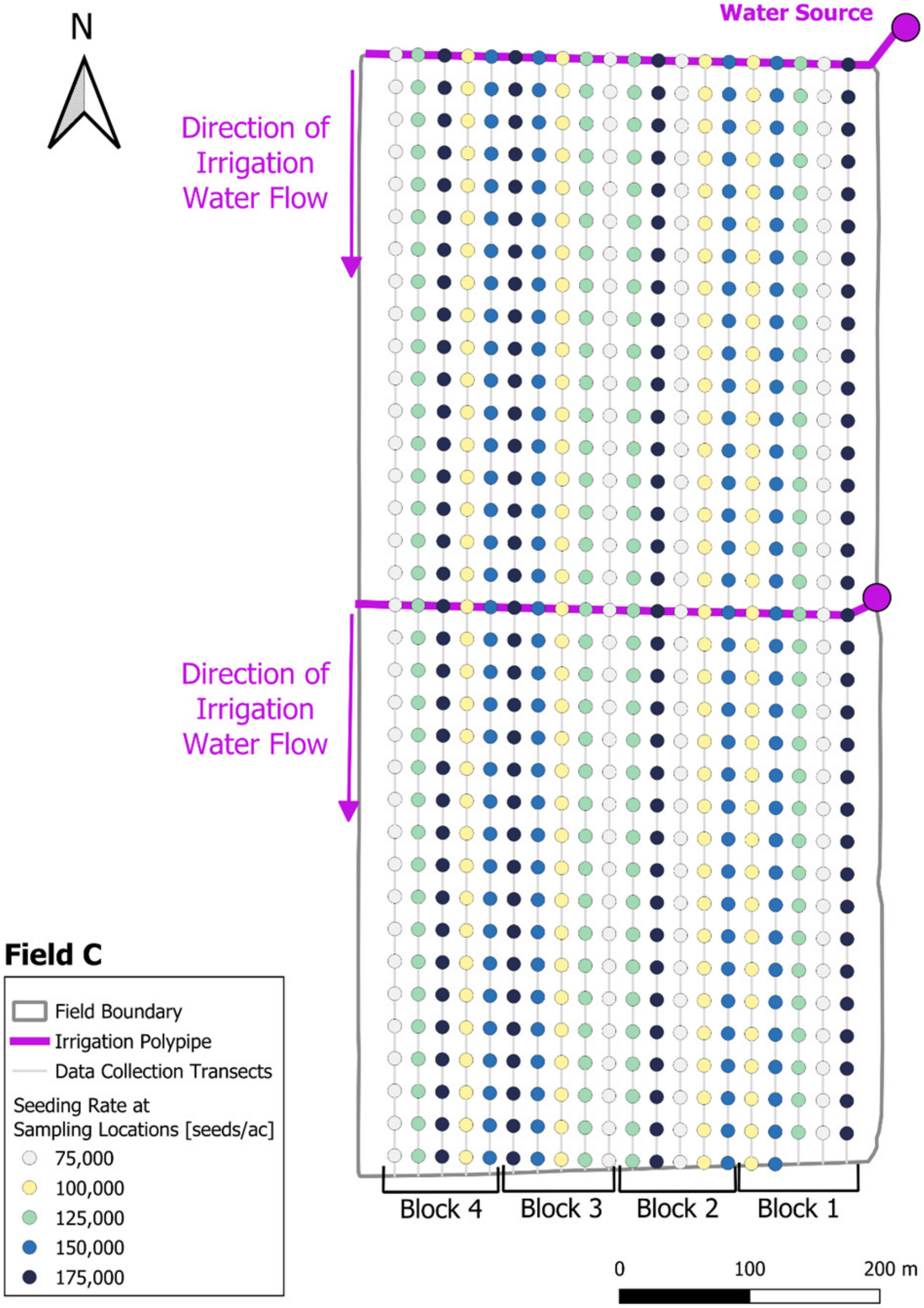

Fig. 3. Seeding rate treatment layout, irrigation setup, and data collection strategy for Field C.

Table 1. Distribution of soybean yield by seeding rate treatment and field.

Field	Seeding Rate	Minimum	1st Quartile	Median	Mean	3rd Quartile	Maximum	CV[a]
	(seeds/ac)	-------------------------------------		(bu./ac)		--------------------------------------		(%)
A	75,000	16.8	59.1	62.8	60.6	65.2	68.8	12.8
	100,000	11.7	61.4	63.9	62.4	67.0	71.0	13.8
	125,000	14.5	62.7	67.2	64.9	69.8	73.3	12.8
	150,000	25.3	63.5	67.0	64.7	69.6	73.7	13.3
	175,000	26.3	63.0	67.6	65.7	70.7	82.0	12.0
B	75,000	32.4	61.1	64.8	63.8	67.7	82.7	10.1
	100,000	44.5	64.2	67.3	66.2	69.0	85.2	8.3
	125,000	52.5	64.5	67.0	66.4	69.0	75.2	6.4
	150,000	27.0	64.8	67.2	66.2	69.6	85.2	11.4
	175,000	49.7	65.1	67.6	66.9	68.9	74.7	6.7
C	75,0000	22.4	58.6	62.4	60.9	65.3	70.9	12.5
	100,000	19.5	61.1	63.9	62.1	66.3	71.0	12.3
	125,000	32.8	62.4	65.2	63.9	68.4	72.1	10.5
	150,000	19.2	62.2	65.4	63.9	68.6	75.8	12.2
	175,000	36.2	63.2	66.1	65.1	68.6	75.2	8.7

[a] CV = Coefficient of Variation.

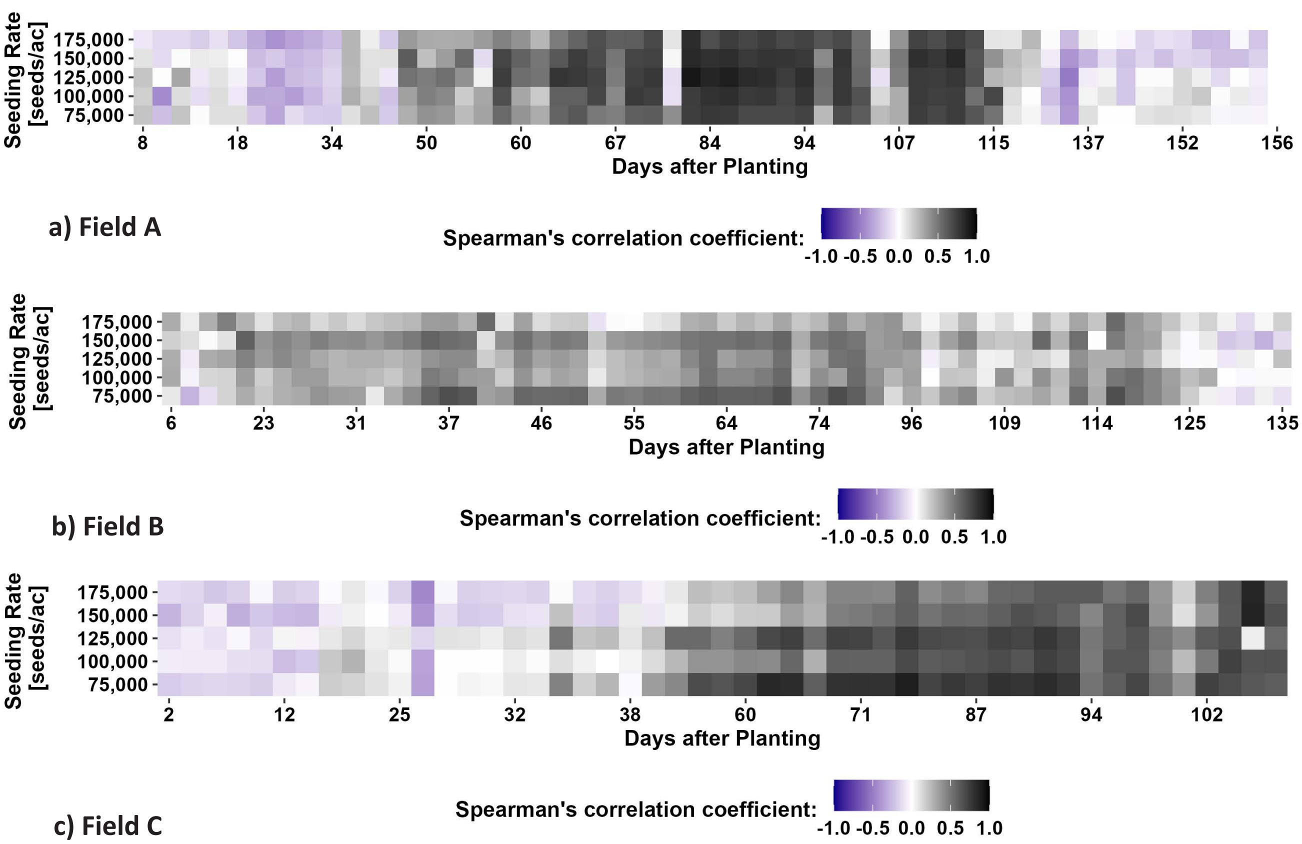

Fig. 4. Spearman's correlation coefficients describing the direction and strength of correlations between soybean yield and the normalized difference vegetation index values computed by seeding rate from satellite images collected between planting and harvest in fields A, B, and C.

Classification of Soybean Chloride Sensitivity using Leaf Chloride Concentration of Field-Grown Soybean 2023 Trial Results

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Abstract

Soybean [*Glycine max* (L.) Merr.] varieties are currently categorized as being chloride (Cl) includers, excluders, or a 'mixed' population. A more specific rating system is needed to differentiate between true Cl excluding varieties and a considerable proportion of varieties that may be mixed includer/excluder plant populations or a population of plants having multiple genes that influence Cl uptake. A field-based Cl monitoring program has been developed, in conjunction with the Arkansas Soybean Performance Tests, to provide a more detailed categorization of Cl tolerance in soybean varieties. A 1 to 5 rating system was developed and implemented on 130 varieties belonging to relative maturity groups 3.5 to 5.9 based on trifoliolate leaf-Cl concentrations included in the University of Arkansas System Division of Agriculture's Rohwer Grown Soybean: 2023 Trial Results Research Station location of the 2023 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 57, 10, 16, 32, and 15 varieties, respectively. The detailed rating system provides producers with more information regarding the relative Cl tolerance of available soybean varieties.

Introduction

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

Procedures

All varieties entered in the Arkansas Soybean Variety Performance trials were sampled at the University of Arkansas System Division of Agriculture's Rohwer Research Station (RRS) in 2023. The trial included early-4, late-4 and 5 maturity group categories that ranged from 4.2–5.8. Soybean was planted on 3 May 2023 in a field having soil mapped as a Desha silt loam following corn (*Zea mays* L.) in the rotation. Rainfall during the growing season (23.8 in.) was substantially less than the 10-year average (37.7 in.), which could have contributed to increased Cl in the soil and a greater uptake of Cl by the soybean plants. Soybean was planted on beds spaced 38-in. apart with each plot having 2 rows. Plots were furrow irrigated 4 times based on an irrigation scheduling program and managed using University of Arkansas System Division of Agriculture's Cooperative Extension Service guidelines for furrow-irrigated soybean. Based on information provided by the originating company or institution, varieties were divided into 3 relative maturity (RM) ranges: RM 4.0–4.4, RM 4.5–4.9, and RM 5.0–5.9. Varieties were arranged as a randomized complete block design with three replications. Additional details of this trial along with 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)

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were included in each block of each maturity group to serve as a ‘check’ to provide a baseline response for relative comparison amongst varieties and locations within the field.

A composite sample comprised of 1 recently matured (top 3 nodes) trifoliolate leaflet (no petiole) collected from 10 individual plants in each plot and placed in a labeled paper bag when soybean was in the R3 to R4 stages. Plant samples were oven-dried, ground to pass a 2-mm sieve, and extracted with deionized water as outlined by Liu (1998). Extracts were analyzed for Cl on an inductively coupled plasma atomic emission spectrophotometer.

The tissue-Cl concentration mean 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 University of Arkansas System Division of Agriculture’s Rohwer Research Station (RRS) provides a unique opportunity for this research to be conducted as the combination of irrigation water source, high soil Cl concentrations, and low permeability soils increases the likelihood of Cl toxicity in soybean. The mean leaflet-Cl concentrations ranged from 20 to 4054 ppm Cl across the 130 varieties sampled (Tables 1–3). The maximum tissue-Cl concentrations from the RRS in 2023 are roughly 14 times higher than what was observed from the data presented in the 2022 trial located at the University of Arkansas System Division of Agriculture’s Vegetable Research Substation (VSS) (Roberts et al., 2023). In general, the standard deviation increased linearly as the mean Cl concentration increased, suggesting greater variability in variety Cl concentrations for mixed and includer varieties. The range and magnitude of Cl concentrations observed in this study during 2023 were similar to previous reports from samples that were collected at the RRS, but more than one order of magnitude higher than what was observed in 2022 at the VSS. It was apparent that the Cl concentrations in the soil and water at the RRS were significantly higher than at the VSS and the separation of cultivars from 2023 at the RRS was much clearer. The early-4 tests had the least number of varieties with 24 entries combined. Within this group, 9 varieties were identified as strong excluders in category 1 (Table 1). For this maturity group class (early-4), about 1/3 of the varieties were classified as a 3 or 4. These Cl classifications within the early-4 category are similar to the 2022 data that indicated a majority of the varieties in the early-4 maturity group were shifting towards more of a “mixed” or excluder population rather than an includer (Roberts et al., 2023). However, it appears that the options for strong excluders available for producers who need Cl excluder varieties in the early-4 maturity group range are increasing, but overall entries for this maturity group are down significantly from previous years. For producers that may have areas prone to increased soil or irrigation water Cl concentrations, no maturity group 3 varieties were included in the trial to provide Cl tolerance data.

The late-4 class of varieties had the most overall entries with 73 and mean Cl concentrations ranging from 21–3217 ppm. Within this maturity group range, 34 varieties were identified as being strong excluders which all fell within a range of Cl concentrations (Table 2. 21–119 ppm Cl). There were 3 varieties that fell within ranking 2 as moderate excluders. There were 11 varieties that fell within category 3 or mixed trait varieties. The moderate and strong includers were similar to the strong excluder category with 25 total varieties falling under Cl rankings of 4 or 5. These results indicate that there is an even distribution of Cl excluders and includers within the late-4 class of varieties giving producers the opportunity to choose from a wide variety of herbicide tolerant traits and agronomic characteristics. Each year, it appears that more and more options are available for producers interested in varieties with strong or moderate Cl excluder traits in the late-4 maturity group subset.

For the maturity group 5 class, there were a total of 33 entries and the mean Cl concentration ranged from 20–4054 ppm across this group of varieties. Within the late-4 class of varieties, there were a significant number of varieties (13) identified as strong excluders (Table 3), which is much higher than data reported in previous years, suggesting that more work is being done to provide varieties with higher Cl tolerance in this maturity group. The trend of increasing strong excluders in this category is promising, as this has historically been an issue with maturity group 5 varieties. Almost half (15) of the varieties in the maturity group 5 class fell within the moderate or strong includer categories.

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 the 2023 field trial results are much higher than values reported for 2022, but like 2021. The field location in 2023 was the same field used in 2021 and 2019, and our results from several years of implementing field-based assessments 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 that have irrigation water with high Cl concentrations or fields that may harbor Cl ions in the soil profile due to poor internal drainage from clayey soil texture or elevated sodium (Na) concentrations. The numerical rating system (1 to 5) based on the Cl concentrations of field-grown plants provides clear ratings that more accurately represent the variability of Cl uptake by soybean varieties than the three-tier rating system of includer, excluder, and mixed. One primary benefit of the new 1 to 5 rating system is that it provides higher-resolution data for producers to use when selecting soybean varieties. Producers can now compare Cl tolerance with higher resolution across a wide range of herbicide tolerance and agronomic characteristics. If the producer is in search of a variety with specific traits and a high level of Cl tolerance, this new ranking system can allow him to tease out differences in Cl tolerance amongst varieties that would traditionally be lumped together as "mixed". When comparing 2 varieties with similar traits, a producer can now differentiate between varieties traditionally classified as mixed and select a variety rated as 2 over one rated as 4, knowing that there are distinct differences in the Cl tolerance of those 2 varieties. The new rating system will especially benefit growers that farm with marginal irrigation water high in Cl concentration.

Acknowledgments

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Table 1. Mean leaflet chloride (Cl) concentrations and preliminary rating for "Early Group 4" varieties (4.0–4.4) as determined from field-grown plants at the University of Arkansas System Division of Agriculture's Rohwer Research Station Soybean Variety Performance trial in 2023. A rating of 1 means strong excluder and a rating of 5 means strong includer.

Variety[a]	Mean (ppm)	Rating[b]	Variety[a]	Mean (ppm)	Rating[b]
AG42XF4	20	1	DG 44XF75/STS	1601	3
AG44XF4	20	1	DM 45F23	1074	3
AG45XF3	20	1	Dyna S42XF93S	1494	3
Pioneer P44A60LX	20	1	Revere 4237XFS	1507	3
Pioneer P45A70LX	20	1	NK44-Q5E3S	1345	3
Revere 4526XFS	20	1	Innotech 4233E3S	1809	4
NK42-A6E3S	20	1	Revere 4415XF	1902	4
R19C-1012	20	1	Integra XF4454S	1865	4
R19C-1035	32	1	AG43XF2	2432	5
Pioneer P44A21X	136	2	Innotech 4545E3S	2273	5
R19C-1081	440	2	NK44-J4XFS	2887	5
S19-10701	197	2	Integra XF4142S	2425	5

[a] Abbreviation key: AG = Asgrow; DG = Delta Grow; DM = DONMARIO; Dyna = Dyna Gro; NK = Syngenta; R = University of Arkansas; S = University of Missouri.

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

Table 2. 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 University of Arkansas System Division of Agriculture's Rohwer Research Station Soybean Variety Performance trial in 2023. A rating of 1 means strong excluder and a rating of 5 means strong includer.

Variety[a]	Mean (ppm)	Rating[b]	Variety[a]	Mean (ppm)	Rating[b]
Osage (Check)	107	1	S17-17644	40	1
AG46XF3	56	1	Integra X4660	84	1
AG48XF2	35	1	Integra XF4634S	30	1
AG48XF3	42	1	Integra XF4893S	37	1
DG 46E10	66	1	DG 46XF54	233	2
DG 46E30	49	1	Progeny P4798XF	233	2
DG 46X65/STS	43	1	R19C-2678	307	2
DG 47E20/STS	118	1	46i20C (Check)	1332	3
DG 48E59	58	1	DG 49XF85/STS	1042	3
DG 48X45	102	1	Axis 4613XF	1448	3
DG 48XF42	28	1	Dyna S49XF82	1398	3
DG 49E30/STS	119	1	Progeny P4822XFS	855	3
Innvictis B4603E	113	1	NK48-A8XFS	1356	3
Innvictis B4903E	104	1	R19-39415	1574	3
Dyna S47XF23S	31	1	R19-39444	1202	3
Pioneer P46A20LX	48	1	R19C-1001	1172	3
Pioneer P46A90LX	43	1	Integra XF4914S	1043	3
Pioneer P47A64X	21	1	ES4800E3	2102	4
Pioneer P48A04LX	29	1	ES4875XF	2467	4
Progeny P4623XFS	74	1	AG47XF2	2553	4
Progeny P4665XFS	32	1	AG47XF4	2481	4
Progeny P4691XFS	29	1	DG 47XF38	1880	4
Progeny P4775E3S	66	1	DM48F53	2552	4
Progeny P4850E3	95	1	Axis 4641XFS	2645	4
Progeny P4947XFS	43	1	Axis 4813XFS	2201	4
Progeny P4999E3S	81	1	Dyna S49XF43S	1766	4
Innotech 4983E3S	106	1	Progeny P4778XFS	1753	4
Revere 4826XF	41	1	Progeny P4806XFS	2224	4
USG 7474XFS	21	1	Revere 4727XF	1867	4
NK49-C2XFS	94	1	Revere 4925XFS	2054	4
NK49-T6E3S	52	1	USG 7463XF	2605	4

[a] Abbreviation key: AG = Asgrow; DG = Delta Grow; DM = DONMARIO; Dyna = Dyna Gro; ES Eagle Seed; Innv. = Innvictis; NK = Syngenta; R = University of Arkansas; 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 2. Continued.

Variety[a]	Mean (ppm)	Rating[b]	Variety[a]	Mean (ppm)	Rating[b]
NK46-B4XFS	2307	4	Progeny P4604XFS	3019	5
R18C-13665	2200	4	Progeny P4755XFS	3217	5
R19C-3147	2342	4	Revere 4731XF	2900	5
Integra XF4621S	2452	4	Revere 4934XF	2846	5
DG 48XF33/STS	2977	5	USG 7461XFS	3066	5
Dyna S46XF31S	2773	5			

[a] Abbreviation key: AG = Asgrow; DG = Delta Grow; DM = DONMARIO; Dyna = Dyna Gro; NK = Syngenta; R = University of Arkansas; 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 "Group 5" varieties (5.0–5.9) as determined from field-grown plants at the University of Arkansas System Division of Agriculture's Rohwer Research Station Soybean Variety Performance trial in 2023. A rating of 1 means strong excluder and a rating of 5 means strong includer.

Variety[a]	Mean (ppm)	Rating[b]	Variety[a]	Mean (ppm)	Rating[b]
AG56XF2	20	1	Innvictis A5503XF	936	3
DG 55X25	20	1	AG52XF0	1839	4
DG55XF23	29	1	DG 52XF22	1886	4
Innvictis B5013E	20	1	DG 53XF95/STS	1752	4
Progeny P5751XF	57	1	Progeny P5056XFS	1784	4
Revere 5143E3	20	1	Progeny P5441XF	1357	4
NK52-D6E3	20	1	Progeny P5641XF	1638	4
R18-10491	36	1	Revere 5029XF	1445	4
R18-10919	22	1	NK54-J9XFS	1426	4
R19-410712	37	1	R19-424115b	1624	4
R19-4593	58	1	R19-42447b	1705	4
R19-45980	43	1	R19C-3194	1464	4
R19-46252	31	1	AG53XF2	2835	5
Innvictis A5813XF	259	2	NK56-Z6XFS	3475	5
R19-411424	100	2	R19C-3085	4054	5
S18-6328	361	2	S18-6013	3984	5
Innvictis A5003XF	1027	3			

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

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

EDUCATION

Soybean Science Challenge: Cultivating Soybean Knowledge

J. C. Robinson,[1] Keith Harris,[1] and Diedre 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 the support of classroom-based lessons and applied student research. The SSC educates and engages junior high and high school science students and teachers in 'real-world' Arkansas-specific soybean science education through an original NGSS-aligned curriculum in 7E and GRC-3D format and a continuum of educational methods. These methods include teacher workshops, state and national conference presentations, 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 has continued to change into 2023–2024. The Soybean Science Challenge (SSC), by nature of its existing design, methodology, and adaptability, continues to launch new online Next Generation Science Standards (NGSS) Aligned Gathering Reasoning and Communicating (GRC)-3D and 7E lesson plans for teachers. Short one-period lessons for teachers on the go are included. Online content has been enhanced, including a condensed online Soybean Science Challenge, adding NGSS-aligned mini-lesson videos for the science classroom, and adding 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 participants at both the regional and state levels, and the SSC is in its fourth year of the junior-level award at regional science fairs. Through the SSC, teachers now have access to a plethora of educational instructions that bring real-world agricultural critical thinking both into the classroom, and homes of students. The SSC has learned that not only do Arkansas teachers and students benefit from these additional resources, but teachers and students across the nation benefit as well.

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 a virtual presence 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 to develop relationships with Arkansas teachers by supplying them with cutting-edge educational tools and the knowledge they need through online teacher in-service and face-to-face workshops. The 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, Southern Arkansas University STEM Night, 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 the SSC, the number of students enrolled in the SSC online course and the fairs over the last year, plus the usage of resources, were tabulated and noted in Tables 2 and 3. These outcomes include Spring of 2024, 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 2023–2024, the SSC Pre-test, student learning, and knowledge averaged 47% (Table 1). However, the post-test

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average was 93%, a marked increase in student knowledge of soybeans attributed to online course completion. The increase in pre- and post-test scores is a strong indication that the course is successful at teaching 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 14 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, providing student information and education to reach a higher level of research.

Through this program, the Arkansas Soybean Promotion Board (ASPB) invested $9,100 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 45 individual or team projects were judged, with 15 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 12 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 400 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.

Another indicator of the success of the SSC is the quality and quantity of science fair entries. The SSC had 45 entries in science fairs this year. At least 2 regional winners received the ISEF Finalist position, showing the increased quality and caliber of projects judged. A list of regional and state science fair winners can be found in Table 2. 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 to tell them how much the SSC has influenced their child's decision regarding future careers in agriculture. The SSC created a promotional video in the fall of 2023 to highlight the program's history and impact. The teachers and students who had participated in SSC offered to be a part of the video. The video (https://www.youtube.com/watch?v=-I_2Oh_MnWs&t=38s) has 141 views to date. These stories cannot be quantified, but they demonstrate some of the impact the SSC has in the classroom and the home. A more extensive list of soybean science challenge products, audience, activities, and impacts can be found in Table 3. It shows that people noticed that 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.

Acknowledgments

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

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Table 1. 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
60[a]	42	47	93	5	4

[a]With a shift of students choosing to take the condensed online course this spring, we are starting to see an overall increase in the number of student participants.

Table 2. 2024 Soybean Science Challenge Regional and State Science Fair Winners

Science and Engineering Fair	Winner(s) Name and High School	Project Title
Arkansas State Science and Engineering Fair University of Central Arkansas, 30 March	First Place: Bennet Chen, Little Rock Central High School	*Forecasting the future: a predictive modeling approach to deciphering climate change's impact on county-level soybean yields.*
	Second Place: Jana Abuelem, Pulaski Academy	*The effects of caffeine on Glycine max proteogenomics.*
	Honorable Mention: Sullivan Schaffer, Gravette High School	*Does radiation affect soybean growth?*
Arkansas School for Mathematics, Science, and the Arts: Hot Springs – Sciences and the Arts Science Fair, February 23.	Alice Dong, ASMSA	*Effects of ALAN on soybean phenology and chlorophyll levels.*
Central Arkansas Regional Science and Engineering Fair University of Arkansas-Little Rock, 1 March.	Senior Level: Bennet Chen, Little Rock Central High School	*Forecasting the future: a predictive modeling approach to deciphering climate change's impact on county-level soybean yields.*
	Junior Level: Suleyman Acikgoz, Lisa Academy West Middle School	*What is the Effect of Magnetic Fields on the Germination and Water Absorption of Soybeans.*
Northwest Arkansas Regional Science and Engineering Fair University of Arkansas-Fayetteville, 8 March	Senior Level: DuYen Do, Fayetteville Christian Academy	*The effect of varied light cycles on soybean seed germination.*
	Junior Level: Hadley Panek, St. Joseph Catholic School, Fayetteville.	*The effects of pretreatments on soybeans.*
Southeast Arkansas Regional Science Fair UA Monticello, 7 March	Senior Level: Sydney Fuller, Stuttgart High School	*Effects of soil nutrients on plant growth.*
Northeast Arkansas Regional Science Fair Arkansas State University-Jonesboro, 8 March.	Senior Level: Sydney Wolf and Anna Leslie, The Academies at Jonesboro High School	*How effective is green filtering?*
	Junior Level: Me'Shelle Hinton, Paragould JR High School	*Water filtration.*
Southwest Arkansas STEM Night Emerson High School Magnolia, 18 April.	Senior Level: Ka'Lee Hanson, Emerson High School	*Which variety of soybeans grow best in hydroponics.*
	Junior Level: Aiden Watson, Emerson High School	*The Effect of different types of soil on Soybean Plant Growth.*
Ouachita Mountains Regional Science and Engineering Fair Hot Springs, 1 and 13 March.	Senior Level: Kacylyn Reupta, Albert J Murphy JR High School	*Do different varieties of soybeans all grow at the same rate?*
	Junior Level: Zane Morris, Albert J Murphy JR High School-Texarkana	*Best brown for beans.*

Table 3. Soybean Science Challenge Products, Audience, Activities and Impact 2023–2024.

Product	Target Audience	Activities and Impact
Soybean Science Challenge student online course	6–12th grade	60 Students enrolled; 42 completed
Soybean Science Challenge Online Course – Teacher In-Service (7 Hrs.)	Science Teachers	5 Teachers enrolled; 3 completed
Soybean Science Challenge Online Course – Teacher Resources	Science Teachers	4 Users
Partnering with seven regional science fairs, STEM Night, and the Arkansas State Science Fair, 2023–2024 Attended and judged seven Arkansas science fairs, State science fair, and one STEM night. 2023–2024	Science Teachers/Students Science Fairs STEM Night participants	45 articles published or posted in newspapers or on websites. 15 individual/team student winning projects with 31 student/teacher awards; Totaling $5900 for the 2024 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 2,500 Science and AG Teachers each year for 2023–2024.
Condensed Soybean Science Challenge Online Course	Science Teachers/Students	The course was condensed to make it more accessible to all students of all learning styles. The course has proven to be popular and useful for students.
Farm Bureau Meeting, December 2023	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, October 2023	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.
Garland County Plant Show, April 2023	General public	Discussed Soybean Science Challenge materials such as lessons, VFT Manuals, resource guides, and SSC promotional items. Handed out soybean seeds for gardens.
Thunder over the Rock at USAF in Jacksonville, Ark. October 2023	General Public	Discussed Soybean Science Challenge materials such as lessons, VFT Manuals, resource guides, and SSC promotional items. Played 'where's the soy' game with over 1500 students and teachers.
Soybean Science Challenge Seed Store announcement	Junior High and High School Students/Teachers	SCIENCE List Serve, AR Educational Cooperatives, personal emails; soywhatsup, CES web page; workshops; teacher conferences; emailed to over 2500 Arkansas Science and AG Teachers.

Table 3. Cont.

Soybean Science Challenge Brochure	6-12th Grade High School Students/ Teachers	SCIENCE List Serve; AR Educational Cooperatives; personal emails; soywhatsup, 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, 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 – www.uaex.uada.edu/soywhatsup	Science Teachers/Students	AR Educational Cooperatives; personal emails; soywhatsup, 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. Even have publications in other states about our programs.
Soybean Science Challenge Video https://www.youtube.com/watch?v=-I_2Oh_MnWs&t=31s	General Public	Video is posted on the SSC website and reaches up to 200 people a day.
2016-2017 Arkansas High School Science Project Development Guide	Science Teachers/Students	Several handed out to teachers and students; posted on soywhatsup, 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, Community Garden Participants	65 gardens across the state and USA as of 3/26/2024. 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. Of Arkansas's many agricultural products, 23 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 the soft skills that 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. Other desirable soft skills include the ability to demonstrate integrity and ethical behavior, acting 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 15–19 May 2023, 15 Arkansas college juniors and seniors participated in the Arkansas Future Ag Leaders Tour. Students enrolled at five (5) Arkansas institutions and three (3) out-of-state institutions participated, including the following institutions:

- University of Arkansas – Fayetteville
- Southern Arkansas University - Magnolia
- Arkansas State University – Jonesboro
- Arkansas State University – Beebe
- University of Central Arkansas – Conway
- Central State University – Wilberforce, Ohio
- Oklahoma State University – Stillwater, Oklahoma
- Texas A&M University – Commerce, Texas

Majors of the tour participants included:

- Agriculture Business
- Agriculture Education
- Animal Science
- Sustainable Agriculture and Food Systems
- Family and Consumer Science
- Plant and Soil Science

[1]Associate Professor, Department of Community, Professional, and Economic Development, Little Rock.

The 5-day professional development opportunity included professionalism skills and team building to kick off the week on Monday, 15 May. On Tuesday, 16 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:

- Anheuser-Busch
- Cooperative Extension Service
- Woodruff County Electric Coop
- Farm Credit
- Evergreen Packing
- Riceland
- Farm Bureau
- Peco Foods
- RiceTec
- Greenway Equipment
- Dabbs Farm, Stuttgart
- Arkansas Department of Agriculture
- NRCS

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 apply on the job; responses specifically mentioned new knowledge gained, new professional skills, networking experiences, and new connections (Table 2).

The following 2023 Ag Leaders Tour evaluation results demonstrate:

- 100% of participants reported that participating in the tour changed or expanded their career options.
- 100% of participants made new networking connections.
- 100% of participants agreed that their knowledge of agricultural job opportunities in Arkansas increased a lot or a great deal.
- Three 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 apply in the future; 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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NACE. 2024. National Association of Colleges and Employers. Career readiness defined. Accessed 1 April 2024. Available at: https://www.naceweb.org/career-readiness/competencies/career-readiness-defined/

Table 1. Participant evaluation question–What did you learn?

Arkansas agriculture is very interconnected
There are so many opportunities in ag and you don’t have to limit yourself
Opportunities
Chicken plant does more work than I thought
Aquaculture
Water table
Electric
I learned how to put my goals and mission in Ag into marketable words/terms
The Ag industry is HUGE, but also so SMALL
AR Ag careers are super wide-spread
About the industry of ag and how networking in it is very important
All agencies in Arkansas usually work together
It’s who you know
A better idea of what my career might look like
Networking and connections
Not what you know, but who you know
The value of asking employers about benefits
Networking is EVERYTHING
Networking
The intricacies of industries and companies like Peco, Anheuser-Busch rice mill, etc.

Table 2. Participant evaluation question–What will you apply?

Change career options
How to separate the three pillars of sustainability, pick one to specialize in
How to build relationships with people in my degree field
Concentrate on experiences and connections not so much on degrees (still important though)
Take advantage of your opportunities, seize every one you can.
Networking aspect and make sure I put myself out there and ask questions.
Apply knowledge to educate future generations of agriculturalists, but also apply skills and knowledge to get my feet under me in the industry
Create a Facebook page to share resources and educational topics that I have learned along the way
Issues and politics and needs in Ag world such as climate mitigation
Networking
Get a LinkedIn and make a website for networking
Follow-up with all speakers in hope of collaboration and networking
Utilize certain internship/volunteer work programs and recall information that may prove useful from people in the ag industry
Networking
Building connections
Internships and job applications
Continue to build those connections
Be an advocate
Farm Bureau and YF&R
Volunteer

Utilization of Winter Nursery for Soybean Line Development through Backcrossing

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Abstract

The University of Arkansas System Division of Agriculture's Soybean Breeding Program aims to meet the needs of Arkansas soybean growers by developing and releasing cultivars with high yield potential, a comprehensive disease package, and the herbicide resistance background of their choice. To quickly build a pipeline for herbicide-resistant materials, a backcrossing program was initiated in 2020 to convert elite breeding lines into Enlist-E3® products. By 2023, 4 conversion waves of backcrossing materials (May 2020, September 2020, April 2021, and June 2022) have been implemented in Puerto Rico and Chile. Funding provided for this project has fully supported the establishment of the June 2022 conversion. The first products from the May 2020 conversion (163 Enlist-E3®) entered yield testing in Arkansas in 2023. Based on multi-environment performance, 45 Enlist-E3® lines were selected for further internal evaluation in 2024, and 7 of those will be simultaneously entered in the 2024 USDA preliminary test and the Arkansas Official Variety Tests. Pending satisfactory performance, they may be proposed for commercial release. Products from September 2020 and April 2021 conversions will enter yield trial testing in 2024, while products from June 2022 conversions will enter multi-environment yield evaluation in 2025. A new Enlist-E3® conversion cycle (December 2023) will be initiated in Puerto Rico, with products entering yield testing in 2026. Simultaneously, a second backcrossing program to convert elite lines into XtendFlex® products will be established at the same off-season nursery. The first converted products of this effort will enter yield testing in 2027.

Introduction

The University of Arkansas System Division of Agriculture's soybean breeding program strives to develop and release maturity group (MG) 4 high-yielding soybean cultivars to meet the needs of Arkansas soybean growers; however, most of our soybean cultivar development efforts have been primarily focused on conventional [non-genetically modified (GM)] materials. With 98% of soybean acreage planted with herbicide-resistant cultivars in Arkansas (USDA, NASS, 2023), the program must build a steady breeding pipeline of herbicide-resistant cultivars to meet the needs of the Arkansas growers. To do this, in 2020, we initiated a backcrossing program to convert elite breeding lines into Enlist-E3® (Pioneer; resistance to 2,4-D choline, glyphosate, and glufosinate) products. Backcrossing is a breeding method used to incorporate one or a few desired genes from a line of interest (donor parent) into an elite breeding line (recurrent parent) through several cycles of crossing back to the recurrent parent, hence generating a nearly identical line to the recurrent parent carrying the gene of interest. Traits such as elevated seed protein content, soybean rust resistance, phytophthora rot resistance, powdery mildew resistance, large seed size, and increased net leaf photosynthesis rate have been transferred through backcrossing (Wilcox and Cavins, 1995; Maphosa et al., 2012; Khanh et al., 2013; Ramalingam et al., 2020; Sjamsijah et al., 2020; Shamim et al., 2021). In our program, we have been incorporating the Enlist® trait into our elite lines. This trait provides herbicide resistance to 2,4-D choline, glyphosate, and glufosinate, enabling the use of 3 modes of action to control weeds. Enlist-E3® soybeans allow farmers to use Enlist Duo® herbicide based on their specific needs, which, combined with a wide application window and practically no product volatility, leads to maximizing yield potential while minimizing the risk of developing resistant weeds (Corteva, 2024).

Our conversion process occurs exclusively in off-season nurseries in Puerto Rico and Chile, where roughly 7 soybean crop cycles can be completed in 3 calendar years. A sustainable backcrossing program for herbicide-resistant product development requires significant investments in multiple years of operations in off-season nurseries. Hence, it is important to utilize off-season nurseries to rapidly convert elite breeding lines into Enlist-E3® or other herbicide resistance technologies and thus support a competitive breeding pipeline of MG 4 soybean herbicide-resistant cultivars.

Procedures

In our backcrossing program to convert elite breeding lines into Enlist-E3® and XtendFlex® (Monsanto Company; resistance to glyphosate, glufosinate, and dicamba), the process begins by sending seeds of our elite conventional breeding lines (females) and the herbicide-resistant donor (male) to Puerto Rico. There, an initial backcrossing block (BC0) is grown with 3 planting dates for the females and 2 plant-

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ing dates for the males. Three planting dates are sown for the females to increase the chance of matching the flowering timing between females and males and prolong the crossing window. Pollinations are made with the aim of producing 10–12 BC_0F_1 seeds per cross. At the end of the season, pods of pollinated flowers and seeds of recurrent plants (females) are harvested. In the next cycle, a backcrossing block (BC_1) is grown where male plants are sprayed with either Enlist Duo® (Corteva Agriscience) or Dicamba (Clarity®, BASF®) at the V2–V3 growth stage. Surviving male plants are individually tagged, and foliar tissue samples are collected for simultaneous molecular marker confirmation. Then, survivors get crossed with recurrent parents, and BC_1F_1 seeds and recurrent parents are harvested. One more cycle of backcrossing is conducted for the Enlist-E3® conversion program and 2 more cycles for the XtendFlex® conversion program. Each cycle includes respective herbicide application and molecular marker confirmation. Populations are then advanced until F_3 generation, spraying the appropriate herbicide in each generation, and 50 single plants with good pod load are individually harvested and threshed per population. Seeds from each converted plant are sown as a single progeny row and harvested in bulk for multi-environment yield evaluation across multiple locations in Arkansas.

Funding from this project has supported a fourth Enlist-E3® conversion wave that was initiated in June 2022 in Chile with 277 breeding lines in their second year of multi-environment yield evaluation. Breeding lines were crossed to Enlist-E3® donors. The performance of the breeding lines in 2022 multi-environment yield trials was used to decide which BC_0F_1 populations would be advanced to the following cycle. Based on this, 20 populations were kept in the backcrossing program. Populations went through a first backcrossing cycle in late 2022 and a second one in early 2023. In each of them, plants received a glufosinate (Basta®) application 2 weeks after planting, and foliar tissue was collected from surviving plants for trait molecular marker confirmation. After these, the 20 BC_2F_1 populations were relocated to an off-season nursery in Puerto Rico, where a third backcrossing cycle took place in early fall 2023. The presence of the Enlist-E3® trait was first identified by making an application of Enlist Duo® and later confirmed with molecular markers. BC_3F_1 seeds were bulked per population and 1 single row was planted per population for generation advancement in December 2023. Three more growing cycles will take place in 2024 in Puerto Rico, and Enlist-E3® converted products will enter multi-environment yield testing in Arkansas in 2025.

Results and Discussion

In the 2023 Enlist-E3® backcrossing program, 163 Enlist-E3® lines were tested across 3 Arkansas locations using a randomized complete block design with 2 replications. Reference checks used in the trials were Enlist® ('NK45-V9E3' and 'NK52-D6E3', Syngenta®; 'P48A14E', Pioneer®) and Xtend® ('AG48X9'®, Asgrow; 'S49-F5X', Syngenta®). A total of 45 Enlist-E3® lines have been selected for further evaluation in 2024. Two of them will be entered in the 2024 USDA preliminary MG 4-early test, 3 in the MG 4-late test, and 2 in the MG 5-early test (Table 1). These 7 lines will be also evaluated in the Arkansas Official Variety Tests MG 4 and 5. Simultaneously, pre-foundation seed will be produced in Stuttgart, Ark. Pending satisfactory performance, they can be proposed for commercial release in late 2024. In addition, a total of 1332 Enlist-E3® progeny rows derived from 15 populations were grown in Puerto Rico and Arkansas in 2023. Of these, 163 Enlist-E3® lines were tested in Arkansas in the 2023 growing season, and 432 Enlist-E3® lines will be entered in our yield trials in 2024 (Table 2).

For the fourth Enlist-E3® conversion (June 2022), in February 2023, 20 BC_1F_1 populations were planted in Chile and plants received a glufosinate (Basta®) application 3 weeks after planting. Foliar tissue was collected from surviving plants for trait confirmation through molecular markers. A second backcross cycle was conducted, producing between 16 and 32 BC_2F_1 seeds per population. BC_2F_1 populations were relocated to Puerto Rico in June, and subsequently subjected to a third backcrossing cycle where plants received an Enlist Duo (Enlist-E3®) application, and the presence of the trait was confirmed through molecular markers. Between 18 and 64 BC_3F_1 seeds were produced per population by the end of November. Seeds were bulked per population and planted in a single row in early December. Three weeks after planting, BC_3F_1 rows received an Enlist Duo (Enlist-E3®) application and foliar tissue was collected from the surviving plants for molecular marker confirmation. BC_3F_2 populations will be harvested by the end of April 2024. Three more growing cycles will take place in 2024 in Puerto Rico and Enlist-E3®-converted products will enter multi-environment yield testing in Arkansas in 2025 (Table 2).

In December 2023, a new Enlist-E3® conversion wave was initiated in Puerto Rico using 25 conventional breeding lines selected for yield evaluation in the 2024 USDA Southern Uniform Trials and the Arkansas Official Variety Tests. These lines are simultaneously being converted to XtendFlex® products. An additional line with high performance in the 2023 preliminary trials is also being converted to Enlist-E3® and XtendFlex®. Lines selected for Enlist-E3® conversion will go through 3 backcrossing cycles and 3 generation advancement cycles in 2 years (2024 and 2025) and will be evaluated in multi-environment yield trials in Arkansas in 2026. Similarly, lines selected for XtendFlex® conversion will go through 4 backcrossing cycles and 3 generation advancement cycles in 30 months (2024, 2025, and Spring 2026), entering multi-environment yield evaluation in 2027 (Table 2).

Practical Applications

The University of Arkansas System Division of Agriculture's Soybean Breeding Program needs to rapidly expand its footprint in herbicide-resistant cultivars. Supplementing the breeding efforts by initiating new conversion waves into

Enlist-E3® and XtendFlex® will support the pipeline of MG 4 herbicide-resistant materials without further straining the genetic gain realized in the conventional breeding program.

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Table 1. 2023 Yield performance of the 7 advanced Enlist-E3® lines developed from the Backcross Program at the University of Arkansas System Division of Agriculture's Soybean Breeding Program.

Line	MG[a]	MAR[b]	PTR[b]	STU[b]	Avg. Yield[c]	Check Mean[d]	Xtend® CK mean[e]	Enlist® CK mean[f]
		----	(bu./ac)	----	----	----	(%)	----
R23PR-00043	4 early	58.6	62.9	83.2	68.2	107	111	103
R23PR-00100	4 early	58.9	67.2	59.4	61.9	101	105	98
R23PR-00037	4 late	60.1	63.9	84.0	69.3	109	113	104
R23PR-00068	4 late	59.7	56.1	91.8	65.7	101	105	99
R23PR-00089	4 late	55.8	67.1	72.8	65.2	107	110	104
R23PR-00035	5 early	60.8	53.9	90.9	68.5	107	111	104
R23PR-00055	5 early	68.0	59.1	83.1	72.0	111	115	108

[a] MG = Maturity group.
[b] MAR = Marianna location; PTR = Pine Tree location; STU = Stuttgart location.
[c] Avg. yield = Average yield.
[d] Check mean = Relative yield to the mean of the Enlist-E3® and Xtend® checks.
[e] Xtend CK mean = Relative yield to the mean of the reference Xtend® checks ‘AG48X9’® (Asgrow®) and ‘S49-F5X’ (Syngenta®).
[f] Enlist® CK mean = Relative yield to the mean of the reference Enlist-E3® checks ‘NK45-V9E3’ and ‘NK52-D6E3’ (Syngenta®) and ‘P48A14E’ (Pioneer®).

Table 2. Enlist® Conversion Waves conducted by the University of Arkansas System Division of Agriculture's Soybean Breeding Program.

Conversion Wave	Recurrent parents	2024 OVT[a] and USDA preliminary trials	2024 Ark. preliminary trials	2024 PROWs[b]	2024 Breeding populations
	------------------------------(number of lines)------------------------------				
May-2020	39	7	23		
September-2020	64		137		
April-2021	253		271		
June-2022	277			900	
December-2023	26				21[c]

[a] OVT = Arkansas Official Variety Tests.

[b] PROWs = Progeny rows

[c] 26 advanced lines will be converted to Enlist® and Xtend®. However, 5 of those are already included in previous Enlist® conversion waves.

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 introduces genetically diverse germplasm with unique economically important traits into our soybean genetic pool to develop and release cultivars and germplasm adapted to Arkansas. In 2023, R18-14147 was released as a high-yielding, maturity group 4 germplasm line derived from genetically diverse parental lines. A total of 2 pre-commercial lines, 54 advanced lines, and 613 preliminary lines with genetically diverse pedigrees were evaluated for grain yield and agronomic traits in multiple Arkansas locations. In addition, 14,310 $F_{4:5}$ progeny rows derived from 130 bi-parental populations were visually evaluated for grain yield and uniformity at the University of Arkansas System Division of Agriculture's Vegetable Research Station in Kibler, Ark. Nearly 2,000 rows were derived from genetically diverse parental lines. Around 200 diverse lines were selected for 2024 preliminary yield tests. Numerous F_1 to F_4 breeding populations were advanced at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark., and in an off-season nursery in Puerto Rico. In addition, 41 genetically diverse parental lines were used to conduct new crosses in the summer of 2023. All these breeding efforts contribute to enhancing the diversity of our Arkansas soybean gene pool and lead to the development of elite soybean cultivars with desirable traits.

Introduction

Soybean [*Glycine max* (L.) Merr.] has a narrow genetic base with about half of the genetic diversity lost during domestication due to intense plant breeding (Zhou et al., 2015) coupled with the extensive use of only a few plant introductions as parental lines (Gizlice et al., 1994). In the Southern United States, 17 ancestors contributed to over 90% of the genes in cultivars adapted to this growing region (Vieira and Chen, 2021), making imperative the introduction of genetically diverse materials to improve key economically important traits such as grain yield and composition, as well as biotic and abiotic stressors tolerance. A vigorous soybean germplasm exchange system is in place among public soybean breeding programs in the United States. In addition, the United States Department of Agriculture (USDA) Soybean Germplasm Collection is a comprehensive source of exotic germplasm as it collects, curates, and distributes over 21,000 soybean accessions to breeders and researchers. Through these germplasm exchanges and subsequent breeding efforts, exotic genes are introduced into elite germplasm, thus enhancing the genetic diversity of upcoming commercial soybean cultivars.

The soybean breeding program at the University of Arkansas System Division of Agriculture has been steadily introducing diverse exotic genes into Arkansas elite soybean lines to develop cultivars and germplasm with desirable genetic traits such as high grain yield, early maturity, broad disease resistance, and local adaptation. Since 2007, the program has developed and released 11 elite germplasm lines with diverse genes and traits; R01-416F, R01-581F, R99-1613F, R01-2731F, R01-3474F, R10-5086, R11-6870 R10-2436, R10-2710, R14-1422, and R16-45 (Chen et al., 2007 and 2011; Manjarrez-Sandoval et al., 2018 and 2020; Ravelombola et al., 2023; Wu et al., 2024). These releases have been used as crossing parents for different soybean breeding programs to enhance genetic diversity. Funds provided by this project aim to broaden the genetic basis of the University of Arkansas System Division of Agriculture's Soybean Breeding Program by developing breeding populations derived from the genetics from other regions and historical cultivars/landraces from the USDA Soybean Germplasm Collection. Herein, we report the efforts made under this project in 2023.

Procedures

To diversify and improve Arkansas germplasm, 84 elite parental lines across maturity groups (MGs) 3 and 4 were entered in our crossing block at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark., in 2023. From these, 41 lines came from other breeding programs and carried economically important traits (biotic and abiotic stressors and seed composition). A total of 150 crossing com-

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binations were completed during the summer. F_1 seeds were harvested and sent to an off-season nursery in Puerto Rico for generation advancement and will return to Arkansas in 2025 as $F_{4:5}$ progeny rows. Breeding populations were advanced from F_1 to F_4 in an off-season nursery and Fayetteville, Ark., using the modified single-pod descent method (Fehr, 1987). Single plants were pulled and individually threshed from F_4 populations to grow progeny rows in 2024. In addition, roughly 7% of the 2023 progeny rows were selected based on overall agronomic traits for multi-environment yield evaluation in 2024 preliminary trials. Similarly, lines in advanced, pre-commercial, and regional trials were evaluated across multiple locations in 2023. Based on performance, 24 high-yielding lines across MG 4 (17 lines) and 5 (7 lines) with genetically and/or geographically diverse parental lines were selected for evaluation in the 2024 Soybean Official Variety Trials (OVT) and the USDA Southern Uniform Trials.

Results and Discussion

In 2023, the Arkansas Soybean Breeding Program released R18-14147, a conventional, indeterminate, maturity group (MG) 4-mid (relative maturity 4.6), high-yielding soybean germplasm with high seed protein content (37.5% on a 13% basis) and resistance to stem canker (caused by *Diaporthe phaseolorum var. merdionalis*). This cultivar is derived from the genetically diverse parental lines LG10-3671-1 and R09-430.

In 2023, 24 high-yielding lines across MGs 4 (17 lines) and 5 (7 lines) with genetically and/or geographically diverse parental lines were advanced to the 2024 regional trials (USDA Southern Uniform Trials and the Soybean Official Variety Trials) based on their multi-environment yield performance (66.2 to 79.3 bu./ac; 89.6% to 108.7% relative yield to the commercial checks, respectively) in our 2-replicate pre-commercial tests grown in Marianna, Pinetree, Rohwer, Stuttgart, DeWitt, and Fisk. These 24 lines are undergoing conversion to both Enlist-E3® (Pioneer; resistance to 2,4-D choline, glyphosate, and glufosinate) and XtendFlex® (Monsanto Company; resistance to glyphosate, glufosinate, and dicamba) herbicide resistance backgrounds.

In 2023, 300 $F_{4:5}$ breeding lines derived from exotic and/or genetically diverse parents were evaluated for yield in our 2-replicate preliminary trials grown in Marianna, Pinetree, and Stuttgart, Ark. Out of these, 39 were selected to be entered into 2024 advanced yield trials in 5 locations with 2 replications. Pending satisfactory performance, these materials will be moved to 2025 regional trials and will be entered into our herbicide resistance conversion program.

A total of 14,310 $F_{4:5}$ progeny rows derived from 130 bi-parental populations were grown in Kibler, Ark., in 2023. Nearly 2,000 rows were derived from genetically diverse parental lines. A total of 972 rows derived from 96 bi-parental populations were selected for preliminary yield evaluation in 2024 in 3 Arkansas locations with 2 replications. Seed composition will be determined via near-infrared spectroscopy (NIR), and the whole set will also be grown under greenhouse conditions for genotyping with a proprietary molecular marker panel for multiple diseases and abiotic tolerance, as well as with a genome-wide marker panel for genomic prediction in collaboration with the USDA in 2024.

In 2023, 84 elite parental lines were entered in our summer crossing block, with 41 of them being genetically and/or geographically diverse lines carrying economically important traits (biotic and abiotic stressors and seed composition), which were added to diversify and improve Arkansas germplasm. Exotic lines were obtained from other public breeding programs and crossed to elite Arkansas cultivars in Fayetteville, Ark. The F_1 seeds from 150 crossing combinations were harvested in the Fall and sent to an off-season nursery for generation advancement. Populations will return to Arkansas as $F_{4:5}$ progeny rows in 2025. In addition, breeding populations were advanced from F_1 to F_4 generations in Fayetteville, Ark., and the off-season nursery using the modified single-pod descent method (Fehr, 1987). The $F_{4:5}$ progeny rows will be grown in Arkansas in the 2024 growing season.

A total of 1,100 breeding lines were genotyped with a genome-wide marker panel for genomic prediction in collaboration with the USDA, as well as with a proprietary molecular marker panel for multiple diseases and abiotic tolerance. In addition, foliar tissue samples of 1,000 $F_{4:5}$ progeny rows were collected and DNA was extracted. Samples were sent to a USDA laboratory for genotyping with a genome-wide marker panel for genomic prediction.

A genetically diverse panel consisting of 431 plant introductions (MG 3 to 6) was grown in 2 Ark. locations in 2023. Preliminary visual field notes were taken at the mid-reproductive stage and maturity to identify accessions with desirable agronomic traits. Genetic diversity analysis through principal components will be conducted in 2024 to identify accessions genetically distant from our materials. Lines meeting both criteria will be used as parental lines in our 2024 crossing block.

As part of the program's efforts to implement genomic prediction, the estimation of population mean and genetic variance (superior population criteria) of over 100,000 possible crossing combinations are ongoing using roughly 100 advanced lines in final and pre-commercial tests and 350 genetically diverse accessions from USDA. The populations with superior mean and genetic variance will be developed in the summer of 2024.

Practical Applications

Efforts made under this project in 2023 have contributed to making significant progress in enhancing the genetic diversity of our Arkansas soybean gene pool. The introduction of economically important traits supports the development of value-added commercial cultivars and germplasm for parental stock. Identification of genetically diverse germplasm and its subsequent introduction into our program by using a fluid germplasm exchange system among public breeding programs have resulted in our latest and upcoming releases having genetically diverse pedigrees.

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BREEDING

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

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Abstract

This study aimed to enhance soybean resistance against southern root-knot nematode (*Meloidogyne* spp.) (SRKN) by employing various breeding strategies and molecular screening techniques. During the summer of 2023, 74 cross-combinations incorporating SRKN-resistant parental lines were developed in the early generation breeding stage (EG1) at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark. during the summer of 2023. Early-generation seeds (EG1) and sixteen (EG2) populations derived from SRKN-resistant parents are being advanced at Puerto Rico's off-season nursery. Additionally, Molecular marker screening was conducted on 1344 genotypes to identify breeding lines resistant to SRKN, encompassing all stages of the 2023 yield trials. As a result, 4 maturity group (MG) 5 soybean lines (R21KB-06852, R21KB-03657, R21KB-05522, and R19-45980) exhibiting the SRKN-resistant allele were identified. R19-45980 showed promising performance in the 2023 Arkansas Crop Variety Improvement Program and is a potential commercial release in 2025. Additionally, R22KB-02812, maturity group (MG) 4 late, and R22KB-16609 (MG 4 early) were identified with the SRKN-resistant allele and will be tested in the multi-environment 2024 final yield trials. Furthermore, these two will undergo a backcross program to introgress the herbicide resistance traits Enlist-E3® and XtendFlex®. Finally, to explore new sources of SRKN resistance, a genomic-based prediction model was applied to more than 10,000 plant introductions (PIs) from MGs 2 to 4, and twenty-six PIs were predicted to be resistant. These findings highlight the progress in developing SRKN-resistant soybean lines and expanding the genetic diversity of resistance.

Introduction

Root-knot nematodes (*Meloidogyne* spp.) (RKN) stand out as one of the most economically damaging plant parasites worldwide, especially in soybean [*Glycine max* (L.) Merr.] producing regions where nematode infestations are endemic (Gorny et al., 2021). Despite there being over 100 species globally (RKN) (Hunt and Handoo, 2009), only a handful pose a significant threat to soybean production. Among these, the southern root-knot nematode (*Meloidogyne incognita* Kofoid and White, 1919) (SRKN) is the primary nematode impacting soybean and cotton production in Arkansas (Faske et al., 2018; Kirkpatrick et al., 2016). Ye et al. (2019) evaluated SRKN presence in samples collected from 39 counties across Arkansas. It was found that SRKN was the sole nematode detected in 95% of the samples analyzed. While substantial losses have been noted in soybean production linked to SRKN damage, there remains a scarcity of information concerning the specific extent of losses attributable to this nematode (Kirkpatrick, 2015). Controlling SRKN presents unique challenges due to their adaptability and ability to circumvent host plant defenses, infecting plants, and overcoming their defense mechanisms (Castagnone-Sereno, 2002). Their short life cycle and broad adaptation to various host plants further complicate control efforts (Trudgill and Block, 2001). Compounding the issue, the rotational management of cultivars becomes impractical due to SRKN's ability to establish infection and feeding sites on a vast array of cultivated crops (Hines, 2012). Furthermore, environmental and human health concerns often restrict chemical controls like the fumigant methyl bromide (Desaeger et al., 2020). Therefore, genetic resistance becomes a critical option for controlling nematode populations. Developing SRKN-resistant soybean varieties is the most efficient approach to mitigate the damages inflicted on soybean production and subsequent losses (Canella Vieira et al., 2021). Hence, the University of Arkansas System Division of Agriculture's Soybean Breeding program is dedicated to developing and releasing high-yielding varieties resistant to SRKN for the benefit of Arkansas growers.

Procedures

Early Generation

Plant introductions (PIs) and breeding lines from various breeding programs known for their SRKN resistance were included in the 2023 crossing block to develop breeding populations with resistance to SRKN. A total of 23 parents possessing the SRKN trait were used for this purpose. Seventy-four cross-combinations with at least 1 parental line carrying resistance to SRKN were performed at the University

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of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center (SAREC) in Fayetteville, Ark., during the crossing block in the summer of 2023. After true cross-evaluation, wherein materials undergo thorough screening to ascertain suitable cross-hybridization and eliminate self-pollinated materials, early generation (EG1) seeds were sent for generation advancement to Puerto Rico's off-season nursery. Additionally, 16 populations (EG2) derived from SRKN-resistant parents are being advanced at Puerto Rico's off-season nursery.

Yield Trials and SRKN Screening

A comprehensive molecular screening was conducted on all Arkansas breeding lines entered in the 2023 yield trials, spanning preliminary, final, and pre-commercial stages, to identify resistance to SRKN. Leaf tissue collection was conducted on a total of 1344 lines, after which DNA isolation was performed using the hexadecyltrimethylammonium bromide (CTAB) protocol (Doyle and Doyle, 1987). Subsequently, the samples were assessed for the presence of the *Gm10-1232205* allele associated with the single nucleotide polymorphism (SNP) *SS715605561* previously linked to resistance against SRKN (Canella Vieira et al., 2022).

2023 Pre-Commercial Lines

In addition to the molecular marker screening, a total of 28 high-yielding advanced pre-commercial lines were screened for SRKN under field conditions. The galling score was performed in August by the pathology group at the University of Arkansas System Division of Agriculture's Lonoke Extension Center. Each entry was planted in 11-foot, single-row plots with 4 replications. Three plants from each plot were sampled on 30 Aug. and rated for the percentage of root system with galling. Response to SRKN was based on the percentage (%) of root system galled, whereas 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.

Expanding Genetic Diversity

To expand the genetic diversity and discover novel genetic resistance against SRKN, the resistance to SRKN of a large selection of 10,225 PIs from MG 1 to MG 4 was predicted. A genomic-based prediction model was applied to the PIs based on galling response (1–5 scale) and nematode resistance (categorical response including Resistant, Moderate, and Susceptible). The complete methodology is described by Canella Vieira et al., 2022. Identified materials showing low predicted galling scores and/or resistant categories will have their resistance confirmed in field and greenhouse screenings in 2024.

Results and Discussion

Early Generation

The EG1 materials are currently advancing in the off-season nursery and will continue to grow there until 2025, when they will be brought back for evaluation as $F_{4:5}$ progeny rows. In Puerto Rico's off-season nursery, a total of 1,600 single plant selections derived from SRKN-resistant parents will be hand-harvested and individually threshed. These $F_{4:5}$ lines will be planted as progeny rows in Kibler, Ark., for the 2024 growing season. Throughout this period, the breeder's evaluation will focus on overall plant architecture, including pod load, lodging, and height. Selected lines will undergo molecular screening for SRKN resistance, and those meeting the criteria will advance to the 2025 preliminary yield trials.

Multi-Location Yield Trails

Following the molecular screening of the 1344 evaluated lines, 40 materials (approximately 3%) spanning all stages of the yield trials were identified as possessing the SRKN resistance trait. This screen marks a significant effort in introducing novel genetic materials resistant to SRKN, which is particularly noteworthy given the current absence of resistance in our breeding materials. In the advanced stages, 4 MG 5 lines—R21KB-06852, R21KB-03657, R21KB-05522, and R19-45980—were identified as having the SRKN-resistant allele. These lines will be tested in the 2024 USDA Southern Uniform Yield trials, the 2024 Arkansas Crop Variety Improvement Program, and our internal multi-environment 2024 pre-commercial yield trials. Moreover, line R19-45980 is a potential 2025 commercial release yielding 100.5% of the test mean in the 2023 Arkansas Crop Variety Improvement Program. It will enter the second year of evaluation in 2024, and pre-foundation seeds will be produced in 2024. Lines R22KB-02812 (MG 4L) and R22KB-16609 (MG 4E) were identified as having the resistant SRKN allele and will be tested in the multi-location 2024 final yield trials. These 6 SRKN-resistant advanced lines are undergoing herbicide resistance introgression into our backcross program. This strategic step aims to incorporate the traits Enlist-E3® (Pioneer; resistance to 2,4-D choline, glyphosate, and glufosinate) and XtendFlex® (Monsanto Company; resistance to glyphosate, glufosinate, and dicamba), facilitating the production of SRKN-resistant lines coupled with the herbicide resistance technology vital for growers. Finally, out of the 14,310 progeny rows assessed during the 2023 season, 972 lines were chosen for evaluation in the preliminary yield trails across Arkansas. Also, samples will undergo genotypic screening for SRKN resistance during the 2024 seasons, and subject to performance, selected lines may progress to the 2025 Finals Stage.

SRKN Field Screening

Field screening evaluating the percentage of root system galled identified 3 lines as SRKN resistant (1.1%–4.0%), 4 lines as moderately resistant (4.1%–9.0%), and 7 lines as moderately susceptible (9.1%–20%) (Table 1). Nine lines were advanced into the 2024 USDA uniform yield trails; lines R19C-1012 and R19-45980 were identified as moderately resistant to SRKN.

Genetic Diversity

A total of 26 PIs from MG 1, 2, and 4, originating from various regions, including the United States, Russia, Japan, South Korea, and China, were predicted to be resistant to SRKN. In addition, to explore alternative sources of resistance, 500 lines with predicted low galling scores and lacking the presence of the major SRKN resistance allele were selected for a principal component analysis (PCA) to identify genetically diverse lines with low galling scores. As a result, an additional 10 lines were identified, and seeds from the selected PIs were requested at the Germplasm Resources Information Network (GRIN). These materials will be screened for SRKN resistance during Spring 2024 in Hope, Ark.

Practical Applications

Efforts to counteract the detrimental effects of SRKN involve the development of resistant, high-yielding conventional and herbicide-resistant soybean lines that are well-suited to the Arkansas environment. By doing so, the damages inflicted by SRKN are mitigated, and the promotion of genetic diversity is also facilitated. This diversity serves as a crucial foundation for ongoing advancements in our breeding program, ensuring the continual development of resistant soybean varieties tailored to the specific needs of Arkansas farmers.

Integrating herbicide-resistant traits into these lines provides Arkansas growers with flexibility in regards to their weed management strategies. This not only enhances the resilience of soybean crops against SRKN but also streamlines weed management practices, contributing to improved overall crop health and yield stability. Thus, developing such resistant lines with herbicide resistance traits not only provides a viable strategy for combating SRKN but also underscores the commitment of agricultural research initiatives to empower farmers in effectively navigating pest pressures and optimizing soybean production in Arkansas.

Acknowledgments

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Table 1. Molecular and phenotypic response to southern root-knot nematode (*Meloidogyne* spp.) (SRKN) of 2023 pre-commercial soybean entries.

Line	MG	Root system galled[a] (%)	2024 Plans	SRKN Allele
R19C-1012	4E	6.8	Tentative 2024 release	S
R18C-13665	4L	30.1	Tentative 2024 release	S
R19C-1035	4E	15.8	24 USDA	S
R19-45980	5E	8.3	24 USDA	R
R19C-1081	4E	23.9	24 USDA	S
R19C-1001	4L	18.5	24 USDA	S
R19-42447b	5E	52.9	24 USDA	S
R19-4593	5E	34.8	24 USDA	S
R19-46252	5E	31.1	24 USDA	S
R19C-2678	4L	3.8	Crossing Block	R
R18-10919	5E	3.9	Crossing Block	R
R19-43217	5E	3.4	Crossing Block	R
R18CR-80:0005	5M	4.2	Crossing Block	R
R19-39415	4L	17.9	Discontinued	S
R19C-3147	4L	8.4	Discontinued	S
R19-39444	4L	46.0	Discontinued	S
R19-411424	5E	25.9	Discontinued	S
R18CR-83:0004	5E	16.7	Discontinued	S
R18CR-144:0005	5E	23.8	Discontinued	R
R18CR-328:0005	5E	7.9	Discontinued	S
R18-10491	5E	36.7	Discontinued	S
R19C-3194	5E	15.3	Discontinued	S
R19C-3085	5E	46.9	Discontinued	S
R19-424115b	5E	31.7	Discontinued	S
R19-410712	5E	31.3	Discontinued	S
R19-42848	5E	28.1	Discontinued	S
R18CR-461:0001	5M	16.4	Discontinued	S
R18CR-287:0004	5M	17.3	Discontinued	S
DG49XF29 (S-CK)[b]		20.8	-	-
P43A42X (R-CK)[b]		0.3	-	-

[a] SRKN susceptibility was based on % root system galled whereas 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. MG = maturity group.

[b] S-CK = susceptible check; R-CK = resistant check.

BREEDING

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 is dedicated to developing high-yielding, stress-resilient soybean cultivars tailored to the needs of Arkansas growers. The breeding process consists of early generation population development (EG) followed by extensive multi-environment yield trials. In the EG phase, genetic diversity is introduced by integrating materials from other breeding programs and utilizing plant introductions (PI). Promising candidates are identified for advancement through meticulous selection based on genetic and plant architecture traits. Molecular marker testing is employed to identify and maintain desired traits precisely. Selected lines undergo 3 years of replicated, multi-environment yield testing, culminating in the final and pre-commercial stages. Only the highest-performing breeding lines progress to potential commercial release, with pre-foundation seed production initiated. In 2023, extensive cross-combinations and progeny row evaluations were conducted, advancing promising lines to yield trials. Molecular markers were utilized to identify resistance to various yield-limiting stressors. The program demonstrates a comprehensive approach to soybean breeding, ensuring the development of superior cultivars tailored to the region's needs.

Introduction

Breeding programs are pivotal in developing high-yielding cultivars tailored to specific environments, providing growers with genetically superior and well-adapted genetic materials. Public breeders operate under time constraints, endeavoring to navigate various logistical challenges beyond selecting optimal materials for crossing. They must contend with weather, costs, and human resources while striving to produce materials promptly. As Vieira and Chen (2021) outlined, developing and releasing a new cultivar typically spans 4 to 6 years. The development process involves several stages in the breeding pipeline. It starts with selecting parental lines and continues with developing bi-parental breeding populations. Subsequently, 4 generations of advancement have culminated in evaluating $F_{4:5}$ plants in progeny rows, where visual selection is conducted based on overall plant architecture and agronomic traits. Following this, selected lines undergo 2 years of intense yield testing in replicated trials across multiple environments. Finally, successful lines progress to state and regional testing before being considered for commercial release.

The mission of the University of Arkansas System Division of Agriculture's Soybean Breeding Program is to serve the needs of Arkansas growers through the continual development and release of soybean cultivars highly adapted to local environments. Our program is driven by the goal of providing farmers with access to elite cultivars adapted to excel in Arkansas' unique agricultural landscape. Therefore the focus is on both conventional and herbicide-resistant cultivars.

Through years of research and breeding efforts, the program has released numerous cultivars including Lonoke (Sneller et al., 2004), Ozark (Chen et al., 2004), Osage (Chen et al., 2007), UA5612 (Chen et al., 2014a), UA5014C (Chen et al., 2016), UA5414RR, UA5615C, and UA5115C (Florez-Palacios et al., 2019). Osage and UA5612 have been extensively used as a yield check in the United States Department of Agriculture (USDA) Uniform Soybean Trials (https://www.ars.usda.gov/southeast-area/stoneville-ms/crop-genetics-research/docs/uniform-soybean-tests). In this article, we summarize the breeding effects of the 2023 breeding season and share the results and the ongoing progress in the development of maturity group (MG) 4 and 5 soybean cultivars. We aim to provide an overview of the results achieved thus far and highlight the ongoing advancements in our pursuit of developing elite soybean cultivars to meet the needs of Arkansas farmers.

Procedures

In the initial early generation population development (EG) phase, we prioritize introducing genetic diversity to enrich our program with novel traits and genetic resources. Materials are sourced from other breeding programs and integrated into new genetic resources such as plant introductions (PI) harboring unique genetic diversity. For instance, 153 new cross-combinations were developed, and more than 13,000 cross-in attempts were performed during the 2023 summer crossing season. These materials are the foundation for creating novel cross-combinations, which undergo

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systematic advancement each season. During generation advancement, breeding selections are based on genetic considerations and plant architecture attributes such as maturity, lodging, pod load, and plant height. Additionally, stringent selection processes increase each generation to identify the best candidates for breeding enhancements. To expedite the breeding process and ensure year-round progress, selected EG materials are sent to off-season nurseries, enabling off-season generation advancement to expedite the breeding pipeline process. Moreover, materials undergo molecular marker testing, facilitating the identification of crucial traits such as iron chlorosis tolerance, southern root-knot nematode (*Meloidogyne incognita*; Kofoid and White, 1919) resistance, maturity genes, among others, vital for the development of superior cultivars. This strategic use of molecular markers empowers us to precisely target trait selections, facilitating the early identification of materials possessing the desired characteristics. During the 2023 season, a total of 1,364 breeding lines encompassing all lines across all stages of the breeding pipeline were tissue sampled and evaluated with 22 molecular markers for various stressors.

Following the advancement through the EG phase, the selected $F_{4:5}$ breeding lines underwent rigorous evaluation at our Kibler, Ark. Site. During 2023, 14,310 progeny rows (PROWs) derived from 130 bi-parental populations were evaluated. Throughout the growing season, breeder selections were carried out, with visual assessments focusing on pod load, maturity, height, and overall plant architecture. For instance, in 2023, nearly 1000 PROWs exhibiting exceptional characteristics were selected for advancement into our 2024 preliminary stage, the first year of replicated, multi-environment yield testing. Following selection, the chosen lines progressed through 2 additional years of replicated, multi-location testing, namely the final and pre-commercial (PCM) stages; during the 2023 growing season, 175 and 40 lines were evaluated in each stage, respectively. Only the most promising materials are advanced each year based on their outstanding yield performance and plant adaptation.

Additionally, materials advanced to PCM will be integrated into the herbicide introgression program for the Enlist-E3® (Pioneer; resistance to 2,4-D choline, glyphosate, and glufosinate) and XtendFlex® (Monsanto Company; resistance to glyphosate, glufosinate, and dicamba) technologies. In the regional tests, which include pre-commercial (PCM) yield trials, the USDA uniform trials (USDA-UT), and the Official Arkansas Variety Testing (OVT), materials undergo a thorough evaluation, with only the highest-performing candidates selected for potential release. Chosen cultivars then undergo pre-foundation seed production in preparation for cultivar release and commercialization.

Results and Discussion

Lines R19C-1012 and R18C-13665 are potential commercial releases in 2024. They were evaluated in the 2023 USDA Preliminary Uniform Trials (UP); R19C-1012 placed 4 out of 31 in the PIV-Early test, and R18C-13665 placed 4 out of 27 in the PIV-Late test. Additionally, R19C-1012 was identified as moderately tolerant to flooding conditions at early vegetative stages. These lines will be tested for the third year in the 2024 Official Arkansas Variety Testing (OVT), the 2024 USDA Uniform (UT), and the 2024 pre-commercial internal yield trial. Also, 0.2 acres of pre-foundation seed will be grown in Stuttgart, Ark., in preparation for commercial release. In addition, R19C-1012 and R18C-13665 are being converted into Enlist-E3® and XtendFlex® herbicide-resistant backgrounds.

Nineteen lines underwent testing in the 2023 PCM Yield Trials, the USDA Uniform Yield Trials, and/or the Official Arkansas Variety Testing. Eight lines demonstrated exceptional performance and were advanced for regional evaluation in the 2024 USDA Uniform Yield Trials. Noteworthy achievements include the rankings of Lines R19C-1035, R19C-1012, and R19C-1081, securing the fourth, fifth, and eighth positions, respectively, out of a total of 31 evaluated lines (USDA UP-4 Early). These 3 lines also showed flood tolerance in the 2023 Official Arkansas Variety Testing. Additionally, line R19C-1001, assessed in the USDA UP-4 Late, claimed the sixth position among 27 lines, while SRKN-resistant line R19-45980, in the UP-5 Early, secured the third place out of 37 lines evaluated. Lines exhibiting low-yield performance have been discontinued.

Practical Applications

The program aims to empower producers with choices that cater to their specific needs while ensuring optimal productivity and profitability by providing a diverse range of cultivar options. Focusing on enhancing yield potential and economic viability, the University of Arkansas System Division of Agriculture's Soybean Breeding Program serves as a vital resource for the state's agricultural community, driving innovation and sustainability in soybean production.

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Genomic Prediction to Enhance the Efficiency of Soybean Breeding

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Abstract

The University of Arkansas System Division of Agriculture's Soybean Breeding program integrates advanced genomic tools to develop high-yield soybean cultivars for Arkansas farmers. Adopting genomic prediction (GP) is a pivotal strategy to enhance the efficiency and precision of the breeding process. Genomic prediction leverages genotypic data to predict trait performance, enabling breeders to make informed selections guided by genomic information. This project is investigating the integration of GP and cross-validation methods to optimize breeding efficiency and precision. A total of 1364 genotypes have been genotyped with the BARCSoySNP3K Illumina assay platform and simultaneously tested for grain yield across multiple Arkansas environments. The project objectives are to evaluate the predictive potential of molecular markers and compare statistical models to develop an optimized GP model to identify superior materials and genetic gain. Findings demonstrate GP's promise in identifying desirable genotypes, potentially streamlining selection processes, and minimizing reliance on extensive multi-environment field trials. This study contributes to ongoing efforts to innovate soybean breeding practices by strategically integrating genomic prediction and cross-validation techniques, paving the way for developing well-adapted, superior soybean cultivars for Arkansas farmers.

Introduction

The University of Arkansas System Division of Agriculture's Soybean Breeding program incorporates advanced genomic tools to maximize the efficiency and overall genetic gain of the soybean breeding pipeline and to develop high-yielding cultivars adapted to Arkansas. The primary challenge in developing new soybean cultivars lies in the time and cost of evaluating new genetic material across several locations for multiple years (Canella Vieira and Chen, 2021). Innovative genomic techniques are being introduced to enhance the precision and efficiency of the overall breeding process. Genomic prediction (GP) harnesses genotypic data to analyze and predict trait performance. This method allows breeders to make selections guided by genomic information, ensuring a precise and targeted approach (Lorenz et al., 2011). Genomic prediction uses genotypic and phenotypic data from a training population to predict a non-observed candidate population's genomic estimated breeding values (GEBV) relying on their genotypic information (Jannink et al., 2010). Various statistical models have been implemented for GP. Currently, there is no universally superior model for GP, and its efficacy relies primarily on the quality and structure of the dataset used in the analysis (Montesinos Lopez et al., 2022a). Moreover, individual factors such as the size of the training dataset, the number of molecular markers included as predictors, and trait heritability, among others, collectively determine the accuracy of the algorithms used in the model (Spindel et al., 2015).

Several breeding programs in the private sector have implemented GP as a regular methodology in their breeding pipeline. However, public breeding programs still face a difficult transition and implementation of GP mainly due to the lack of high-quality historical multi-environment data, the high upfront cost of genotyping, the logistics of a timely genotyping protocol, as well as the availability of well-trained individuals. The Soybean Breeding program aims to streamline the breeding pipeline by routinely implementing GP, ultimately delivering superior soybean cultivars in a more timely and cost-effective manner.

Procedures

A total of 1364 genotypes representing breeding lines across various breeding stages, including preliminary, final, and pre-commercial, were used in this study. Samples were planted in replicated randomized complete block designs in multi-location yield trials. Preliminary tests were evaluated in 3 locations (Marianna, Pine Tree, and Stuttgart), while final and pre-commercial trials were evaluated in 6 locations, including Marianna, Pine Tree, Stuttgart, Rohwer, Dewitt, and Fisk. The sampled genotypes ranged from maturity group 3 to 5, with 28.2% belonging to MG 3, 64.5% to MG 4, and 7.3% to MG 5. Leaf samples underwent DNA extraction using the hexadecyltrimethylammonium bromide (CTAB) protocol (Doyle and Doyle, 1987) at the University of Arkansas System Division of Agriculture's Soybean Breeding Lab before being dispatched to the USDA Soybean Genomics and

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Improvement Laboratory. Genotyping was completed with the Soy3KSNP Bead Chip derived from the BARCSoySNP6K assay (Song et al., 2020).

The phenotypes for each line in each environment were adjusted using the Best Linear Unbiased Estimators (BLUEs) from single-environment trial models to account for spatial variation. In this model, genotype was included as a fixed effect, and the experiment (test name), the experiment × genotype interaction, the effect of block (replication) nested within experiments, and the effect of columns and rows nested within experiments were included as random effects.

Cross-Validation Schemes

Genomic prediction studies often conduct cross-validation (CV) using 2 independent datasets, i.e., the training and validation populations. The training population (TP) is used to train the models and estimate the effects of single nucleotide polymorphisms (SNPs), and a validation population (VP) is used to validate the predictions and check their predictive ability.

The CV0 scheme predicted the performance of observed individuals (i.e., phenotyped for a specific trait) in an unknown location, where all phenotypic data from one location was used as the validation set, and the remaining locations were used as the training set until all the locations were used as the validation set. The CV1 predicted the performance of unknown individuals in observed locations (i.e., locations where phenotypic data has been collected), where five partitions were randomly sampled, and each partition was used as the validation set and the others as the training set until each partition was used as the validation set. The CV2 predicted the performance of observed individuals in observed locations, with some individual-location combinations masked. This procedure was done for 5 different partitions; each partition was once used as the validation set, and the remaining partitions were used as the training set. Each CV scheme was run at 10 different replications, and the predictive ability among replications was averaged to evaluate the performance of the models.

SNP Importance Estimation and Ranking

This study employed an additional independent set other than training and validation sets to estimate the importance of each SNP. This was done to analyze how progressively including the most important SNPs would affect the predictive ability of the validation set. After estimating the importance of each SNP, they were ranked from the most important to the least important.

We employed different methods to estimate the importance of SNPs and rank them as follows: Permutation, Genome-Wide Association Studies (GWAS), Minimax Concave penalty (MPC), and Random. The Permutation importance (Breiman, 2001) ranked the SNPs based on their contribution to the model performance. The GWAS-based importance ranked the SNPs based on the p-values calculations and was adjusted by the R package GAPIT 3 (Wang, 2021) with the multiple loci method BLINK (Huang, 2019) using 3 principal components. The MCP-based importance ranked the SNPs by calculating the marginal false discovery rates (mFDR). The Random method ranked the SNPs in a random order and was used as a baseline to compare the other methods.

Genomic Prediction Models

After ranking the SNPs based on their importance and using the BLUEs as the response variable, different GP models were adjusted, including one SNP at a time, starting from the most important until the least important SNP was used. Specifically, the models used were Partial Least Squares (PLS), Random Forest (RF), and Ridge Regression Best Linear Unbiased Prediction (rrBLUP), with the SNPs being used as the covariates. All the models included the environment variable as a fixed effect.

The PLS model (Wold, 1966) is used to deal with the problem of having a much larger number of covariates than the number of observations. Thus, it is suitable for GP because the number of SNPs is usually larger than the number of phenotyped lines. The PLS model iteratively seeks the best transformation of the covariates and the response variable that maximizes the covariance between them. More details about PLS applied to GP can be seen in Montesinos-López (2022b). The Random Forest model (Breiman, 2001) works by constructing many decision trees and averaging their predictions to improve prediction accuracy. The rrBLUP model (Endelman, 2011) is a regression method that shrinks the effects of some SNPs using a penalty parameter. Unlike the usual ordinary least squares (OLS) regression method, rrBLUP can be used even when the number of SNPs is larger than the number of observations.

Results and Discussion

For the CV0 scheme, all the GP models exhibited similar trends, with predictive ability increasing as more SNPs were incorporated until it reached a plateau when using a significant number of SNPs (around 1500 for PLS, 1200 for RF, and 2000 for rrBLUP). Among all models, RF showed the best mean predictive ability of 0.48 using the MCP ranker method with 1216 SNPs (Fig. 1). In the CV1 scenario, the PLS and RF models exhibit a declining trend after including a small subset of SNPs (around 250 for PLS and 170 for RF). Conversely, rrBLUP demonstrated an improvement by including more SNPs in the model. The RF demonstrated the highest mean predictive ability of 0.75 using the GWAS ranker method with 168 SNPs (Fig. 1). In the CV2 scheme, a similar trend was observed, with both PLS and RF demonstrating a decrease in performance after reaching a small number of SNPs (around 260 for PLS and 65 for RF). In contrast, rrBLUP showed a performance improvement by including significantly more SNPs compared to PLS and RF. Remarkably, the RF model showed the best performance, reaching 0.78 when using the GWAS ranker method with 63 SNPs (Fig. 1).

In general, across the 3 models evaluated and CVs, all the ranker methods outperformed the Random ranker, which arranges SNPs in random order. Also, it is important to highlight that the mean predictive ability does not begin at zero when using a single SNP, as the location was consistently factored in as a fixed effect across all models (Fig. 1).

Practical Applications

Incorporating GP into our soybean breeding pipeline promises to elevate both the accuracy and efficiency of our breeding selections. This study serves as a pivotal first step toward developing a precise GP model optimized for our breeding program's specific genetics and necessities. By evaluating 3 distinct models and pinpointing the optimal number of SNPs, we lay the foundation for further improvement of our statistical model. This iterative process will empower us to harness GP effectively, enabling us to pinpoint superior genotypes with heightened precision. However, the models and algorithms used need further evaluation and testing. We remain committed to exploring innovative strategies for genetic enhancement and integrating them into our existing breeding pipeline.

Acknowledgments

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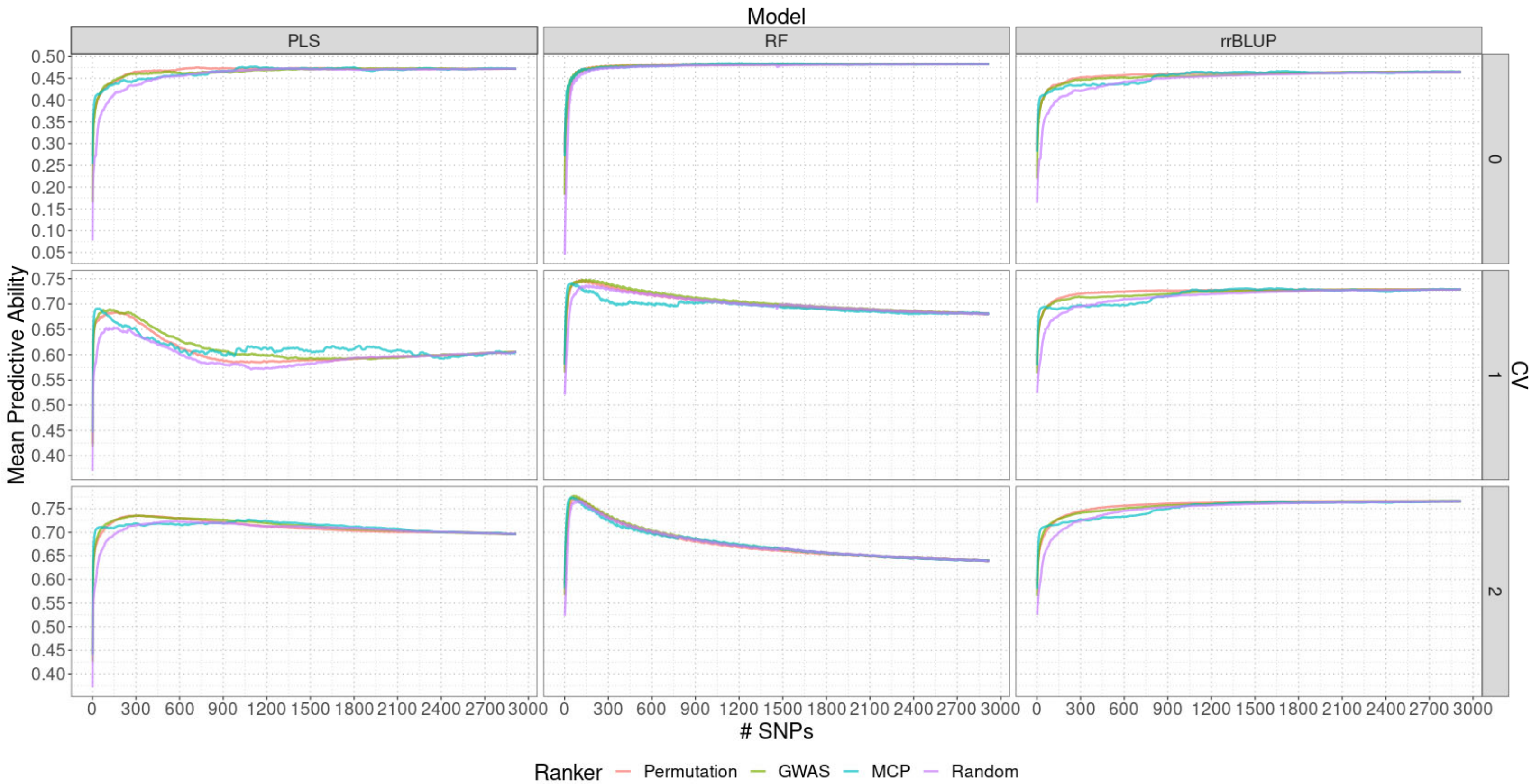

Fig. 1. Mean predictive ability for each cross-validation scheme and genomic prediction model across five folds and 10 repetitions. The x-axis represents the number of single nucleotide polymorphisms (SNPs) used in the model. Lines with different colors represent the different ranker methods used to rank the SNPs from more important to least important. PLS = Partial Least Squares, RF = Random Forest, and rrBLUP = Ridge Regression Best Linear Unbiased Prediction.

Determining the Impact of Variety and Fungicides on Post-Harvest Grain Quality, 2023

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Abstract

Soybean grain quality evaluations were assessed in 127 varieties. Diseases on grain were minimal this year, although some differences did appear in certain varieties. Diseases observed were frogeye leaf spot, soybean virus complex, purple seed stain, and Phomopsis seed decay. Insect damage and unaffected grains were observed as well. Insect pressure was good, averaging 17.7% damaged grains across all varieties. Grains with no visual defects ranged from 10.2% to 69.5%.

Introduction

Seed quality can be impacted significantly by insect damage or by diseases caused by plant pathogens (Rupe and Luttrell, 2008). Multiple insect species are commonly observed in Arkansas soybean production, where both adults and nymphs feed on soybean pods and grain. These insects feeding on pre-mature grain can cause yield loss by initiating pod and/or seed abortions, as well as seed size reduction. Quality reduction is also caused by digestive fluids entering seed during insect feeding, leading to deterioration and discoloration of the seed. (Lorenz et al., 2000) These wounds created by actively feeding insects can also create opportunities for pathogens to colonize and reproduce.

Common soybean fungal diseases impacting seed include purple seed stain (PSS), Phomopsis seed decay (PSD), Frogeye leaf spot (FLS), and soybean viral complex (SVC). 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 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 grain, reducing quality (Telenko, 2019) (Fig. 3). Soybean viral complex is composed of soybean mosaic virus and bean leaf beetle viruses. These viruses are vectored in by aphids and leaf-feeding beetles, respectively. When these 2 viruses appear on the same plant, a synergistic effect is created. The symptoms of these viruses on grain are mottling (often referred to as a bleeding hilum) and require laboratory tests to determine its presence and differentiate between the two (Fig. 4). (Mueller et al., 2016)

Procedures

A variety trial was planned on 30 June at the University of Arkansas System Division of Agriculture's Rohwer Research Station. The trial was arranged in a randomized complete block design on 38-in. row spacings with plots measuring 10-ft long and 2 rows wide and planted at 110,000 seed/ac. The trial was separated into Roundup Ready® Xtend® and non-Xtend® groups and then further divided into smaller groups by maturity between 8 and 18 varieties for statistical purposes. One hundred twenty-seven varieties were evaluated, containing 83 Xtend and 44 non-Xtend. The test was replicated 3 times and harvested on 23 Oct. Seed samples were collected from the combine mid-plot at harvest in plastic bags, labeled, and transported to the Monticello laboratory for evaluation. Grain was rated for FLS, PSD, PSS, and SVC diseases on a percentage scale. In addition, the grain was also rated for percentages of insect damage, and grain with no visual defects (normal) were recorded. All data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Tukey's honest significant difference (HSD) at $P = 0.05$.

Results and Discussion

Among the non-Xtend varieties in maturity groups (MG) 4.2–4.6, differences were observed in percent normal, SVC, and PSD levels. These and non-significant (NS) data can be viewed in Table 1. Percent normal and PSS grains contained differences in MG 4.7–4.8 (Table 2). Differences in FLS were observed in MG 4.9–5.1 and averaged 1% or less (Table 3). Purple seed stain averaged 5.3% or less in MG 5.2–5.4 and was the only variable with differences (Table 4).

The Xtend varieties had differences in the percentage of normal grains in MG 4.2–4.5 (Table 5), while MG 4.6 had none (Table 6). Maturity group 4.7 had differences in percent

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normal and percent insect-damaged grains (Table 7). Differences were not observed in MG 4.8 (Table 8). Table 9 shows MG 4.9–5.0 had differences in percent normal and percent PSD grains, while Table 10 shows MG 5.2–5.8 having differences in the same variables.

Across all MG, the average FLS and SVC was less than 0.5%, PSS averaged 1.5%, and PSD averaged 2.4%. Disease on grain this year was minimal; however, with percent diseased grain averaging 4.9, the percent insect damage at 17.7%, and the percent normal grains only averaging 52.4%, that leaves 25% damage due to other causes.

Practical Applications

The data presented can be useful for choosing varieties that may be included here. Varieties with higher percentages of 'normal' seed (those without visual defects) may be chosen to possibly reduce dockage at the elevators. Likewise, varieties with lower insect damage percentages may be chosen for the same reason.

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Fig. 1. Soybean seed exhibiting purple seed stain.

Fig. 2. Soybean seed exhibiting Phomopsis seed decay.

Figure 3. Soybean seed exhibiting Frogeye leaf spot.

Fig. 4. Soybean seed exhibiting soybean virus complex.

Table 1. Percent disease, insect, and normal percentages on soybean grain from a non-Xtend® variety trial including maturity groups 4.2–4.6 at the University of Arkansas System Division of Agriculture's Rohwer Research Station in 2023.

Variety	Normal†	FLS	SVC	PSS	PSD	Insect
	------(%)------					
DELTA GROW 46E10	47.0 ab‡	0.7	0.2 b	0.2	4.4 ab	10.0
DELTA GROW 46E30	43.5 abc	0.0	0.0 b	1.0	2.7 ab	19.4
INNOTECH 4233E3S	54.8 a	0.2	0.5 b	2.6	1.4 ab	11.0
INNOTECH 4545E3S	33.3 bc	0.0	0.0 b	1.6	4.0 ab	11.0
INNVICTIS B4603E	37.4 bc	0.0	0.4 b	2.6	4.8 ab	15.3
NK42-A6E3S	29.4 c	0.3	0.5 b	4.6	3.9 ab	13.1
NK44-Q5E3S	45.1 abc	0.4	0.0 b	2.8	5.0 a	6.5
R19C-1012	47.0 ab	0.9	3.2 ab	1.4	0.6 ab	13.2
R19C-1035	46.3 ab	0.3	0.0 b	2.2	3.1 ab	19.8
R19C-1081	42.9 abc	0.0	0.0 b	2.9	2.5 ab	11.1
S19-10701	48.6 ab	0.0	4.0 a	0.9	0.3 b	12.3
Tukey's HSD *P* = 0.05	16.89	2.23	3.29	4.77	4.56	16.97
Standard Deviation	5.61	0.45	1.10	1.60	1.53	5.6
Grand Mean	43.21	0.26	0.80	2.08	2.97	12.9

†Normal = grain without visual defects, FLS = frogeye leaf spot, SVC = soybean virus complex, PSS = purple seed stain, PSD = Phomopsis seed decay, Insect = Insect damaged grains.

‡Columns followed by the same letter, or no letters are not significantly different according to Tukey's Honestly Significant Difference (HSD) at *P* = 0.05.

Table 2. Percent disease, insect, and normal percentages on soybean grain from a non-Xtend® variety trial including maturity groups 4.7–4.8 at the University of Arkansas System Division of Agriculture's Rohwer Research Station in 2023.

Variety	Normal†	FLS	SVC	PSS	PSD	Insect
	------(%)------					
DELTA GROW 47E20/STS	65.1 ab‡	0.0	0.0	1.8 ab	1.1	1.1
DELTA GROW 48E59	47.8 b	0.2	0.2	6.1 a	1.7	1.7
PROGENY P4775E3S	62.0 ab	0.2	0.0	2.2 ab	0.9	0.9
PROGENY P4850E3	60.4 ab	0.2	0.0	4.2 ab	1.8	1.8
R19-39415	48.8 b	0.7	0.4	2.1 ab	0.5	0.5
R19-39444	69.5 a	0.2	0.0	0.3 b	0.7	0.7
R19C-2678	54.3 ab	0.5	0.0	2.8 ab	0.6	0.6
S17-17644	65.0 ab	0.2	0.0	1.4 ab	1.3	1.3
Tukey's HSD *P* = 0.05	19.22	1.19	0.91	5.28	2.45	2.45
Standard Deviation	6.67	0.41	0.32	1.83	0.85	0.85
Grand Mean	59.11	0.28	0.08	2.61	1.06	1.06

†Normal = grain without visual defects, FLS = frogeye leaf spot, SVC = soybean virus complex, PSS = purple seed stain, PSD = Phomopsis seed decay, Insect = Insect damaged grains.

‡Columns followed by the same letter, or no letters are not significantly different according to Tukey's Honestly Significant Difference (HSD) at *P* = 0.05.

Table 3. Percent disease, insect, and normal percentages on soybean grain from a non-Xtend® variety trial including maturity groups 4.9–5.1 at the University of Arkansas System Division of Agriculture's Rohwer Research Station in 2023.

Variety	Normal[†]	FLS	SVC	PSS	PSD	Insect
	-----------	-----------	-----------	(%)	-----------	-----------
DELTA GROW 49E30/STS	58.3	0.0 b[‡]	0.5	1.1	0.6	20.4
INNOTECH 4983E3S	51.6	0.0 b	0.2	2.9	1.9	25.1
INNVICTIS B4903E	48.8	0.0 b	0.0	3.7	4.8	16.5
INNVICTIS B5013E	51.8	0.0 b	0.6	2.9	0.2	24.0
NK49-T6E3S	48.0	0.0 b	0.0	3.8	2.3	24.8
PROGENY P4999E3S	56.8	0.0 b	0.0	1.2	1.0	19.9
R18C-13665	66.7	0.2 ab	0.0	0.2	0.2	14.2
R19C-1001	52.5	0.2 ab	0.0	1.2	0.4	16.1
R19C-3085	54.4	1.00 a	0.0	1.9	2.5	14.7
R19C-3147	52.1	0.0 b	0.0	0.5	0.7	25.7
REVERE 5143E3	44.6	0.2 ab	0.0	4.0	2.7	16.8
Tukey's HSD *P* = 0.05	23.37	1.00	0.91	5.09	2.17	24.37
Standard Deviation	7.93	0.34	0.31	1.73	1.75	8.26
Grand Mean	53.23	0.15	0.11	1.58	1.58	19.85

[†]Normal = grain without visual defects, FLS = frogeye leaf spot, SVC = soybean virus complex, PSS = purple seed stain, PSD = Phomopsis seed decay, Insect = Insect damaged grains.
[‡]Columns followed by the same letter, or no letters are not significantly different according to Tukey's Honestly Significant Difference (HSD) at *P* = 0.05.

Table 4. Percent disease, insect, and normal percentages on soybean grain from a non-Xtend® variety trial including maturity groups 5.2–5.4 at the University of Arkansas System Division of Agriculture's Rohwer Research Station in 2023.

Variety	Normal[†]	FLS	SVC	PSS	PSD	Insect
	-----------	-----------	-----------	(%)	-----------	-----------
NK52-D6E3	48.6	0.0	0.3	5.3 a[‡]	1.5	21.1
R18-10491	67.6	0.0	0.0	1.9 ab	0.9	11.9
R18-10919	58.6	0.2	0.2	1.1 ab	0.2	24.4
R19-410712	68.9	0.2	0.0	0.0 b	0.5	20.5
R19-411424	66.1	0.0	0.0	1.6 ab	0.2	14.9
R19-424115B	57.5	0.0	0.0	0.4 b	0.6	29.4
R19-42447B	64.3	0.0	0.0	0.6 b	0.0	20.4
R19-4593	61.8	0.0	0.0	1.6 ab	0.6	16.6
R19-45980	60.2	0.0	0.0	1.8 ab	0.2	19.1
R19-46252	67.0	0.0	0.2	1.6 ab	0.6	15.0
R19C-3194	44.6	0.0	0.2	1.8 ab	0.9	29.8
S18-6328	64.5	0.0	0.0	3.4 ab	1.7	16.2
S18-6013	58.2	0.0	0.5	2.6 ab	0.5	19.4
Tukey's HSD *P* = 0.05	33.01	0.50	0.74	4.43	2.36	25.81
Standard Deviation	10.89	0.17	0.24	1.46	0.78	8.51
Grand Mean	60.60	0.03	0.11	1.81	0.65	19.90

[†]Normal = grain without visual defects, FLS = frogeye leaf spot, SVC = soybean virus complex, PSS = purple seed stain, PSD = Phomopsis seed decay, Insect = Insect damaged grains.
[‡]Columns followed by the same letter, or no letters are not significantly different according to Tukey's Honestly Significant Difference (HSD) at *P* = 0.05.

Table 5. Percent disease, insect, and normal percentages on soybean grain from an Xtend® variety trial including maturity groups 4.2–4.5 at the University of Arkansas System Division of Agriculture's Rohwer Research Station in 2023.

Variety	Normal[†]	FLS	SVC	PSS	PSD	Insect
	---(%)---					
AG42XF4	63.6 a[‡]	0.0	0.0	0.7	0.0	27.8
AG43XF2	57.0 ab	0.0	0.0	1.1	0.5	28.3
AG44XF4	67.1 a	0.0	0.2	1.2	0.2	22.4
AG45XF3	68.2 a	0.0	0.0	0.7	0.7	17.4
DELTA GROW 44XF75/STS	59.7 ab	0.0	0.0	0.7	0.0	29.2
DONMARIO DM45F23	51.4 ab	0.0	0.5	0.7	0.7	30.4
DYNA-GRO S42XF93S	48.7 ab	0.0	0.2	1.4	0.5	33.9
INTEGRA XF4142S	43.7 ab	0.0	0.0	0.7	1.2	31.8
INTEGRA XF4454S	43.9 ab	0.3	0.0	0.4	0.4	35.7
NK44-J4XFS	52.0 ab	0.0	0.2	1.8	1.3	22.4
PIONEER P44A21X	51.6 ab	0.0	0.0	2.4	0.0	31.3
PIONEER P44A60LX	38.9 ab	0.0	0.3	1.2	0.8	38.1
PIONEER P45A70LX	43.6 ab	0.0	0.0	1.6	0.7	37.4
REVERE 4237XFS	26.4 b	0.0	0.0	2.1	0.0	34.9
REVERE 4415XF	53.2 ab	0.0	0.0	0.8	0.3	32.8
REVERE 4526XFS	49.5 ab	0.0	0.0	0.8	0.3	34.2
Tukey's HSD P = 0.05	35.98	0.35	0.71	3.28	2.22	27.36
Standard Deviation	11.79	0.11	0.23	1.08	0.73	8.96
Grand Mean	51.16	0.02	0.09	1.14	0.47	30.51

[†] Normal = grain without visual defects, FLS = frogeye leaf spot, SVC = soybean virus complex, PSS = purple seed stain, PSD = Phomopsis seed decay, Insect = Insect damaged grains.

[‡] Columns followed by the same letter, or no letters are not significantly different according to Tukey's Honestly Significant Difference (HSD) at P = 0.05.

Table 6. Percent disease, insect, and normal percentages on soybean grain from an Xtend® variety trial including maturity group 4.6 at the University of Arkansas System Division of Agriculture's Rohwer Research Station in 2023.

Variety	Normal†	FLS	SVC	PSS	PSD	Insect
	------------------------------(%)------------------------------					
AG46XF3	65.3	1.2	0.0	0.5	3.7	17.8
AXIS 4613XF	51.0	1.1	0.0	0.8	3.5	13.3
AXIS 4641XFS	55.8	0.8	0.0	0.3	1.6	22.5
DELTA GROW 46X65/STS	69.2	0.0	0.0	0.7	0.4	21.7
DELTA GROW 46XF54	51.1	0.0	0.0	1.3	1.0	21.7
DYNA-GRO S46XF31S	55.3	0.5	0.0	0.3	0.8	15.4
INTEGRA X4660	64.9	1.7	0.0	0.2	3.5	10.9
INTEGRA XF4621S	46.7	1.2	0.0	1.0	5.9	17.8
INTEGRA XF4634S	53.0	0.3	0.0	1.3	0.5	23.1
NK46-B4XFS	47.0	0.8	0.0	1.3	1.4	23.7
PIONEER P46A20LX	52.2	0.8	0.0	1.6	3.3	21.0
PIONEER P46A90LX	62.7	0.0	0.0	0.2	0.2	28.8
PROGENY P4604XFS	50.4	2.5	0.0	0.3	1.3	14.6
PROGENY P4623XFS	60.8	0.0	0.0	1.1	0.0	25.5
PROGENY P4665XFS	62.8	0.2	0.0	0.5	0.0	25.2
PROGENY P4691XFS	50.2	3.3	0.0	1.3	1.8	8.9
USG 7461XFS	51.3	1.5	0.0	0.5	1.9	26.6
USG 7463XF	56.5	1.0	0.0	0.3	3.8	11.4
Tukey's HSD *P* = 0.05	33.52	3.94	0.00	2.25	8.01	32.71
Standard Deviation	10.90	1.28	0.00	0.73	2.60	10.64
Grand Mean	55.91	0.94	0.00	0.76	1.93	19.44

†Normal = grain without visual defects, FLS = frogeye leaf spot, SVC = soybean virus complex, PSS = purple seed stain, PSD = Phomopsis seed decay, Insect = Insect damaged grains. HSD = Tukey's Honestly Significant Difference.

Table 7. Percent disease, insect, and normal percentages on soybean grain from an Xtend® variety trial including maturity group 4.7 at the University of Arkansas System Division of Agriculture's Rohwer Research Station in 2023.

Variety	Normal[†]	FLS	SVC	PSS	PSD	Insect
	(%)					
AG47XF2	60.1 a[‡]	1.9	0.2	0.7	1.3	10.4 b
AG47XF4	52.4 ab	2.4	0.0	1.2	1.3	17.5 ab
DELTA GROW 47XF38	62.1 a	2.2	0.7	0.4	0.7	10.9 b
DYNA-GRO S47XF23S	66.6 a	1.8	0.0	0.5	1.4	10.1 b
PIONEER P47A64X	35.3 b	1.4	0.0	2.4	3.0	26.5 a
PROGENY P4755XFS	50.9 ab	1.6	0.0	0.4	1.2	16.8 ab
PROGENY P4778XFS	59.9 a	0.2	0.0	2.1	0.7	11.1 b
PROGENY P4798XF	47.5 ab	0.3	0.0	0.8	0.3	19.0 ab
REVERE 4727XF	44.0 ab	1.4	0.7	1.1	1.1	21.7 ab
REVERE 4731XF	57.0 ab	0.4	0.8	0.4	1.0	12.2 ab
USG 7474XFS	43.3 ab	1.6	0.4	1.1	1.4	20.3 ab
Tukey's HSD *P* = 0.05	24.25	3.73	1.72	1.98	3.69	15.24
Standard Deviation	8.22	1.26	0.58	0.67	1.25	5.17
Grand Mean	52.65	1.37	0.26	1.00	1.20	16.05

†Normal = grain without visual defects, FLS = frogeye leaf spot, SVC = soybean virus complex, PSS = purple seed stain, PSD = Phomopsis seed decay, Insect = Insect damaged grains.

‡Columns followed by the same letter, or no letters are not significantly different according to Tukey's Honestly Significant Difference (HSD) at *P* = 0.05.

Table 8. Percent disease, insect, and normal percentages on soybean grain from an Xtend® variety trial including maturity group 4.8 at the University of Arkansas System Division of Agriculture's Rohwer Research Station in 2023.

Variety	Normal[†]	FLS	SVC	PSS	PSD	Insect
	(%)					
AG48XF2	54.4	0.3	0.0	0.3	0.5	7.4
AG48XF3	45.4	1.7	0.0	3.7	0.9	13.5
AXIS 4813XFS	47.9	0.5	0.4	1.3	0.5	6.9
DELTA GROW 48X45	39.7	1.9	0.0	2.2	2.4	18.7
DELTA GROW 48XF33/STS	45.1	0.0	0.0	1.1	1.7	13.7
DELTA GROW 48XF42	43.8	0.3	0.0	0.9	1.4	14.7
DONMARIO DM48F53	58.0	0.0	1.4	0.5	1.1	11.8
EAGLE SEED ES4875XF	38.0	0.0	0.0	1.3	1.3	18.4
INTEGRA XF4893S	50.3	2.2	0.2	1.0	3.2	14.9
NK48-A8XFS	47.5	0.0	0.0	0.0	3.0	12.4
PIONEER P48A04LX	44.0	0.0	0.5	2.1	1.3	14.5
PROGENY P4806XFS	50.8	0.0	0.0	0.8	0.2	13.0
REVERE 4826XF	47.5	0.9	0.0	0.5	2.2	13.1
Tukey's HSD *P* = 0.05	26.24	3.24	2.29	3.35	5.02	17.27
Standard Deviation	8.70	1.07	0.76	1.11	1.66	5.73
Grand Mean	47.10	0.60	0.20	1.21	1.52	13.31

†Normal = grain without visual defects, FLS = frogeye leaf spot, SVC = soybean virus complex, PSS = purple seed stain, PSD = Phomopsis seed decay, Insect = Insect damaged grains. HSD = Tukey's Honestly Significant Difference.

Table 9. Percent disease, insect, and normal percentages on soybean grain from an Xtend® variety trial including maturity groups 4.9–5.0 at the University of Arkansas System Division of Agriculture's Rohwer Research Station in 2023.

Variety	Normal†	FLS	SVC	PSS	PSD	Insect
	----------(%)----------					
DELTA GROW 49XF85/STS	51.7 ab‡	0.0	0.0	1.6	2.3 ab	15.4
DYNA-GRO S49XF43S	48.1 ab	0.4	0.0	3.5	3.6 ab	12.8
DYNA-GRO S49XF82	65.0 a	0.2	0.0	1.0	0.7 b	25.5
INNVICTIS A5003XF	60.6 a	0.2	0.0	2.0	0.4 b	27.3
INTEGRA XF4914S	55.2 ab	0.0	0.0	3.1	1.4 b	17.9
NK49-C2XFS	38.1 ab	0.0	0.0	2.0	4.6 ab	12.1
PROGENY P4947XFS	31.7 ab	0.3	0.0	0.3	11.4 ab	16.4
PROGENY P5056XFS	10.2 b	0.0	0.0	1.8	44.8 a	26.6
REVERE 4925XFS	45.0 ab	0.0	0.0	12.8	16.2 ab	8.5
REVERE 4934XF	49.3 ab	0.2	0.0	0.2	2.2 ab	24.2
REVERE 5029XF	53.7 ab	0.2	0.0	1.6	1.1b	31.7
Tukey's HSD *P* = 0.05	50.21	0.87	0.00	19.07	42.94	56.58
Standard Deviation	17.03	0.30	0.00	6.47	14.56	19.18
Grand Mean	46.23	0.15	0.00	2.71	8.08	19.85

†Normal = grain without visual defects, FLS = frogeye leaf spot, SVC = soybean virus complex, PSS = purple seed stain, PSD = Phomopsis seed decay, Insect = Insect damaged grains.

‡Columns followed by the same letter, or no letters are not significantly different according to Tukey's Honestly Significant Difference (HSD) at *P* = 0.05.

Table 10. Percent disease, insect, and normal percentages on soybean grain from an Xtend® variety trial including maturity groups 5.2–5.8 at the University of Arkansas System Division of Agriculture's Rohwer Research Station in 2023.

Variety	Normal[†]	FLS	SVC	PSS	PSD	Insect
	(%)					
AG52XF0	61.2 a[‡]	0.3	0.7	0.7	0.7 b	23.9
AG53XF2	48.5 ab	0.0	0.0	0.8	0.2 b	29.3
AG56XF2	59.1 a	0.0	0.2	0.2	0.2 b	23.7
DELTA GROW 52XF22	47.7 ab	0.8	0.5	0.5	0.4 b	33.8
DELTA GROW 53XF95/STS	56.6 a	0.0	0.2	1.2	0.8 b	24.9
DELTA GROW 55X25	52.7 ab	0.3	0.0	0.0	0.0 b	22.0
DELTA GROW 55XF23	56.5 a	0.0	1.0	0.3	0.3 b	26.1
INNVICTIS A5813XF	57.3 a	0.0	0.6	0.0	2.1 b	28.5
NK54-J9XFS	26.6 b	0.0	0.0	0.7	50.4 a	15.2
NK56-Z6XFS	58.6 a	0.0	0.9	0.7	0.2 b	24.8
PROGENY P5441XF	58.3 a	0.0	0.0	0.0	1.0 b	26.9
PROGENY P5641XF	65.9 a	0.0	0.2	0.2	0.5 b	16.4
PROGENY P5751XF	61.9 a	0.0	0.2	0.7	0.2 b	18.6
Tukey's HSD *P* = 0.05	26.89	1.27	1.64	1.94	32.59	24.27
Standard Deviation	8.96	0.42	0.55	0.65	10.86	8.08
Grand Mean	54.69	0.11	0.35	0.46	4.39	24.16

[†]Normal = grain without visual defects, FLS = frogeye leaf spot, SVC = soybean virus complex, PSS = purple seed stain, PSD = Phomopsis seed decay, Insect = Insect damaged grains.

[‡]Columns followed by the same letter, or no letters are not significantly different according to Tukey's Honestly Significant Difference (HSD) at *P* = 0.05.

Field Efficacy of Soil-Applied Fluopyram in Soybean

M. Emerson,[1] B. Baker,[1] and T.R. Faske[1]

Abstract

The field efficacy of soil-applied fluopyram (Velum® 4.16 SC) at 4 different rates (3.0, 4.0, 5.0, and 6.0 fl oz/ac) was evaluated in 2023 in a field naturally infested with the southern root-knot nematode (*Meloidogyne incognita*) in Pulaski County. The soybean cultivar used, Delta Grow DG4880 GLY, is susceptible to the southern root-knot nematode. Based on the root system galled, none of the fluopyram treatments, soil- or seed-applied (ILEVO® 600 FS), provided any root protection against nematode infection. Grain yield protection was observed with Velum® at 3.0 and 5.0 fl oz/ac, respectively, compared to the non-treated control and ILEVO. The southern root-knot nematode density at harvest was 1,491 individuals/100 cm^3 soil, which greatly exceeds the fall damage threshold for soybean (60 individuals/100 cm^3 soil). These data suggest that some rates of Velum may provide greater grain yield protection than others when compared to seed-applied fluopyram. Further studies are needed to better understand what rates of soil-applied fluopyram provide the best grain yield protection in soybean in fields with a high population density of the southern root-knot nematode.

Introduction

The southern root-knot nematode (*Meloidogyne incognita*) is the most yield-limiting plant-pathogenic nematode in the southern U.S. From 2018 to 2022, the total number of bushels lost in the southern U.S. is estimated at 57 million for a total value of $645 million dollars (CPN, 2023). In Arkansas, during that same timeline, the estimated bushels lost was 34 million for a total value of $384 million dollars (CPN, 2023).

Host-plant resistance is the most economical and preferred method of managing the southern root-knot nematode in soybean. However, due to the limited availability of cultivars with resistance against the southern root-knot nematode, especially among a wide range of herbicide tolerance traits, farmers often rely on nematicides to protect grain yield.

The first seed-applied nematicide in soybean was Votivo® (*Bacillus firmus* I-1582), a biological nematicide that was commercially available in 2010. Since then, there have been several new chemical and biological nematicides marketed for use in soybean. Fluopyram (ILEVO® 600 FS) has been used in soybean since 2014 as a seed-applied nematicide and fungicide. Fluopyram provides protection against root infection by *Fusarium virguliforme*, which causes sudden death syndrome. In 2022, soil-applied fluopyram was registered for use in soybean under the trade name Velum 4.16 SC. Although Velum has been available for many years in corn and cotton, it is a relatively new application method in soybean and there is little information on its efficacy in soybean. The objective of this study was to evaluate the field efficacy of soil-applied fluopyram to suppress the southern root-knot nematode and protect grain yield in soybean.

Procedures

The field experiment was conducted in 2023 in Pulaski County, Ark. (Table 1). The soil texture was a sandy loam soil with 49% sand, 44% silt and 7% clay. The southern root-knot nematode susceptible cultivar Delta Grow DG4880GLY (Delta Grow Seed Co. Inc., England, Ark.) was planted on 22 May at a seeding rate of 150,000 seed/ac. The previous crop was corn (*Zea mays*), and the field was furrow irrigated. Weeds were controlled per recommendations by the University of Arkansas System Division of Agriculture's Cooperative Extension Service. Plots consisted of 4, 30-ft long rows spaced 30 in. apart. The experimental design was a randomized complete block design with 6 replications separated by a 5-ft fallow alley. All seed were treated with a base fungicide, CruiserMaxx® Vibrance® 2.49 FS at 3.22 fl oz/cwt (Syngenta Crop Protection, Greensboro, N.C.; the active ingredients are mefenoxam, fludioxonil, sedaxane, and thiamethoxam at 0.0945 mg ai/seed). ILEVO® 600 FS (BASF Corporation, Florham Park, N.J.) was applied at 0.075 mg ai fluopyram/seed. Velum 4.16 SC was applied in-furrow at 3.0, 4.0, 5.0, and 6.0 fl oz/ac through a 0.07-in. diameter poly tubing using a pressurized sprayer to deliver a total volume of 6.5 gal/ac. Stand counts and the number of plants per 10 row feet were determined at 14 days after planting (DAP). A vigor rat-

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ing was given for the entire plot at 14 DAP, where 1 = poor growth and 5 = best growth. Phytotoxicity as the severity of a necrotic ring around the cotyledonary leaves was given for the entire plot at 14 DAP where 0 = no discoloration and 5 = severe necrosis with dead cotyledons. Eight root samples were collected at 44 DAP from the outer 2 rows to evaluate the percent root system galled. Galling was assessed on the upper 4 inches of each root system, which is within the protection zone provided by seed- and soil-applied nematicides in soybean. Soil samples were a composite of 8 core samples taken 6 to 8 in. deep with a 0.75-in. diameter soil probe and collected at harvest from the non-treated control plots. Nematodes were collected using a modified Baermann pan system and enumerated using a stereoscope. The two center rows of each plot were harvested on 9 Oct. with an ALMACO SPC40 plot combine (ALMACO, Nevada, Iowa) equipped with a HarvestMaster Single BDS HiCap HM800 weigh system (HarvestMaster Logan, Utah).

Data were subjected to ANOVA using ARM 2023 (GDM Solutions, Inc., Brookings, S.D.) and mean separation when appropriate at $P = 0.05$ according to Fisher's least significant difference procedure. Root galling data were transformed ($\log_{10} +1$) to normalize for analysis, and reverse transformed data were reported.

Results and Discussion

There was no ($P > 0.05$) effect of soil-applied nematicide on seedling stand counts or vigor. The average plant density was 66.25 plants per 10 ft. of row (115,433 plants/ac or 77% of target stand), and the average vigor rating was 4.8. Phytotoxicity was only observed on ILEVO-treated seed (avg. rating = 3.0), which was significantly greater than that (avg. rating of 0.0) of the Velum treatments or the non-treated control (NTC). No significant ($P = 0.82$) suppression of root galling was observed by any nematicide (Fig. 1). A greater ($P \leq 0.05$) grain yield was observed with Velum at 3.0 and 5.0 fl oz/ac than ILEVO, Velum at 4.0 fl oz/ac and the NTC. It is interesting that no rate response in yield protection was observed with Velum, which suggests the lowest rate is sufficient for yield protection. The cost of Velum is $5.80/fl oz for a total treatment cost of 3 fl oz/ac of $17.40 and at 5.0 fl oz of $29.00. Based on USDA-NASS, soybean prices in 2023 were $13.1/bu.; thus, both rates would have been a profitable investment.

The fall damage threshold for southern root-knot nematode and lesion nematode is 60 and 250 individuals/100 cm^3 soil, respectively. Based on soil samples collected at harvest, the population density of the southern root-knot nematode and lesion nematode was 1,491 and 240 individuals/100 cm^3 soil, respectively. The high southern root-knot nematode densities and at-threshold densities of lesion nematode may account for some of the variability in yield protection by the Velum treatments. The nematicide may provide more consistent protection in yield potential of susceptible soybean cultivars at lower nematode densities or on cultivars with at least a moderately resistant rating for the southern root-knot nematode when lesion nematodes are present. These data further our understanding of root and yield protection by soil-applied fluopyram in a field with a high density of the southern root-knot nematode in a sandy loam soil.

Practical Applications

Two of the 4 rates of soil-applied fluopyram (Velum) provided better yield protection than seed-applied fluopyram (ILEVO) and the non-treated control. Unfortunately, there was no rate response, which suggests a lower rate of Velum was as good as a higher rate in a field with a high density of the southern root-knot nematode. These data provide some insight as to the benefit of soil-applied fluopyram, but multiple years are often needed to better predict the conditions where nematicides are best suited to protect soybean yield potential.

Acknowledgments

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

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Table 1. Trade names, rates, and active ingredient for nematicides used in a soybean nematicide experiment in 2023 in Pulaski County.

Trade name and formulation	Rate	App[a]	Active ingredient
Velum 4.16 SC	3.0, 4.0, 5.0, 6.0 fl oz/ac	IF	fluopyram
ILEVO 600 FS	0.075 mg ai/seed	ST	fluopyram

[a] App = application method; IF = in-furrow, ST = seed treatment.

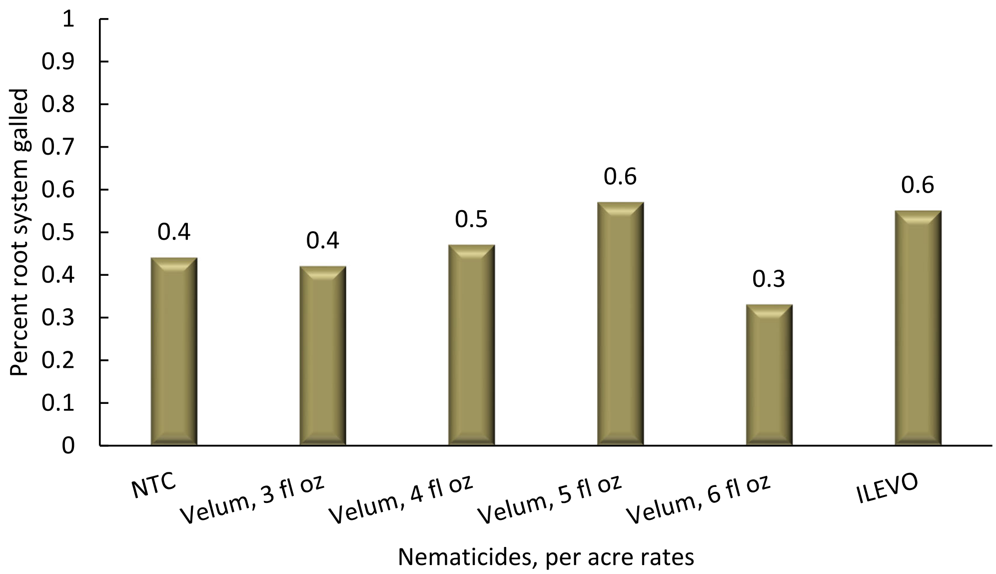

Fig 1. Suppression of the southern root-knot nematode infection by 4 rates of soil-applied fluopyram in 2023 in a field experiment in Pulaski County. Each bar represents the average percent root system galled from 6 replicates collected 44 days after planting.

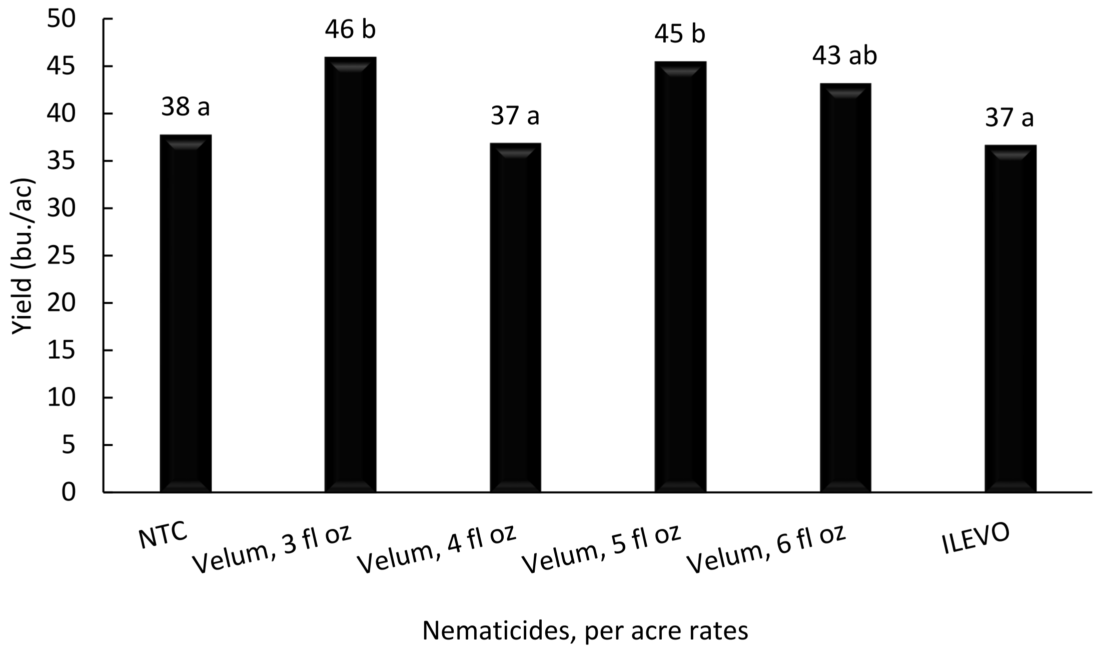

Fig 2. Yield protection by three nematicides in a field with low densities of stubby-root nematode, lesion, nematode, southern root-knot nematode, and stunt nematode in Pulaski County. Grain yield was adjusted to 13% moisture. Different letters above bars indicate a significant difference at α = 0.05 according to Fisher's least significant difference test.

Use of Satellite Imagery to Locate Scouting Positions in Soybean Fields, 2023

T.N. Spurlock,[1] A.C. Tolbert,[1] R. Hoyle,[1] K. Knight,[1] S. Pennington,[1] and Jeremy Ross[2]

Abstract

A procedure for identifying points more meaningful for scouting was developed and evaluated in 2023. Using satellite imagery, we calculated vegetation indices and generated point files that could be visualized on a smartphone with GPS capability. In fields that were scouted, the points with high index values typically had few issues and would be considered 'healthy' areas of fields. Some foliar disease was identified in these 'healthy' areas. Points scouted that had low index values had lower stands, lower amount of area that lapped the middles, drainage issues, weed infestations, insect damage, foliar disease, and stunted plants. After evaluating this scouting procedure in year one, it was determined that the calculations should be adjusted to consider 4 categories for scouting points: low, medium-low, high, and medium-high, to better capture field variability and meaningful observations.

Introduction

Field scouting is a labor-intensive process that is necessary to produce a profitable soybean crop. Typically, scouts walk in arbitrarily selected areas of fields and look for problems such as poor stands, weeds, insect infestations, and diseases. At times, both during and after the season, scouts take soil and plant tissue samples to be tested at an appropriate laboratory to determine nutrient deficiencies. From scouting, actionable information is gathered, and management decisions are made. However, it is essential that scouts make observations from enough field areas to serve as a reasonable sample size and ensure that pest pressure or field problems are not overlooked. The objective of this work was to test a procedure for identifying points that are more meaningful for scouting. Using satellite imagery from the Sentinel 2 constellation, we created a process to mark areas of fields that should be scouted, serving as a guide to both increase scouting efficiency and minimize potential errors by scouts.

Procedures

For each field, a polygon shapefile was drawn to represent the field boundary. The tool was run weekly on fields using multiple vegetation indexes, normalized difference vegetation index (NDVI, Rouse, 1973), simple ratio (SR, Jordan, 1969), optimized vegetation index (OSAVI, Rondeaux, 1996), and others calculated from satellite data were downloaded. From these indices, 2 mathematical models were calculated, producing 10 points in 2 categories: high and low, and producing points in high and low outlier categories using the interquartile range method to locate field areas to be scouted. After each run of the tool, a file with point data representing areas of the fields to be scouted was created for each field. These files were then opened, visualized, and located using a GPS-enabled smartphone. For each area scouted, data was collected within a 5-meter area. Data collected was stand, plant height, diseases present, and other relevant data describing the field condition. For areas the tool repeatedly located, a soil sample was collected prior to harvest. Soil samples were stored in a -80 Celsius freezer for future analysis. At the time of scouting, each point was designated as 'healthy' or 'unhealthy' to confirm that visual observation agreed or disagreed with the category designated by the model run.

Results and Discussion

In fields that were scouted, the points with high index values typically had few issues and would be considered 'healthy' areas of fields. Some foliar disease was identified in these 'healthy' areas (Cercospora leaf blight and Septoria brown spot). Points scouted that had low index values had lower stands, a lower amount of area that lapped the middles, drainage issues, weed infestations, insect damage (infrequent), foliar disease (target spot), and stunted plants. When soil samples were taken in fields, phosphorus, potassium, and other measures of fertility were about half in areas with low index values versus totals in areas with higher index values. After evaluating this scouting procedure in year one, it was determined that the calculations should be adjusted to consider 4 categories for scouting points: low, medium-low, high, and medium-high, to better capture field variability and meaningful observations. It was also encouraging that the tool identified areas where field variability could be quickly assessed.

Practical Applications

A working satellite-based scouting tool has been developed to address inefficiency in our current field scouting pro-

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cedures. This tool seeks to provide a more efficient way to learn as much as possible about soybean fields on a weekly basis. As farm sizes increase and the number of acres consultants are required to scout increases, an updated scouting procedure is needed that will direct scouts to the most important areas of fields and allow more informed management decisions to be made.

Acknowledgments

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

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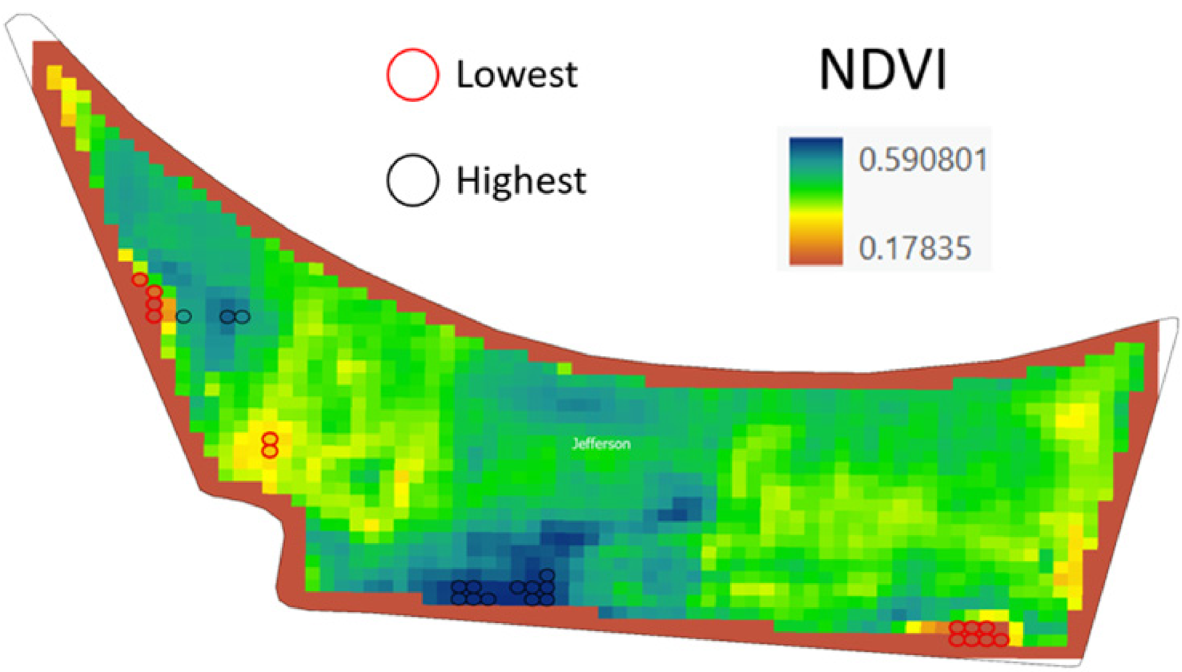

Fig. 1. A soybean field in Jefferson County with normalized difference vegetation index (NDVI) calculated. The highest values indicate the greener areas of the field. Scouting points were calculated from the NDVI and marked as a polygon shapefile. The 'lowest' points had the lowest NDVI values, while the 'highest' points had the highest NDVI values. Points were located without the NDVI map using shape files visualized on smartphones.

Investigating the Impact of Cover Cropping Practices on Soybean Taproot Decline Disease Development

Q. Fan,[1] *T. N. Spurlock,*[2] *and A. Rojas*[1]

Abstract

Soybean taproot decline disease, caused by *Xylaria necrophora*, is an emerging disease in the southern United States. The cover crops planted in the fall, prior to the cash crop, are intended to improve overall soil health; however, they may have adverse effects by serving as a potential host for *Xylaria necrophora*, allowing it to overwinter. In this study, we conducted a field study aiming to investigate the impact of planting cereal rye on disease progression in 3 soybean cultivars over the growing season. Our study revealed that planting cereal rye before soybeans had adverse effects when plots were infected with taproot decline. Higher disease incidence and severity were observed in the cereal rye-treated plots, along with lower stand counts and yields. We also observed a positive correlation between yield and normalized difference vegetation index (NDVI) at reproductive stages (R2–R3 at 0.92 and R5–R7 at 0.95). Collectively, these studies will improve our overall understanding of taproot decline on soybean and provide information to aid in disease management.

Introduction

Soybean taproot decline, reported to be an emerging disease in the southern United States, is caused by the soilborne fungus *Xylaria necrophora* (Xn) (Garcia-Aroca et al., 2021). Early infection can lead to seed rot and seedling death at the onset of the growing season. The disease can persist throughout the growing season, colonizing roots and turning them charcoal-colored, which deteriorates the taproot. This results in interveinal leaf chlorosis and necrosis, ultimately impacting yield. The total yield loss attributed to taproot decline in the mid-southern United States was estimated to be 2028 thousand bushels in 2018 and 1383 thousand bushels in 2019 (Bradley et al., 2021). In 2021, soybean taproot decline was found in 15 counties in the Arkansas Delta region (Spurlock et al., 2021), posing a potential threat to soybean growers.

While there are examples of pathogens surviving on cover crops, information is lacking on the potential benefits of cover crops for controlling Xn or their adverse effects as potential hosts, which may allow the pathogen to overwinter. A previous study determined that cereal rye exhibited higher tolerance to Xn infection compared to 8 other types of cover crops tested in vitro and in growth chamber experiments. In the current study, we conducted a field study aiming to investigate the impact of planting cereal rye on disease progression in 3 soybean cultivars throughout the growing season.

Procedures

The field experiment followed a split-plot randomized complete block design (RCBD), with the main plots assigned to cover crop and fallow. The RCBD included combinations of inoculation (inoculated and non-inoculated) and soybean cultivar (Osage, Hutcheson, and R10-230). Cover crop cereal rye was planted in October 2022 and terminated in April 2023, 3 weeks before soybean planting. Two Xn isolates, TRD_AR (provided by the Spurlock lab) and MSU_SB201401 (provided by B. Bluhm), were used. Both isolates were grown on millet, respectively, and evenly mixed for inoculation. Sterile millet planted with soybean served as the non-inoculated control. The trial was harvested in October 2023. Data collected included stand counts at 15 and 30 days post-planting, root samples, aerial images, disease incidence (percentage of infected plants per plot), and severity (using a scale from 0 = healthy plant to 5 = dead plant) at 4 growth stages (vegetative stages V1–V3, V5–V7, reproductive stages R2–R3, and R5–R7), and yield at harvest. Aerial imagery was captured using a drone-mounted multi-spectral sensor collecting individual near infrared (NIR) and red bands (RED). These images were processed through Pix4Dmapper and QGIS to generate normalized difference vegetation index (NDVI) values for each plot using the equation NIR – RED / NIR + RED. Disease rating data and NDVI analysis were conducted using RStudio.

Results and Discussion

In the early season, higher stand counts were observed in all non-inoculated plots compared to the inoculated ones. Throughout the growing season, Xn was persistently observed in the inoculated plots, indicating a higher disease pressure in plots treated with cereal rye. Disease severity de-

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creased as the plants grew into the reproductive stage, and the plant canopy developed more vegetation. Cereal rye-treated plots tended to have lower yields compared to fallow in both inoculated and non-inoculated plots. We calculated the correlation between the NDVI of soybeans at reproductive stages and yield. The NDVI at stage R2–R3 was positively correlated with yield, with a coefficient of 0.92, and it increased towards the end of the season at R5–R7, with a coefficient of 0.948. Overall yield in the trial was extremely low. By the end of the season, fallow plots planted with cultivar Hutcheson had the highest yield among all non-inoculated plots, averaging 21 bu./ac. Cultivar Osage, planted after rye, yielded the lowest among all cultivars tested, with an average of 3.6 bu./ac in inoculated plots and 6.5 bu./ac in non-inoculated plots. Our study revealed that planting cereal rye before soybeans had adverse effects when plots were infected with taproot decline.

Practical Applications

While cover crops could produce benefits for soil health, the interaction with soilborne pathogens is unpredictable since it could help to reduce inoculum or actually increase it. As more adoption of cover crops happens, it is necessary to characterize potential interactions with existing issues in Arkansas. Our study suggests that in fields artificially inoculated with *Xylaria necrophora*, the pathogen compromises seed germination and causes seedling death. It is necessary to dissect the role of cover crop and pathogens independently since there are issues with germination during cover crop adoption. However, the planting of cereal rye cover crops increases disease pressure for this study and, consequently, impacts the yield of soybeans when fields are infected with taproot decline.

Acknowledgments

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

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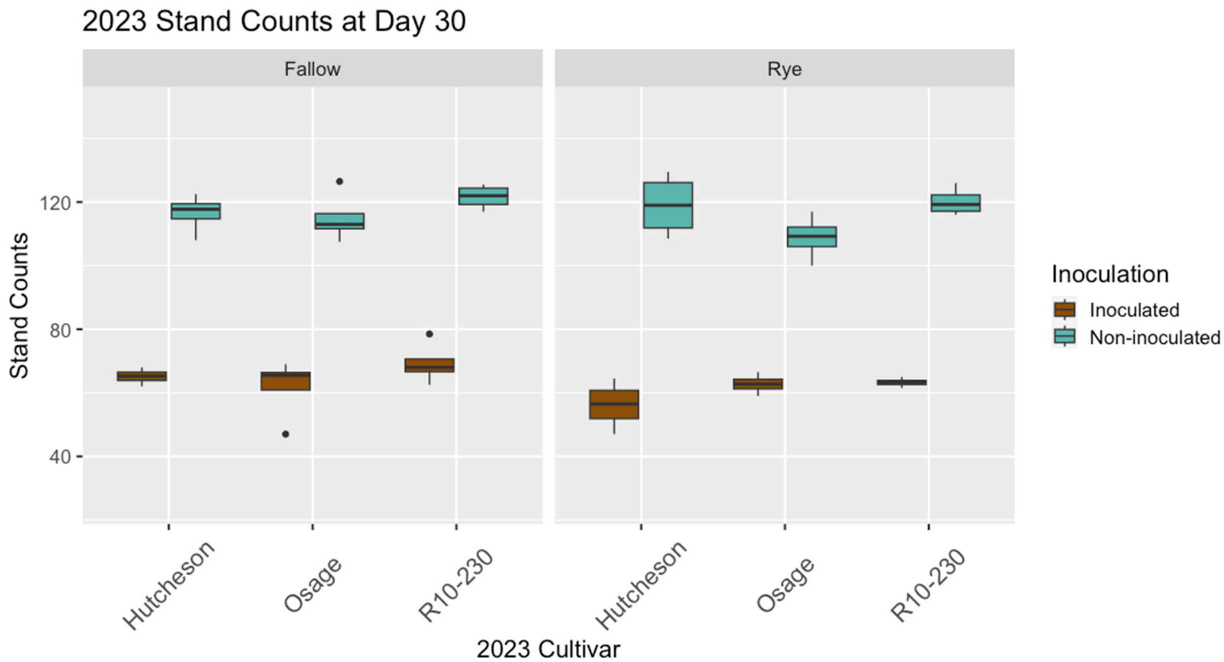

Fig 1. Stand count data from 30 days post-planting of 3 soybean cultivars under cover crop rye and fallow conditions with and without inoculation of *Xylaria necrophora* at the University of Arkansas System Division of Agriculture's Milo J. Shult Research and Extension Center in Fayetteville, Ark. in 2023.

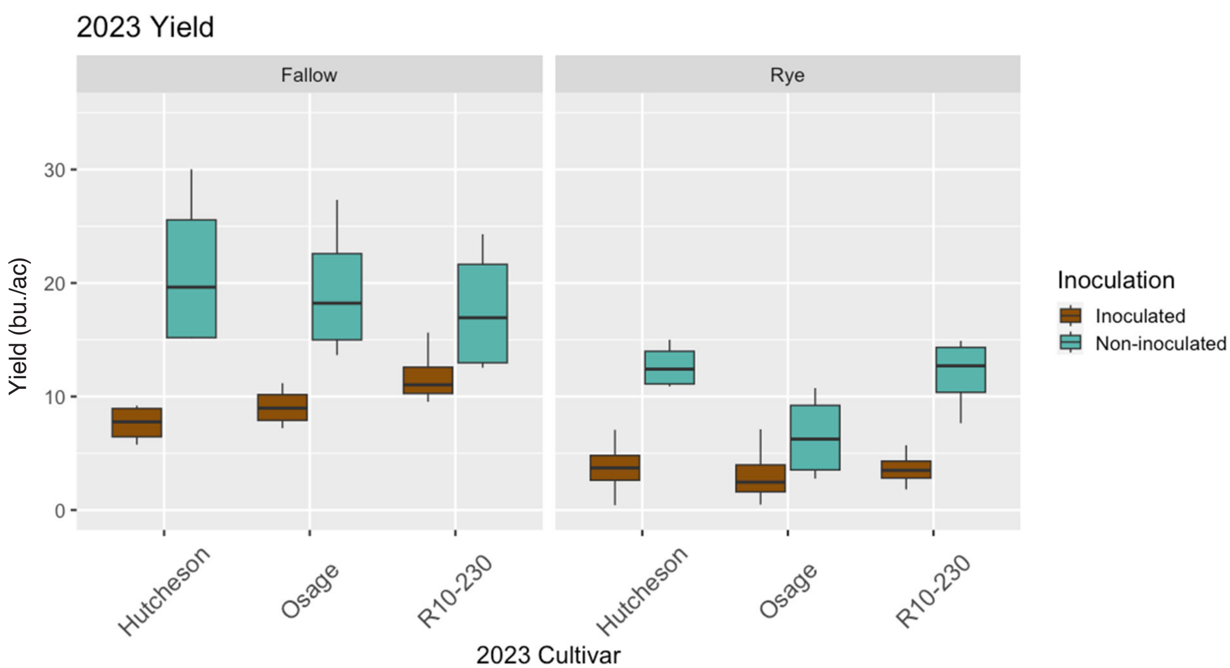

Fig 2. Yield (bu./ac) of 3 soybean cultivars under cover crop rye and fallow conditions with and without inoculation of *Xylaria necrophora* at the University of Arkansas System Division of Agriculture's Milo J. Shult Research and Extension Center in Fayetteville, Ark. in 2023.

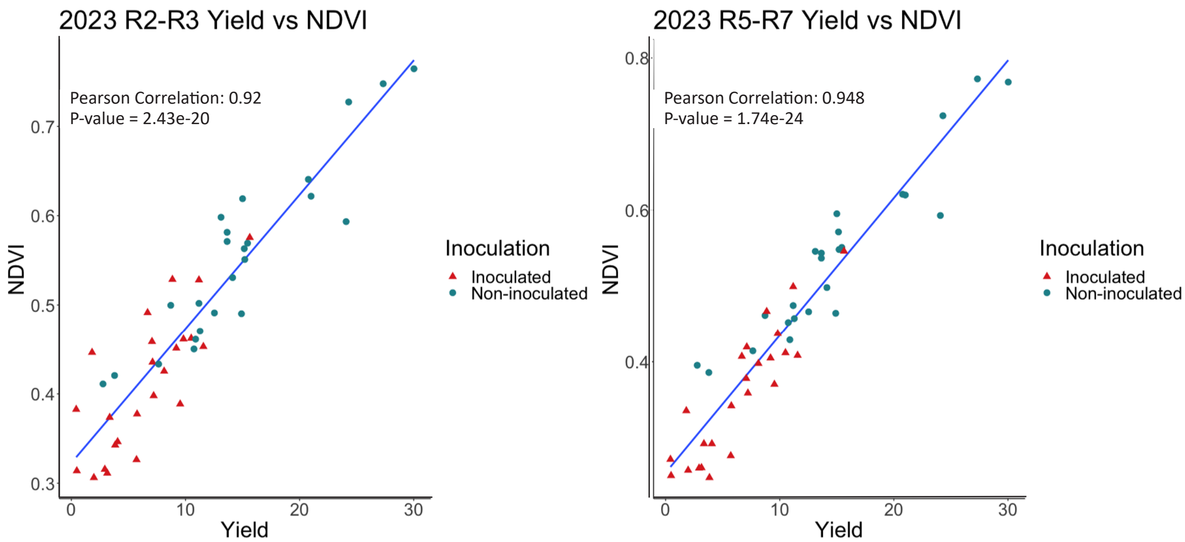

Fig 3. Correlation among normalized difference vegetation index (NDVI) and yield for all soybean cultivars tested at reproductive stage R2–R3 and R5–R7 calculated from aerial imagery captured by a drone-mounted multi-spectral sensor.

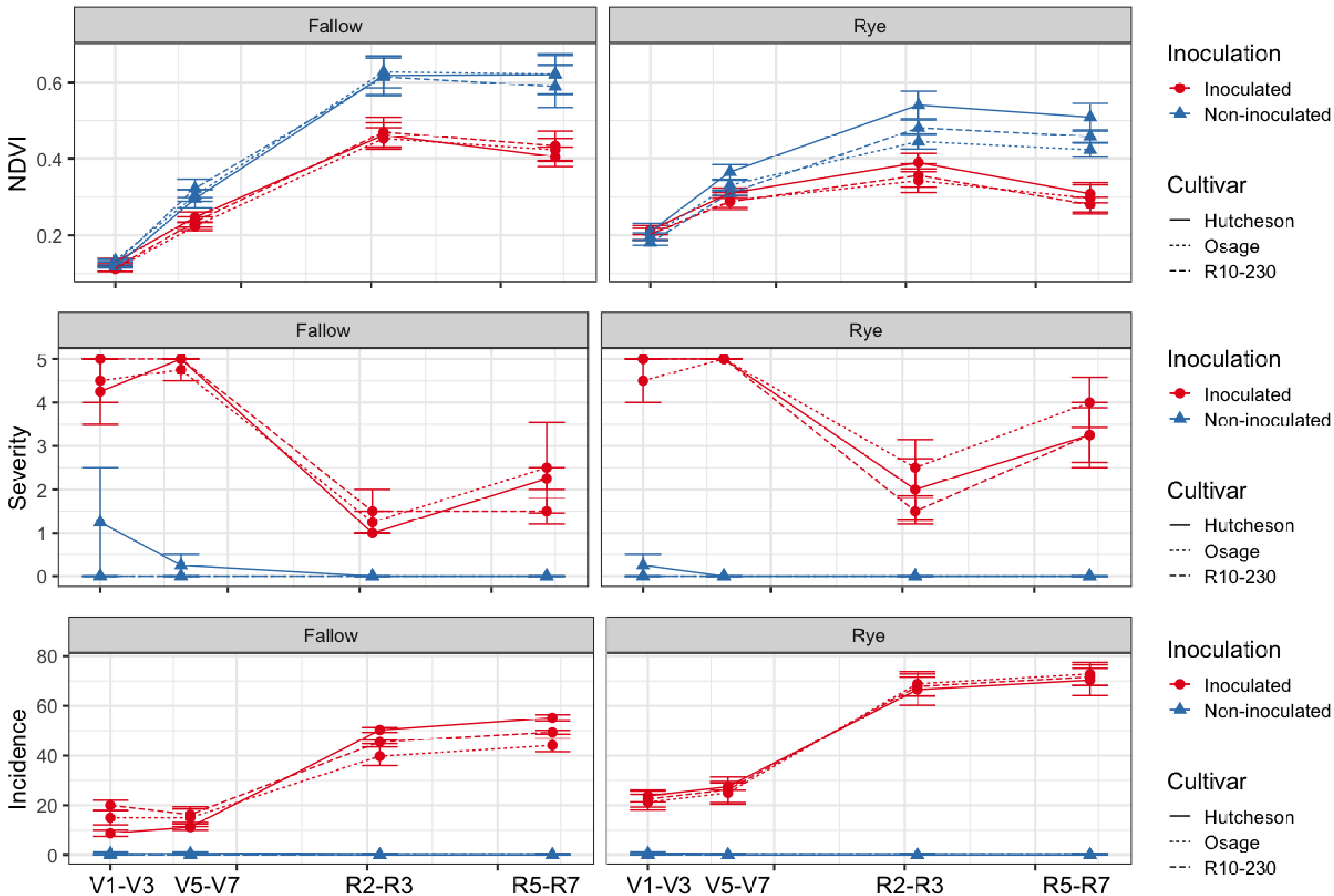

Fig 4. Normalized disease vegetation index (NDVI), disease severity, and incidence progress over the soybean growth stages for three cultivars, Hutcheson, Osage, and R10-230, planted in fallow grounds or cereal rye, with and without inoculation at the University of Arkansas System Division of Agriculture's Milo J. Shult Research and Extension Center in Fayetteville, Ark. in 2023.

On-Farm Soybean Fungicide Trial Summary, 2023

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

Abstract

Eight large block foliar fungicide trials were established in soybean fields in 7 Arkansas counties in 2023. 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 all 8 trials. In 2 of 8 trials, fungicide application protected the crop above the application cost. There were numerically positive yield gains in all trials.

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 every year. Therefore, it is important to continually determine fungicide efficacy and determine the yield loss each disease has the potential to cause across a range of locations, planting dates, and varieties to understand the economic impacts of the most common foliar diseases and management options for each.

Procedures

Eight large block foliar fungicide trials, ranging in size from 15–50 acres, were established in soybean fields in 7 Arkansas counties in 2023. 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. Fungicides were applied at R3 growth stage (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 the R6 stage 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 with an automated model using Python 3.6. Weather and soil data as well as high-resolution field images were included in the reports distributed to each cooperating farmer and county agent.

Results and Discussion

In all, 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 5 locations; target spot,

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caused by *Corynespora cassiicola*, was rated at 7 locations; and Cercospora leaf blight, likely caused by *Cercospora flagellaris*, was rated at 1 location. Yields were available for all trials. Average yields for the trials ranged from 25.2 bushels per acre (bu./ac) to 83.28 bu./ac (Table 2). In previous years, fields were at the R3 stage and fungicide was applied on dates beginning in June and ending in August, offering the opportunity to compare a wider range of dates with or without yield response to application when compared to the nontreated. In 2023, the earliest application timing was 2 June and the latest was 28 July. 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

As 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, group 5 soybean varieties may have a higher likelihood of increased foliar disease pressure as they are generally maturing later in the year. As a rule, one should consider the use of a fungicide more likely to be profitable if a field is in the pod-fill stage during late July into August.

Acknowledgments

The authors appreciate the cooperating farmers for granting space for these studies on their farms as well as support provided by Arkansas soybean producers through checkoff funds administered by the Arkansas Soybean Promotion Board. Support was also provided by the University of Arkansas System Division of Agriculture. The authors would also like to acknowledge the cooperating county agents Grant Beckwith – Arkansas County, Steven Stone – Lincoln County, Jerrod Haynes – White County, Chris Grimes – Craighead County, Scott Hayes – Drew County, Kurt Beatty – Chicot County, and Brady Harmon – Jefferson County.

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Table 1. Fungicide trial location and products applied, 2023.

Trial location	Approximate location[†]	Products applied	Rate applied (fl oz/ac)
Jefferson	34.15236, -91.9687	Miravis Top 1.62 SC	13.7
		Lucento 4.17 SC	5.5
Arkansas A	34.5486, -91.50965	Miravis Top 1.62 SC	13.7
		Revytek 3.33 SC	7
		Provysol 3.34 SC +	1.9
		Sercadis 2.47 SC	4.1
Arkansas B	34.54855, -91.50519	Miravis Top 1.62 SC	13.7
		Revytek 3.33 SC	7
		Provysol 3.34 SC +	1.9
		Sercadis 2.47 SC	4.1
Drew	33.65903, -91.67765	Miravis Top 1.62 SC	13.7
		Lucento 4.17 SC	5.5
Chicot	33.33893, -91.31816	Miravis Top 1.62 SC	13.7
		Lucento 4.17 SC	5.5
Lincoln	33.96488, -91.67117	Miravis Top 1.62 SC	13.7
		Domark 230 ME	5
		Lucento 4.17 SC	5.5
White	35.09086, -91.62249	Miravis Top 1.62 SC	13.7
		Lucento 4.17 SC	5.5
Craighead	35.74429, -90.61407	Miravis Top 1.62 SC	13.7
		Lucento 4.17 SC	5.5

[†] Longitude, latitude in geographic coordinate system ‘WGS 1984.’

Table 2. Summary of fungicide trial results, 2023.

Trial location	Application date (growth stage R3)	Diseases rated	Disease levels	Treatment response[†]	Average Yield[‡]	Gain from Fungicide Application[§]
					----------------(bu./ac)----------------	
Jefferson	6/2/2023	---	low	NA	61.40	0.5
Arkansas A	6/5/2023	target spot /frogeye leaf spot	low	NS/NS	72.50	3.1
Craighead	6/28/2023	target spot /frogeye leaf spot	moderate/ low	**/NS	83.28***	1.75
Chicot	7/18/2023	target spot /frogeye leaf spot	moderate/ moderate	**/*	52.98	6.6
Drew	7/20/2023	target spot /aerial blight	low/ moderate	NS/**	25.20	1.7
Arkansas B	7/26/2023	target spot/ Cercospora leaf blight	low/ moderate	*/***	68.03*	3.6
White	7/26/2023	target spot /frogeye leaf spot	moderate/ moderate	*/***	61.10***	5.5
Lincoln	7/28/2023	target spot /frogeye leaf spot	high/high	*/***	74.71***	2.1

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

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

[§] Yields of fungicide treatments were averaged and the yield from the nontreated subtracted.

Field Performance of Forty-Four Soybean Varieties Marketed as Resistant to Southern Root-Knot Nematode, 2023

M. Emerson,[1] B. Baker,[1] and T.R. Faske[1]

Abstract

The susceptibility of 44 soybean cultivars to the southern root-knot nematode (*Meloidogyne incognita*) was evaluated in 3 field trials in 2023 near Kerr, Arkansas. The damage threshold across all trials was severe, with an average population density of 916 second-stage juveniles/100 cm^3 of soil at harvest. Host susceptibility was based on the percent of root system galled at the R5–R6 growth stage. Cultivars were considered very resistant if the percentage of root system galled was between 0.0% and 1.0%, resistant between 1.1% and 4.0%, and moderately resistant between 4.1% and 9.0%. Of the maturity group 4 Roundup Ready®, Roundup Ready/Xtend®, XtendFlex®, and Enlist E3® cultivars, Pioneer P43A42X and Delta Grow 4940 GLY were very resistant, while Pioneer P46A36X and Delta Grow DG46E10 were resistant, while GoSoy GS493E22N and Delta Grow DG49E90 were moderately resistant. In the maturity group 5 Roundup Ready®, Roundup Ready/Xtend®, XtendFlex®, and Enlist E3® trial, Pioneer P54A36 and Pioneer P56A71E were very resistant, while Pioneer P55A49, Pioneer P54A54, Armor 55-D57, Progeny P5554RX, and Progeny P5751XF were resistant, while Pioneer P52A14, NK56-Z6XFS, Armor 54-F34, Delta Grow DG55XF23, and Innvictis A5813XF were moderately resistant. The 11 very resistant to resistant cultivars would be a preferred choice in fields with a high density of southern root-knot nematode; however, the other seven moderately resistant cultivars would be useful at lower nematode densities.

Introduction

The southern root-knot nematode (SRKN), *Meloidogyne incognita*, is the most widespread, commonly encountered, and most economically important plant-parasitic nematode on cotton, corn, and soybeans in the southern U.S (CPN, 2021). In Arkansas, the SRKN is the most damaging and most common nematode species that affects soybean production (Kirkpatrick et al., 2014). Yield losses in Arkansas were estimated to be 4.3% (7,246,210 bushels) due to *Meloidogyne incognita* during the 2023 cropping season; however, yield loss estimates were slightly lower at 1.4% (13,057,303 bushels) across the southern U.S (CPN, 2024).

Management of the SRKN is very difficult because they are soilborne pathogens with a wide host range of over 3,000 species of plants, including vegetables, ornamentals, fruit trees, agronomic field crops, cover crops, and weeds; however, the best management strategies for SRKN is an integrated approach that utilizes nematicides, crop rotation, and resistant cultivars. Seed-treated nematicides have increased in recent years to approximately 6 commercially available products; however, this system is most effective at low nematode population densities or when multiple species of soybean nematodes are present. Crop rotation can be an effective tool when hosts such as peanuts (*Arachis hypogaea* L.) are used in a cropping sequence; however, this crop may not fit all production systems. The use of resistant soybean cultivars is the most economical and, by far, the most 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 (UADA) Cooperative Extension Service and only provides information on those cultivars that are entered into the official UADA Official Variety Testing Program (OVT) (Emerson et al., 2023). The objective of this study was to expand on the RKN susceptibility and yield response of a few MG 4 and 5 cultivars that are marketed as resistant or identified as resistant from the OVT.

Procedures

Forty-four soybean cultivars were evaluated in a local producer'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 for Arkansas (Tables 1–3). Experiments were divided between maturity groups. Fertility, irrigation, and weed management followed recommendations by the UADA Cooperative Extension Service. Plots consisted of 4 rows, 30-ft long, spaced 30-in. apart, separated by a 5-ft fallow alley. Plots were furrow irrigated. Seeds were planted using a Kincaid Precision Voltra Vacuum plot planter (Kincaid Equipment Manufacturing, Haven, Kan.) on 27 May 2023 at a seeding rate of 150,000 seeds/ac. The experimental design

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was a randomized complete block with 4 replications per cultivar. The population density of RKN at planting averaged 54 second-stage juveniles (J2)/100 cm^3 of soil with a final population density of 916 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, and 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 16 Oct 2023 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 2023.3 (Gylling Data Management, Inc., Brookings, S.D.). When appropriate, mean separations were performed using Tukey's honestly significant difference (HSD) test at $P = 0.05$.

Results and Discussion

Of the maturity group 4 Roundup Ready®, Xtend®, Xtend Flex®, and Enlist E3® cultivars, there was a wide range in susceptibility with 0.1% to 59% 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 (Table 1 and 2); however, this Pioneer 43A42X was moderately resistant in 2021 in a similar study (Emerson et al., 2022). This is 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 average yield (39 bu./ac) of the susceptible cultivars.

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). The grain yield average of these resistant cultivars was 44 bu./ac, which was 12 bu./ac greater than the average yield (32 bu./ac) of the susceptible cultivars.

Practical Applications

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

Acknowledgments

The authors would like to thank Agri Gold, Corteva, Delta Grow Seed, Dyna Gro, Gateway Seed, Innvictis Seed, Local Seed Company, NK Seed, Progeny Ag Products, Seed, Stratton Seed, and Windfield Solutions LLC Company for providing seed for this study; Fletcher Farms and Hartz Farm Management Inc. for providing space in the field to conduct these trials; the Arkansas Soybean Promotion Board and the University of Arkansas System Division of Agriculture for supporting this research.

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Table 1. Susceptibility and yield of 12 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 43A42X (check)	0.1 f¶	VR	76.7 a
GoSoy GS493E22N	8.6 ef	MR	74.4 a
Pioneer P46A36X	2.5 f	R	72.9 a
Delta Grow DG49E90	4.9 f	MR	68.4 a
Delta Grow DG4940 (Check)	1.0 f	VR	66.9 a
Innvictis B4921E	10.2 def	MS	66.6 a
NK44-Q5E3S	14.8 c-f	MS	61.6 ab
Progeny P4806XFS	28.5 b-e	S	45.1 bc
Delta Grow DG46XF54	51.1 ab	VS	28.0 cd
Delta Grow DG4880 GLY (check)	38.7 abc	S	26.7 cd
Delta Grow DG48XF42	32.5 a-d	S	26.6 cd
Innvictis A4862XF	39.71 abc	S	25.7 cd
Donmario Seed DM48F53	32.9 a-e	S	23.1 d
Delta Grow DG44XF75	40.4 abc	S	23.1 d
Gateway Seed 45XFS	58.8 a	VS	20.1 d
Delta Grow DG49XF29 (check)	27.33 a-e	S	19.5 d

† 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 the 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, and 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 12 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 43A42X (check)	0.6 g¶	VR	63.8 a
Delta Grow DG4940 (Check)	0.3 g	VR	60.8 ab
Delta Grow DG46E10	3.4 fg	R	60.0 ab
Progeny P4444RXS	11.9 efg	MS	59.3 ab
Innvictis A4448X	12.8 d-g	MS	57.4 abc
Armor 49-F09	31.5 a-e	S	43.4 a-d
NK48-A8XFS	17.6 c-g	MS	37.6 bcd
Progeny P4665XFS	34.6 a-d	S	36.7 bcd
Delta Grow DG4880 GLY (check)	36.3 abc	S	36.6 bcd
NK49-T6E3S	25.2 a-f	S	36.3 bcd
Agri Gold G4650XF	40.8 ab	VS	32.0 cd
Armor 45-F65XF	21.7 b-g	S	31.3 d
Donmario Seed DM49F62S	28.0 a-e	S	29.7 d
Delta Grow DG49XF85	33.0 a-e	S	27.8 d
Innvictis A4503XF	44.6 a	VS	25.0 d
Delta Grow DG49XF29 (check)	31.9 a-e	S	20.1 d

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

‡ Susceptibility was based on the 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, and 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 18 Roundup Ready©, Xtend©, Xtend Flex©, and Enlist E3© maturity group 5 soybean cultivars grown in a southern root-knot nematode infested field.

Cultivar	Percent root system galled[†]	Susceptibility[‡]	Yield[§]
	---- (%) ---		(bu./ac)
Pioneer P55A49	3.2 bcd[¶]	R	70.8 a
Pioneer P54A36	1.0 cd	VR	68.9 a
Pioneer P52A05	9.6 a-d	MS	68.6 a
Pioneer P52A14 (check)	4.2 bcd	MR	65.3 a
Pioneer P54A54	3.9 bcd	R	63.2 a
Pioneer 56A71E	0.7 d	VR	62.4 ab
Armor 55-D57	2.7 bcd	R	62.1 ab
NK56-Z6XFS	5.7 a-d	MR	60.2 ab
Armor 54-F34	8.1 a-d	MR	60.1 ab
Progeny P5554RX	2.4 bcd	R	59.6 abc
NK52-D8E3	12.9 a-d	MS	56.9 a-d
Delta Grow DG55XF23	9.0 a-d	MR	46.6 b-e
Innvictis A5813XF	6.1 a-d	MR	43.8 c-f
NK52-V1XF	23.3 a-d	S	43.7 c-f
Progeny P5751XF	2.2 bcd	R	42.5 def
Armor 51-F29	25.2 abc	S	38.6 efg
Delta Grow DG52XF22	17.0 a-d	MS	33.0 efg
Innvictis A5003XF	39.1 a	S	32.2 efg
Delta Grow DG53XF95	29.4 ab	S	30.1 fg
Delta Grow DG51E30 (check)	29.6 a-d	S	23.7 g

[†] 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 the 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, and 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.

The Efficacy of Selected Insecticides for Management of Soybean Loopers in Arkansas

P.G. Maris,[1] N.R. Bateman,[2] B.C. Thrash,[3] S.G. Felts,[2] W.A. Plummer,[3] and T. Davis[3]

Abstract

Soybean loopers (*Chrysodeixis includens*) are a consistent insect pest for soybean [*Glycine max* (L.) Merr] producers in Arkansas. As defoliators, soybean loopers pose a yield threat if not controlled. A trial was conducted in 2023 on soybeans in Tillar, Ark. to evaluate Besiege®, Elevest®, Plemax®, Intrepid® plus acephate and various rates of Intrepid, Denim®, and Intrepid Edge® for control of soybean loopers. All rates of Intrepid lost residual activity by 12 days after application. All treatments other than Intrepid at 4 and 8 oz/ac, Intrepid plus acephate, and Plemax decreased defoliation when compared to the untreated check. No yield differences were observed between treatments.

Introduction

Soybean [*Glycine max* (L.) Merr] is the most widely grown row crop in Arkansas. With 3,180,000 acres of soybean planted in Arkansas in 2021, soybean production is a major economic component of Arkansas agriculture (Ross, 2022). In 2022, Arkansas soybean producers experienced a loss of $112.33/ac in control costs and yield losses associated with insect pests (Musser et al., 2023). Soybean looper (*Chrysodeixis includens*) (SBL) is a major insect pest of soybeans in the mid-southern United States and is consistently the second most economically important insect pest of soybean in the mid-south. Approximately 65% of Arkansas soybean acres were infested with SBL in 2020, costing producers $29,181,360 in treatment costs and yield losses (Musser et al., 2021). Adult SBL migrate to Arkansas in July and August and infest late-season soybeans. After entering the field, SBL can cause severe defoliation. Foliar insecticide application is the primary treatment method for SBL. The treatment threshold for SBL is 40% defoliation pre-bloom and 25% defoliation plus 6-8 loopers per row foot post-bloom (Bateman et al., 2021).

Procedures

The trial was conducted in Tillar, Ark., in 2023. Tested insecticides (rates) include Besiege® (8 oz/ac), Denim® (8 oz/ac), Denim® (12 oz/ac), Intrepid Edge® (4 oz/ac), Intrepid Edge® (5 oz/ac), Elevest® (6.75 oz/ac), Intrepid® (4 oz/ac), Intrepid® (6 oz/ac), Intrepid® (8 oz/ac), Intrepid® (4 oz/ac) plus acephate (8.21 oz/ac), and Plemax® (5 oz/ac). Plot size was 12.5 ft (4 rows on 38-in. centers) by 50 ft, and all treatments were arranged as a split block design with 4 replicate blocks. Applications were made using a Bowman Mudmaster fitted with Teejet XR 8002 dual flatfan nozzles at 19.5 spacing with a spray volume of 10 gal/ac at 40 psi. SBL populations were determined 5, 8, 12, and 21 days after treatment by shaking 2 rows over a 2.5-foot black drop cloth twice within each plot for a total of 10 row feet sampled. A defoliation rating was taken 21 days after treatment. Yield was recorded in bu./ac. Data was analyzed using SAS version 9.4, and means were separated using the PROC GLIMMIX function with an alpha level of 0.05.

Results and Discussion

At the first sampling date, 5 days after application, Denim 12 oz/ac, Intrepid Edge 4 oz/ac, Intrepid Edge 5 oz/ac, Intrepid plus acephate, and Plemax had fewer SBL than the untreated check (Table 1). At the second sampling date, 8 days after treatment, Besiege, both rates of Denim, both rates of Intrepid Edge, Elevest, Intrepid at 6 and 8 oz/ac, Intrepid plus acephate, and Plemax reduced SBL populations when compared to the untreated check. At the third sampling date, 12 days after application, all rates of Intrepid lost residual control, whereas all other treatments reduced SBL populations. At the fourth sampling date, 21 days after application, Denim 12 oz/ac and Intrepid edge 4 oz/ac were the only treatments that reduced SBL populations when compared to the untreated check. All treatments other than Intrepid 4 oz/ac, Intrepid 8 oz/ac, and Intrepid plus acephate reduced defoliation when compared to the untreated check. No yield differences were observed between treatments.

Practical Applications

Soybean loopers are a problematic insect pest for Arkansas soybean growers. Due to their migratory nature, insecti-

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cide efficacy can vary greatly from year to year. Trials such as these allow us to evaluate insecticide efficacy to quickly change recommendations during the growing season.

Acknowledgments

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Table 1. Soybean looper counts (*Chrysodeixis includens*), defoliation, and yield by insecticide treatment at selected days after application (DAA) in Tillar, Ark.

Insecticide	5 DAA	8 DAA	12 DAA	21 DAA	Defoliation	Yield
(oz/ac)		(Loopers/10 row feet)			(%)	(bu./ac)
Untreated	48.00 a	68.25 a	64.75 a	46.0 a	20.50 a	50.42 a
Besiege 8 oz/ac	33.25 abc	35.75 bcd	43.25 bcde	42.0 ab	8.75 cd	50.51 a
Denim 8 oz/ac	30.00 abcd	26.50 cde	31.25 defg	40.0 ab	8.50 cd	52.54 a
Denim 12 oz/ac	17.00 cd	14.75 e	15.00 g	16.0 b	6.25 d	50.77 a
Intrepid Edge 4 oz/ac	17.25 cd	17.75 de	23.75 efg	14.0 b	8.75 cd	47.32 a
Intrepid Edge 5 oz/ac	11.50 d	14.50 e	23.00 fg	37.0 ab	12.75 bcd	54.47 a
Elevest 6.75 oz/ac	33.75 abc	39.75 bc	39.00 cdef	26.5 ab	12.00 bcd	49.83 a
Intrepid 4 oz/ac	40.25 ab	52.75 ab	59.00 ab	39.0 ab	20.75 a	47.88 a
Intrepid 6 oz/ac	42.25 ab	46.00 bc	46.75 abcd	35.5 ab	13.25 bc	54.04 a
Intrepid 8 oz/ac	36.00 abc	40.75 bc	56.75 abc	32.0 ab	16.50 ab	51.11 a
Intrepid 4 oz/ac + Acephate 8.21 oz/ac	22.25 bcd	29.50 cde	34.25 defg	44.5 a	17.50 ab	54.95 a
Plemax 5 oz/ac	18.25 cd	28.00 cde	30.00 defg	35.5 ab	13.00 bc	48.95 a

Means followed by the same letter are not significantly different at $P = 0.05$.
Significance is determined separately for each sampling period.

Two-Year Impact of See & Spray™ Premium at Two Extreme Detection Settings in Soybean

T.H. Avent,[1] J.K. Norsworthy,[1] L.M. Schwartz-Lazaro,[2] and M.M. Houston[2]

Abstract

Targeted herbicide applications provide an opportunity for Arkansas soybean producers to reduce herbicide inputs, improving profitability. John Deere currently offers See & Spray™ Premium, which can be purchased or retrofitted to new sprayers. The Premium system allows for targeted applications utilizing the See & Spray technology but uses a single tank and boom, which would force all herbicides to be either targeted or applied in 2 passes when applying postemergence and preemergence products separately. Research was initiated at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center at Keiser, Ark., to determine the year-to-year impact of a high and low detection setting with See & Spray Premium compared to traditional broadcast programs in a long-term study. In 2022 and 2023, the 3 application methods utilized the same herbicide program, and plots stayed in the exact location each year. Residual herbicides were also targeted with the postemergence herbicides using See & Spray. See & Spray at the low sensitivity setting provided better savings than the high setting in both years at the early-postemergence timing. However, the low setting missed more weeds in 2023 than the broadcast or high sensitivity setting. Plots treated using a low sensitivity setting in 2022 had higher weed counts in 2023 than the other applications, indicating an increase in the weed seedbank from one year to the next. Overall, See & Spray herbicide savings ranged from 41% to 59%. The low sensitivity caused 37 Palmer amaranth (*Amaranthus palmeri* S. Watson) escapes/plot prior to harvest, whereas the broadcast and high sensitivity setting led to 9 and 12 escapes, respectively. Based on these results, producers should be cautious about utilizing the low sensitivity setting with See & Spray if both postemergence and residual herbicides will be applied as targeted applications in a single pass.

Introduction

Precision sprayers in current production systems could reduce herbicide inputs (Cardina et al., 1997; Metcalfe et al., 2019; Wiles et al., 1992). John Deere recently commercialized See & Spray™ Premium, which targets herbicide applications to weeds detected by the technology. The Premium system mainly differs from the See & Spray Ultimate by only having a single tank and boom system. With the Premium system, producers may be inclined to apply residuals through targeted applications rather than making 2 trips applying postemergence and residuals separately to the entire field. See & Spray also allows producers to change detection sensitivity, affecting which weeds get treated with herbicides and the area that receives residual herbicides. With the increasing cost of operating inputs (USDA-NASS, 2022), producers may be inclined to turn down the detection sensitivity setting to reduce the area sprayed, but this could result in missed weeds.

Arkansas soybean [*Glycine max* (L.) Merr.] producers need more insight into the capabilities of this new technology for their production systems. However, no published literature has compared the year-to-year impact of See & Spray Premium in different detection settings to that of traditional broadcast herbicide applications. Additionally, producers should be aware of the tradeoffs between herbicide savings and the potential increase in weed populations from one year to the next. Therefore, an experiment was conducted in 2022 and 2023 at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) at Keiser, Ark., to determine the year-to-year impact of 2 extreme detection settings with See & Spray Premium in XtendFlex® soybean.

Procedures

The experiment was designed as a randomized complete block with 6 replications. Plots were 8 rows wide (25.2 ft) and 250 ft long and kept in the same location the following year to monitor the changes over time. Three treatments utilized the same herbicide program in both years and only differed by application method [broadcast (BC), See & Spray Premium at the highest detection sensitivity setting, or See & Spray Premium at the lowest detection sensitivity setting]. Additionally, for each of the postemergence applications, residual herbicides were applied with the postemergence herbicides, whether broadcasted or targeted. At planting, paraquat, flu-

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mioxazin, and pyroxasulfone were broadcasted to the field at 0.64, 0.06, and 0.08 lb ai/ac, respectively. At early-postemergence (EPOST), glufosinate, glyphosate, and *S*-metolachlor (0.59, 1.13, and 1.43 lb ai/ac, respectively) were applied as a broadcast or as targeted applications with See & Spray at the two different settings. At mid-postemergence (MPOST), glufosinate and acetochlor were applied using the 3 application methods at 0.59 and 1.13 lb ai/ac, respectively. Planting and preemergence applications occurred 4 May 2022 and 17 May 2023; EPOST and MPOST applications occurred 39 and 50 days after planting in 2022 and 19 and 33 days after planting in 2023. All applications occurred with a prototype See & Spray machine attached to the front-end loader of a JD6130R designed with a 12.5-ft wide boom calibrated to deliver 15 gallons per acre at 12 miles per hour and PS3DQ005 nozzles.

At the time of each application, recordings of each plot were collected and analyzed using John Deere's proprietary software to determine the percent area sprayed. Additionally, blue dye was included with the herbicides, and after application, 2 furrows were walked for the length of the plot and counted for the number of weeds present and missed. Before harvest, the total number of reproductive Palmer amaranth (*Amaranthus palmeri* S. Watson) plants/plot were counted. After, plots were harvested with a JDS690 with a 25.2-ft header. Soybean yield was adjusted to 13% moisture and extrapolated to bu./ac. These data were subjected to a repeated measures analysis of variance and considered significant at $\alpha = 0.05$. The repeated measure factors included application timing and year. The application method factor was considered a fixed effect and nested within the repeated measures. Means were separated using Fisher's protected least significant difference at $\alpha = 0.05$. Data were analyzed using JMP Pro version 17 (SAS Institute, Cary, N.C.) with the Fit Model platform.

Results and Discussion

In 2022, the number of weeds in the plots at each application averaged 13 to 15 plants/500 ft (Table 1). The species counted at application included a mix of morningglory species (*Ipomoea* spp.), Palmer amaranth, and broadleaf signalgrass [*Urochloa platyphylla* (Munro ex C. Wright) R.D. Webster]. Additionally, during the first year, no weeds were missed, and this is likely a function of large weeds since rainfall in 2022 prevented a timely early-postemergence application. However, in 2023, more weeds were observed in plots treated with targeted herbicide applications at a low detection sensitivity. Furthermore, this same treatment missed more weeds in 2023, which was a timely application to labeled weed sizes. The presence of more weeds in the subsequent year indicates an increase in the soil seedbank for plots treated with low sensitivity in 2022 despite the lack of differences in escapes at harvest in 2022.

More escapes were also observed with this same treatment in 2023, with the broadcast and See & Spray at a high detection sensitivity only allowing 9 and 12 Palmer amaranth escapes at harvest versus the low setting, allowing 37 to escape before harvest (Table 1). For herbicide savings, averaged over the two years, See & Spray at both settings provided a 41% to 59% reduction in herbicides used at either application timing (Table 2). At early postemergence, the high detection sensitivity had less herbicide savings than the low, which provided 41% and 59%, respectively. By the mid-postemergence timing, no differences existed between the 2 sensitivity settings.

Practical Applications

Better savings occurred with the low sensitivity setting, but the risk associated with missing weeds and the higher number of escapes at harvest indicate that these savings would diminish and could likely cause more detriment in future years. One possibility is that the density could increase so that the low sensitivity no longer produces herbicide savings in future years. Another concern is that applying residual herbicides through targeted applications could result in more weeds emerging before full canopy closure. We continue to recommend utilizing the See & Spray for herbicide savings on postemergence products while broadcasting residuals. Splitting the applications is not always possible due to time constraints and efficiency. Based on the results of this study, if residual herbicides are applied through targeted applications with See & Spray, a high detection sensitivity setting should be used.

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Table 1. Effects of year and treatment application method on weed counts, misses, and Palmer amaranth (*Amaranthus palmeri* S. Watson) escapes.

Year	Treatment	Weed counts at application		Palmer amaranth escapes
		Present	Missed	
		------- (#/500 ft of row) --------		(#/plot)
2022	BC[†]	15 B[‡]	0 B	0 B
	S&S high	15 B	0 B	1 B
	S&S low	13 B	0 B	3 B
2023	BC	12 B	0 B	9 B
	S&S high	19 B	1 B	12 B
	S&S low	44 A	6 A	37 A
	P-value	0.0020	< 0.0001	< 0.0173

[†] Abbreviations: BC = broadcast; S&S = See & Spray™

[‡] Means within a column followed by the same letter are not significantly different according to Fisher's protected least significant difference at α = 0.05

Table 2. Effects of application timing and treatment application method on herbicide savings.

Timing	Treatment	Herbicide Savings
		(%)
Early-postemergence	Broadcast	0 -
	See & Spray™ high	41 C
	See & Spray low	59 A
Mid-postemergence	Broadcast	0 -
	See & Spray high	55 AB
	See & Spray low	52 B
	P-value	0.0020

[†] Means within a column followed by the same letter are not significantly different according to Fisher's protected least significant difference at α = 0.05. Means followed by a "-" were excluded from the analysis as broadcast treatments sprayed 100% of the area.

Genomic Analyses and Development of Biocontrol Agents of Palmer Amaranth (Pigweed)

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Abstract

Palmer Amaranth (*Amaranthus palmeri* S. Watson; pigweed) is the most problematic pest management issue faced by Arkansas soybean producers. Management options are limited, and pigweed populations have evolved resistance to most existing herbicide chemistries. Biological control is a promising alternative to conventional chemical control strategies for pigweed, but more information is urgently needed about potential pathogens and pests that could contribute to biological control. In previous work, we identified 2 promising biological control pathogens of pigweed, strains AF22 and AF24. These 2 fungi are capable of infecting and killing pigweed plants and inducing a pattern of cell death consistent with a host-selective phytotoxin. To optimize AF22 and AF24 as biological control organisms and to identify the genetic basis of phytotoxin production, we sequenced, assembled, and analyzed the genomes of both strains. Short-read sequencing at a predicted depth of ~40x coverage was sufficient to create draft genome assemblies of AF22 and AF24. These genome assemblies were sufficient for taxonomic placement of AF22 and AF24 in the *Diaporthe* species complex. Comparative analyses of the largest contigs suggested that AF22 and AF24 were closely related, but not clonal, strains. However, the relatively small average contig size of both assemblies and the apparent overprediction of total genome size for both strains suggested a high percentage of repetitive genomic sequences unresolvable by short-read sequencing. Long-read sequencing will be required to fully support the identification of genes underlying phytotoxin biosynthesis and to further advance AF22 and AF24 as biological control organisms for pigweed.

Introduction

Palmer amaranth (*Amaranthus palmeri* S. Watson; pigweed) has become entrenched as the most economically important weed pest of soybean production in Arkansas (Barber et al., 2015). Many factors contribute to making pigweed difficult to control, including high levels of genetic diversity driven by a dioecious reproductive strategy, large numbers of seeds produced per plant, the long-term persistence of pigweed seeds in soil seedbanks, high levels of seed dispersal, a short timeframe for reproductive development leading to multiple seed production cycles per growing season, hardiness and rapid growth, and the rapid evolution of resistance to multiple herbicide modes of action (Ward et al., 2013). The evolution of herbicide resistance is particularly problematic for pigweed control, and concerns are growing that pigweed populations may ultimately evolve to become “superweeds” that are resistant to most, if not all, existing chemical control options (Damalas and Koutroubas, 2024).

Given the ability of pigweed to evolve herbicide resistance, biological control has increasingly been considered as a potential alternative, or complementary tool, for pigweed management in soybean production. The conceptual basis of biological control is to utilize organisms such as naturally occurring fungal pathogens to reduce populations of an unwanted pest such as pigweed (Waage and Greathead, 1988). In previous work supported by the Arkansas Soybean Promotion Board, we identified 2 fungal pathogens, strains AF22 and AF24, that show excellent potential as biological control organisms targeting Palmer amaranth (Swift et al., 2022). Both strains are capable of killing pigweed plants, and both strains cause plant cell death in a manner consistent with the production of a host-selective phytotoxin. However, information needed to fully exploit AF22 and AF24 as biological control organisms has been lacking, such as the taxonomic identity of the strains and information about potential genes underlying phytotoxin biosynthesis.

In this study, we utilized a short-read DNA sequencing technology to obtain draft genome sequences for AF22 and AF24. The resulting genome assemblies were then utilized for taxonomic placement, analyses of genetic relatedness of the two strains, to assess the genetic basis of virulence, and search for gene clusters potentially underlying phytotoxin biosynthesis. The work described in this study represents an important step forward in the development of AF22 and AF24 as biological control organisms targeting Palmer amaranth.

Procedures

Genome Sequencing and Analysis

AF22 and AF24 were grown on V8 agar amended with carbenicillin (Fig. 1). Colonized agar plugs were cut from actively growing cultures and homogenized in 2-mL screw-cap centrifuge tubes containing 10 to 15 sterile glass beads (2 mm

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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 23.0.5 for quality control analyses, de novo genome assembly, comparative genomic analyses, and alignments.

Results and Discussion

Genome Assembly

The genomes of AF22 and AF24 were each assembled using Qiagen CLC Genomics Workbench. The genome assemblies of both strains were similar in size, coverage, and quality (Table 1, Table 2). For both strains, 2 assemblies were created. The first assemblies were constructed with parameters that limited the minimum contig length to 2,000 nucleotide base pairs (bp). The resulting assemblies had N50 values of 19,028 bp and 18,049 bp for AF22 and AF24, respectively. When the genomes were reassembled using parameters that limited the minimum contig length to 10,000 bp, the resulting N50 values stayed about the same, but the genome size of AF22 and AF24 decreased by about 30,000,000 bp. This means that about 25% of the genomes of AF22 and AF24 can be represented by contigs less than 10,000 bp long. We suspect that a high number of transposable elements and repetitive regions exist in each genome, and these repetitive sequences were over-represented during genome assembly.

Taxonomic Identification

Five key barcoding loci were identified and extracted from the genome sequences of AF22 and AF24. The loci analyzed included the internally transcribed spacer (ITS) of the ribosomal DNA, the beta-tubulin (TUB) gene, the histone (HIS) gene, and the calmodulin (CAL) gene, and translation elongation factor 1-α (TEF1). These barcoding loci are commonly used to identify a wide range of fungi to the species level (Xu, 2016). A multi-locus phylogeny was constructed using the barcoding loci from AF22, AF24, and other fungi in the class Sordariomycetes. The multi-locus phylogeny revealed that AF22 and AF24 belong to a clade of host-specific plant pathogens within the genus *Diaporthe*. Species of *Diaporthe* typically have genome sizes ranging from approximately 52,000,000 bp to 65,000,000 bp (NCBI, 2024).

Comparative Analyses of AF22 and AF24 Genomes

Initial alignments of the largest contigs from AF22 and AF24 indicated a high level of nucleotide identity. Small (1–2 kb) translocations were observed among some contigs when compared across the 2 genomes, although these were potentially artifacts of genome assembly due to the high percentage of repetitive elements in both genomes. Because of the relatively low number of large contigs in both genome assemblies, the full extent to which the 2 strains are related cannot be determined until improved genome assemblies are available.

Conclusions

The taxonomic placement of AF22 and AF24 in the *Diaporthe* species complex is encouraging, as members of *Diaporthe* are increasingly appreciated as potential sources of bioherbicides due to their prolific production of secondary metabolites and restricted host ranges (Hilário and Gonçalves, 2022). The draft genome assemblies created in this study were sufficient to perform taxonomic analyses, as complete sequences for all major barcoding genes were extracted for AF22 and AF24. Additionally, the assemblies were sufficient for comparative analyses assessing genetic relatedness and potential clonality of the 2 strains. However, the average contig size of both assemblies was smaller than ideal and likely insufficient to conclusively identify larger gene clusters potentially required for phytotoxin production. The likely overprediction of total genome size for both strains suggested the presence of extensive regions of repetitive genomic sequence that will be difficult to resolve with short-read sequencing. Immediate future plans include performing long-read sequencing to create a more accurate and complete reference genome sequence for AF22 and AF24. An improved genome assembly will directly complement ongoing, parallel activities to identify potential host-restricted phytotoxins via biochemical approaches.

Practical Applications

This research directly supports the development of biological control products targeting Palmer amaranth, one of the most economically important pests affecting Arkansas soybean production. The development of biological control products targeting Palmer amaranth will give growers urgently needed new options for pigweed control. Based on biological control products developed to target other weeds, biological control products targeting Palmer amaranth are predicted to be affordable, accessible, and cost-effective.

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Table 1. Summary statistics for genome sequencing and assembly of strain AF22.

Measurements	Assembly with minimum contig length set to 2,000 bp[a]	Assembly with minimum contig length set to 10,000 bp
Minimum contig size	2,001 bp	10,017 bp
Maximum contig size	258,284 bp	258,282 bp
N75[b]	9,812 bp	16,606 bp
N50[c]	19,028 bp	25,127 bp
N25[d]	31,470 bp	37,685 bp
Average length	11,774 bp	22,374 bp
Contigs in final assembly	9,983	3,912
Genome size	117,541,499 bp	87,525,644 bp

[a] bp = nucleotide base pairs.
[b] N75 = sequence length of the shortest contig at 75% of the total assembly length.
[c] N50 = sequence length of the shortest contig at 50% of the total assembly length.
[d] N25 = sequence length of the shortest contig at 25% of the total assembly length.

Table 2. Summary statistics for genome sequencing and assembly of strain AF24.

Measurements	Assembly with minimum contig length set to 2,000 bp[a]	Assembly with minimum contig length set to 10,000 bp
Minimum contig size	1,987 bp	10,004 bp
Maximum contig size	185,667 bp	259,623 bp
N75[b]	9,080 bp	16,318 bp
N50[c]	18,049 bp	24,465 bp
N25[d]	30,590 bp	36,208 bp
Average length	11,048 bp	21,965 bp
Contigs in final assembly	10,372	3,723
Genome size	114,588,036 bp	81,775,093 bp

[a] bp = nucleotide base pairs.
[b] N75 = sequence length of the shortest contig at 75% of the total assembly length.
[c] N50 = sequence length of the shortest contig at 50% of the total assembly length.
[d] N25 = sequence length of the shortest contig at 25% of the total assembly length.

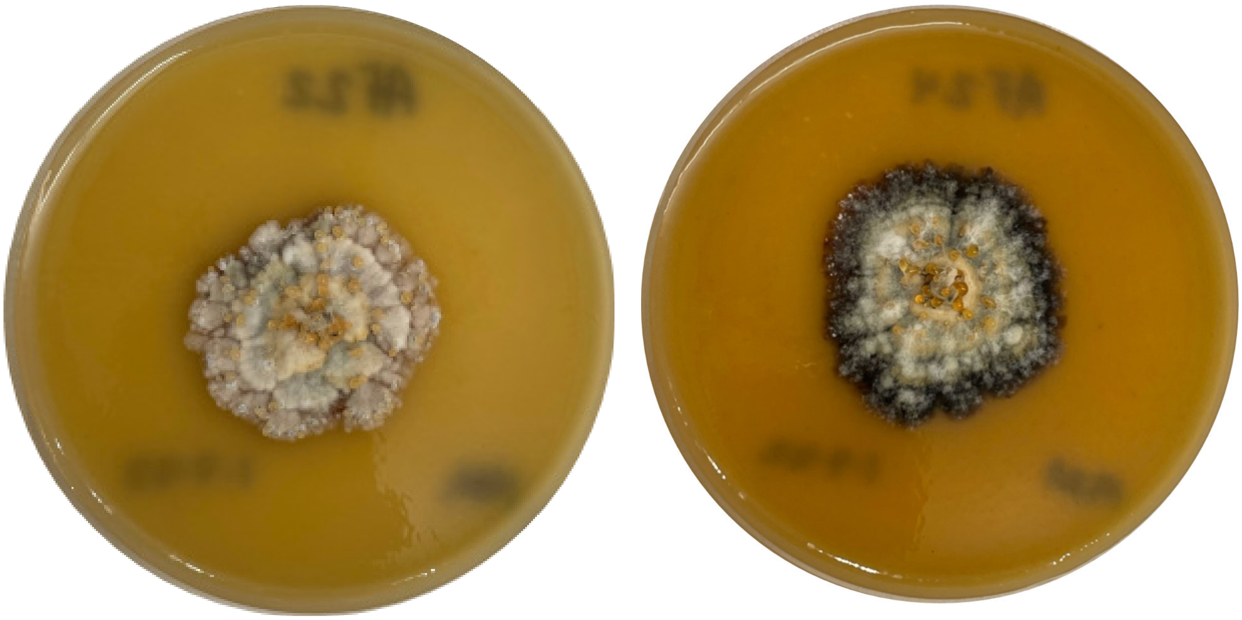

Fig. 1. Fungal strains AF22 and AF24 growing on center-inoculated plates of V8 agar + 100 µg/ml carbenicillin.

Addition of Metabolic Disruptors to Glufosinate and the Impact on Weed Control

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Abstract

Glufosinate (Liberty® or Interline®) efficacy is often impacted by environmental factors and approaches to ensure successful applications are highly sought after. Therefore, the impact of metabolic disruptors added to glufosinate-ammonium on Palmer amaranth (*Amaranthus palmeri* S. Wats.) control was evaluated at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark., and the Northeast Research and Extension Center (NEREC) in Keiser, Ark. The experiment was designed as a randomized complete block with 2 factors, and each treatment had 4 replicates. Factor 1 was glufosinate with or without metabolic disruptors [baicalin, diethyl maleate, 4-chloro-7-nitrobenzofurazan, and ultra-low dose of saflufenacil (Sharpen® at 0.04 fl oz/ac)]. Factor 2 consisted of the time of application, at 10 a.m. or dusk. Additionally, due to concerns regarding solubility and plant uptake, a premix of the natural glutathione S-transferase-inhibitor baicalin plus glufosinate was formulated (EXPH-107), and further experiments were conducted to evaluate weed control efficacy of EXPH-107 compared to glufosinate alone. The experiments were designed as a randomized complete block with a single factor and 4 replicates. There was no difference among treatments applied at 10 p.m. with or without metabolic disruptors. Conversely, applications at 10 a.m. resulted in improved control when the low dose of saflufenacil was added to glufosinate, while diethyl maleate addition increased control at 3 weeks after treatment (WAT). Improved Palmer amaranth and common lambsquarters (*Chenopodium album* L.) control occurred at 3 WAT when using the EXPH-107 premix (glufosinate formulated with baicalin) compared to glufosinate alone. There is potential to improve control by adding metabolic disruptors to glufosinate, but it is necessary to ensure that the additives are absorbed by targeted weeds and are safe for crops.

Introduction

Glufosinate-ammonium (Liberty® or Interline®) is among the few over-the-top options to control herbicide-resistant weeds (Mahoney et al., 2020; Singh et al., 2023). However, environmental conditions highly influence glufosinate efficacy, and strategies to optimize applications are sought (Coetzer et al., 2001; Hess, 2000). The addition of products that can inhibit metabolism or induce stress is among the approaches to overcome the inconsistency in herbicide performance, consequently increasing weed control, and it has been pursued in the past (Norsworthy and Priess et al., 2020; Takano et al., 2020). For instance, Palmer amaranth (*Amaranthus palmeri* S. Wats.) control improved significantly when a glutathione S-transferase (GST) inhibitor was added to glufosinate (Norsworthy and Priess, 2020).

The GST enzymes play an important role in detoxifying xenobiotic compounds, including herbicides, and certain natural products are strong GST inhibitors (Georgakis et al., 2021; Marrs, 1996). Additionally, the addition of an ultra-low dose of saflufenacil (Sharpen®) to glufosinate applications enhanced control by inducing the accumulation of reactive oxygen species (Takano et al., 2020). Therefore, the objective of this study was to determine if the addition of metabolic disruptors is an effective approach to improve the efficacy of glufosinate-ammonium weed control.

Procedures

To evaluate the impact on Palmer amaranth control by metabolic disruptors added to glufosinate-ammonium, 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, Ark., and in 2023 at the Northeast Research and Extension Center (NEREC) in Keiser, Ark. Applications occurred at the label-recommended weed stage, targeting young plants that were under 3 in. and actively growing (Anonymous 2021). The experiments were designed as a randomized complete block with 2 factors, and each treatment had 4 replicates. Factor 1 was glufosinate with or without metabolic disruptors. Factor 2 consisted of the time of application, at 10 a.m. or dusk. All treatments had glufosinate at 0.59 lb ai/ac (32 fl oz/ac of Interline®, UPL NA Inc., King of Prussia, Pa.). The metabolic

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disruptor rates are described in Table 1. A nontreated control was maintained for comparison. The treatment with an ultra-low dose of saflufenacil (0.0009 lb ai/ac; Sharpen® at 0.04 fl oz/ac) was sprayed with methylated seed oil at 0.5% v/v. All other treatments included nonionic surfactant at 0.25% v/v. Additionally, the treatments, including a GST-inhibitor or depleter (Table 1), were solubilized in dimethyl sulfoxide at 2% v/v and 70% ethanol at 50% v/v.

Due to concerns regarding solubility and plant uptake, a premix of the natural GST-inhibitor baicalin plus glufosinate was formulated (EXPH-107), and experiments were conducted to evaluate weed control efficacy of EXPH-107 compared to glufosinate alone. Experiments focusing on Palmer amaranth and common lambsquarters (*Chenopodium album* L.) control were conducted in 2023 at the Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Ark., and at the Northeast Research and Extension Center (NEREC) in Keiser, Ark. The experiments were designed as a randomized complete block with a single factor and 4 replicates. The treatments consisted of glufosinate alone (Interline®, UPL NA Inc., King of Prussia, PA) versus glufosinate formulation including baicalin (EXPH-107). Glufosinate was applied at 0.53 lb ai/ac (29 fl oz/ac of product) in both treatments and a baicalin rate equivalent to 0.06 lb ai/ac.

For both trials, visible control per weed species was assessed at 1, 2, and 3 weeks after treatment (WAT) using a scale of 0 to 100, with 0 being no control and 100 being complete weed control (Frans et al. 1986). The weed control data were subjected to analysis of variance using PROC GLIMMIX function in SAS v. 9.4 (SAS Institute, Cary, N.C. 27513). Regardless of the F test significance, the treatments in the experiment evaluating several metabolic disruptors were analyzed using the SLICE function in SAS to detect differences at each application time. Student's t-test ($P < 0.05$) was used to compare means if significant in the experiment comparing glufosinate alone to the EXPH-107 premix.

Results and Discussion

The first set of experiments evaluated Palmer amaranth control with the addition of different metabolic disruptors to glufosinate-ammonium (Table 2). At 10 p.m., no differences were detected among treatments. However, the addition of an ultra-low dose of saflufenacil increased control at 2 and 3 WAT, while diethyl maleate showed increased control at 3 WAT. All treatments, including a metabolic disruptor, displayed numerically higher control compared to glufosinate alone. Similarly, the addition of a low dose of saflufenacil to glufosinate increased Palmer amaranth control even under non-optimal environmental conditions (Takano et al., 2020). Improved Palmer amaranth and common lambsquarters control was observed at 3 WAT when using the EXPH-107 premix (glufosinate formulated with baicalin) in comparison to glufosinate alone (Table 3; Table 4). In fact, common lambsquarters control improvement was observed at all evaluation timings. These results show that a premix of glufosinate with the GST-inhibitor baicalin improves weed control. Previously, increased weed control was observed by adding GST-inhibitors to glufosinate and other herbicides (Norsworthy and Priess, 2020; Schwarz et al., 2021).

Practical Applications

The addition of metabolic disruptors to glufosinate increased the control of the species evaluated and has the potential to provide improved control if a commercial product becomes available. It is necessary to ensure that additives to glufosinate are properly solubilized to maximize plant uptake and, in turn, weed control. Additional research is necessary to evaluate the impact of these disruptors on different problematic species, including grasses and crop safety.

Acknowledgments

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Table 1. List of different treatments with or without metabolic disruptors and 2 application times. All treatments were applied with glufosinate at 0.59 lb ai/ac (Interline® at 32 fl oz/ac) plus nonionic surfactant at 0.25% v/v or methylated seed oil at 0.5% v/v (treatment with reactive oxygen species enhancer).

Treatments	Additive type	Rate	Application timing
		(lb ai/ac)	
Nontreated	-----	-----	-----
Glufosinate alone	-----	-----	10 a.m. dusk
Glufosinate + baicalin	GST-inhibitor‡	0.25	10 a.m. dusk
Glufosinate + diethyl maleate	GSH-depleter§	0.25	10 a.m. dusk
Glufosinate + NBD-Cl†	GST-inhibitor	0.25	10 a.m. dusk
Glufosinate + saflufenacil	ROS enhancer¶	0.001	10 a.m. dusk

† NBD-Cl = 4-chloro-7-nitrobenzofurazan.
‡ GST = glutathione *S*-transferases.
§ GSH = glutathione.
¶ ROS = reactive oxygen species.

Table 2. Palmer amaranth control from glufosinate with or without metabolic disruptors at 1, 2, and 3 weeks after treatment (WAT). The values are the average of two trials.

	Palmer amaranth control							
	1 WAT		2 WAT			3 WAT		
Treatment	10 am	10 pm	10 am		10 pm	10 am		10 pm
	------ (%) ------							
Glufosinate	71	77	71		72	49		71
Glufosinate + baicalin	71	77	63	ns	73	61	ns	67
Glufosinate + diethyl maleate	74	75	75	ns	70	72	*	76
Glufosinate + NBD-Cl†	68	82	67	ns	75	63	ns	73
Glufosinate + saflufenacil	82	78	86	*‡	72	76	*	71
	------ *P*-value ------							
	0.2972	0.7880	0.0142		0.9403	0.0108		0.7147

† NBD-Cl: 4-chloro-7-nitrobenzofurazan.
‡ Asterisks are used to separate treatments different than glufosinate using a SLICE function in SAS v. 9.4.

Table 3. Palmer amaranth control from glufosinate alone versus the premix containing baicalin (EXPH-107) at 1, 2, and 3 weeks after treatment (WAT). The values are the average of two trials.

	Palmer amaranth control		
Treatment	**1 WAT**	**2 WAT**	**3 WAT**
	---------- (%) ----------		
Glufosinate	80	80	74 b[†]
EXPH-107	84	85	83 a
	---------- *P*-value ----------		
	0.3350	0.1998	0.0447

[†] Treatments with the same lowercase letter are not different according to Student's t-test at α = 0.05.

Table 4. Common lambsquarters control from glufosinate alone versus the premix containing baicalin (EXPH-107) at 1, 2, and 3 weeks after treatment (WAT). The values are the average of two trials.

	Common lambsquarters control		
Treatments	**1 WAT**	**2 WAT**	**3 WAT**
	---------- (%) ----------		
Glufosinate	74 b[†]	66 b	58 b
EXPH-107	90 a	84 a	80 a
	---------- *P*-value ----------		
	<0.0001	0.0002	0.0012

[†] Treatments with the same lowercase letter are not different according to Student's t-test at α = 0.05.

PEST MANAGEMENT: WEED CONTROL

Influence of Soybean Width on Palmer amaranth Emergence and Yield Potential in a Relay Intercropped System

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Abstract

The rapid evolution of herbicide resistance by weeds such as Palmer amaranth (*Amaranthus palmeri* S. Wats) threatens to reduce the effectiveness of herbicide applications. Relay intercropping is a cropping strategy that may help to alleviate this problem by suppressing early-season weed emergence. Therefore, this experiment was conducted to evaluate the suppressive effect of winter wheat (*Triticum aestivum* L.) on Palmer amaranth emergence in a winter wheat-soybean [*Glycine max* (L.) Merr] relay intercrop. This experiment was conducted in 2023 at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Arkansas. Soybean monocrops with soybean either drilled on 7.5-in. rows or planted on 36-in. rows were compared to wheat-soybean intercrops with soybean planted at the same row spacings. Monocrop wheat was also included as a check for intercrop wheat yield. Compared to the soybean monocrops, season-long Palmer amaranth emergence was drastically reduced in the intercrop treatments, regardless of soybean row spacing. This reduction in emergence occurred in the first 5 weeks after soybean planting when the wheat was providing early-season ground cover. Wheat yield in the intercrops was reduced by 54% compared to the monocrop wheat check. This is likely due to the large fraction of wheat being damaged by traffic at soybean planting with small-plot equipment. Reductions are expected to decline when using commercial-scale equipment. Averaged over row spacing, intercrop soybean yielded 20% less than monocrop soybean. Both wheat and soybean may have experienced yield losses compared to their respective monocrops, but the intercrops generated yields of both crops. Economic analyses are being conducted comparing the profitability of monocrops and intercrops. Results of this experiment indicate that winter wheat in a winter wheat-soybean intercrop greatly reduces Palmer amaranth emergence compared to a soybean monocrop. Growers need not worry whether they prefer to drill or plant soybean on wider rows as weed suppression was similar regardless of spacing.

Introduction

Palmer amaranth (*Amaranthus palmeri* S. Wats) continues to terrorize Arkansas growers, being voted both the most common and troublesome weed in soybean [*Glycine max* (L.) Merr] in a 2022 survey (van Wychen, 2022). Herbicides have historically provided control of this weed, but Palmer amaranth has proved to be adept at developing resistance to many commonly used chemistries. Resistance to a total of 10 sites of action has been discovered worldwide and at least 6 of these resistances are known to be present in Arkansas (Heap, 2024). As resistance evolution continues to erode the efficacy of herbicide applications, alternative weed control strategies need to be explored.

Intercropping is an ancient agricultural practice that is defined as growing 2 or more crops simultaneously on the same plot of land. More specifically, relay intercropping is the act of growing 2 or more crops on the same plot of land so that their life cycles overlap (Andrews and Kassam, 1976). Relay intercropping increases the duration of the year a field is covered by crops. For example, a winter wheat (*Triticum aestivum* L.)-soybean relay intercrop provides ground cover from wheat emergence in the fall until soybean harvest the subsequent fall. Ground cover can decrease both the daily soil temperature fluctuations and the amount of light that reaches the soil surface (Pinamonti, 1998). Since temperature fluctuations and light are known to stimulate weed seed germination, research is needed to evaluate the suppressive effects of a relay intercrop on weed emergence (Travlos et al., 2020).

Procedures

A field experiment was conducted in 2023 at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Arkansas, to evaluate the influence of soybean row width on Palmer amaranth emergence in a winter wheat-soybean relay intercrop. Treatments included a soybean monocrop planted on 36-in. rows, a soybean monocrop drilled on 7.5-in. rows, a winter wheat-soybean relay intercrop with soybean planted on 36-in. rows, and a winter wheat-soybean relay intercrop with soybean planted on 7.5-in. rows. A treatment of monocrop wheat was also included to compare inter-

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crop wheat yields. In treatments containing wheat, wheat was drilled on 7.5-in. rows. The wheat cultivar used was Smith's Gold, seeded at 100 lb/ac and planted on 11 October 2022. The soybean cultivar used was AG45XF0, seeded at 140,000 seeds/ac and planted on 17 April 2023. Plots were 12-ft wide by 30-ft long and all plots received an application of Zidua© SC at a rate of 2 fl oz/ac at the delayed preemergence timing for wheat for fall weed control. This trial was designed as a randomized complete block with five replications.

Once Palmer amaranth began to emerge in the spring, two 5.4-ft^2 quadrants were established in each plot. On a weekly basis, Palmer amaranth emergence was tracked by counting and removing plants from these quadrants. Once these counts were performed each week, nonresidual, postemergence herbicides were applied if needed to keep the trial weed free. Visual ground cover evaluations were also recorded on a weekly basis. These recordings considered coverage provided only by wheat and soybean biomass and ranged on a scale from 0% to 100%, with 0% being bare ground and 100% being full coverage. Wheat and soybean yields were recorded at their respective maturities. Data were subjected to an analysis of variance and means were separated using Fisher's protected least significant difference $\alpha = 0.05$.

Results and Discussion

Intercropping greatly reduced the season-long emergence of Palmer amaranth compared to the monocrop treatments (Table 1). The drilled soybean monocrop saw the largest number of Palmer amaranth emerge, followed by the monocrop with 36-in. soybean. The intercrops experienced similar emergence numbers and, on average, saw 96% and 91% less emergence than the drilled and 36-in. soybean monocrops, respectively. The differences in season-long Palmer amaranth emergence can be traced to the first 5 weeks after soybean planting. Again, the drilled soybean monocrop saw the largest number of plants emerge, likely due to the increased soil disturbance of the drill. The monocrop with 36-in. soybean saw the second most emergence, followed by the intercrops, which had similar emergence numbers. On average, the intercrops saw 99% and 97% less emergence than the drilled and 36-in. soybean monocrops, respectively. The differences in Palmer amaranth emergence within the first five weeks after soybean planting are likely due to wheat in the intercrops providing high levels of ground cover early in the season (Fig. 1). There were no differences in emergence between treatments from 5 weeks after soybean planting to the end of the season (Table 1).

Intercrop wheat yields were similar between the two soybean spacings. On average, intercrop wheat yielded 54% less than the monocrop wheat check. Other researchers have found that relay intercropping winter wheat and soybean reduces wheat yields 15%–34% (Jeffers and Triplett, 1979; Reinbott et al., 1987; Moomaw and Powell, 1990). The severity of wheat yield reduction present in this experiment is likely due to the use of small-plot equipment. When planting soybean, a large portion of wheat was run over by the tractor. In a commercial setting where larger planters are used, the fraction of trampled wheat would decrease. The interaction between cropping system and soybean row spacing was not significant regarding soybean yield; however, both main effects were significant separately. Overall, intercrop soybean yielded 20% less than monocrop soybean, and 36-in. row soybean yielded 25% less than drilled soybean. Other researchers have reported reductions of 16%–43% in relay intercropped soybean compared to monocrop soybean (Jeffers and Triplett, 1979; Reinbott et al., 1987).

Practical Applications

Relay intercropping winter wheat and soybean has shown to be a system capable of suppressing Palmer amaranth emergence. Large reductions in Palmer amaranth emergence were observed in intercrops compared to monocrops, with these reductions credited to the early-season ground cover provided by wheat. Palmer amaranth suppression in the intercrops did not differ between soybean row spacing, providing flexibility in planting method within this system. Further research is being conducted into herbicide programs for wheat-soybean relay intercrops as well as the best timing for planting soybean into standing wheat. The economics of this system are complex and being analyzed. This system requires more passes over the field with equipment, increases seed costs, and reduces yield compared to a soybean monocrop; however, the wheat yield and increased weed control may prove to offset these drawbacks.

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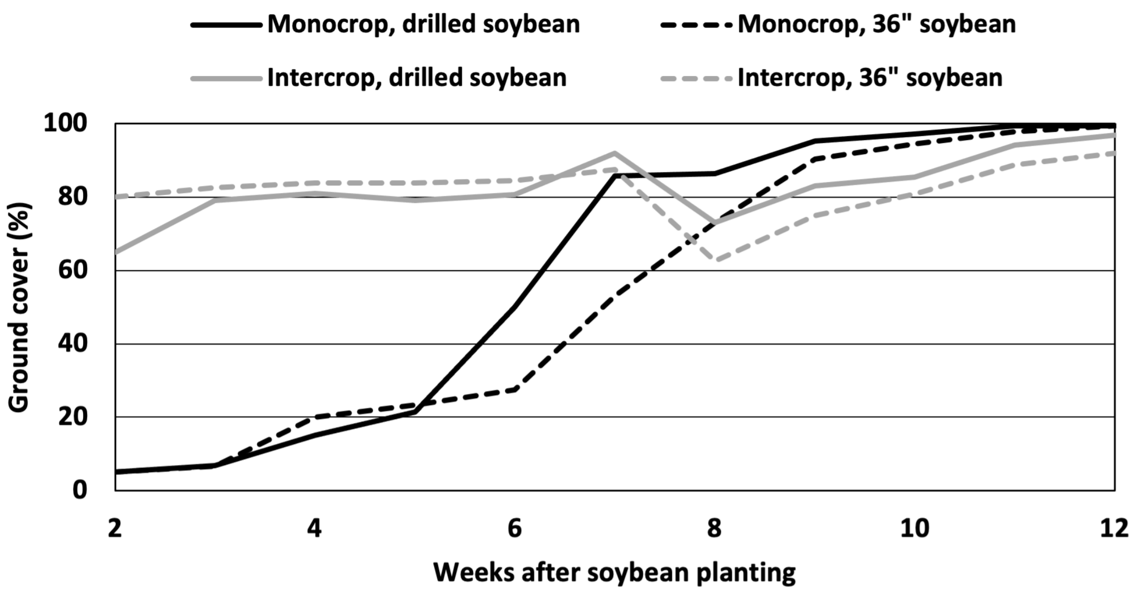

Fig 1. Percent ground cover provided by wheat and soybean biomass throughout the season by different treatments.

Table 1. Cumulative Palmer amaranth emergence the first 5 weeks after planting soybean (WAP), the remainder of the season after 5 WAP, and the season-long Palmer amaranth emergence.

	Cumulative Palmer amaranth emergence		
Treatment	**0-5 WAP**	**>5 WAP**	**Season-long**
	----------------------	(plants/ft^2)	----------------------
Monocrop, drilled soybean	48.1 a[†]	2.5	50.6 a
Monocrop, 36-in. soybean	17.9 b	2.5	20.4 b
Intercrop, drilled soybean	0.7 c	1.6	2.3 c
Intercrop, 36-in. soybean	0.5 c	1.0	1.5 c

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

Table 2. Wheat yield collected at maturity at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Arkansas.

Treatment	Wheat yield
	(bu./ac)
Monocrop, drilled soybean	-
Monocrop, 36-in. soybean	-
Intercrop, drilled soybean	41 b†
Intercrop, 36-in. soybean	41 b
Monocrop wheat	90 a

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

Table 3. Soybean yield collected at maturity at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Arkansas.

Treatment	Soybean yield
	(bu./ac)
Cropping system	
Monocrop	92 a†
Intercrop	74 b
Soybean row spacing	
Drilled	95 a
36-in.	71 b

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

Does Application Timing of a Diflufenican-Premixture Affect Soybean Tolerance and Palmer amaranth Control?

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Abstract

Bayer CropScience has announced its intentions to launch Convintro™ brand herbicides, one being a diflufenican:metribuzin:flufenacet premixture for use preemergence in soybean [*Glycine max* (L.) Merr.]. Diflufenican is a Weed Science Society of America group 12 herbicide adding a new site of action for soybean producers to integrate into herbicide programs. Diflufenican has activity on broadleaf weed species and is targeted to control Palmer amaranth (*Amaranthus palmeri* S. Wats.) in soybean. Therefore, field experiments in 2022 and 2023 were conducted at the University of Arkansas System Division of Agriculture's Milo J. Shult Agriculture Research and Extension Center in Fayetteville, Ark., to evaluate Palmer amaranth control and soybean tolerance to various application timings of the diflufenican:metribuzin:flufenacet premixture. The application timings included 14-day preplant, 7-day preplant, preemergence, and 3 days after planting at the anticipated 1X rate for a silt loam soil. Injury 21 days after planting (DAP) ranged from 0% to 6% in 2022 and 2% to 20% in 2023 with injury increasing the later the application of the premixture occurred. By 42 DAP, less than 5% injury was observed for all application timings evaluated. Palmer amaranth control ranged from 87% to 99% 21 DAP and 65% to 90% 42 DAP in 2022 with the 14-day preplant timing being the least effective treatment. In 2023, Palmer amaranth control was >95% 21 DAP and ≥89% 42 DAP for the preemergence and 3 days after planting application timing. Grain yield was reduced by the 3 days after planting application timing compared to the 14-day preplant application.

Introduction

Currently, Weed Science Society of America (WSSA) groups 2, 3, 4, 5, 14, and 15 are recommended for use preemergence in soybean [*Glycine max* (L.) Merr.] (Barber et al., 2023). Palmer amaranth [*Amaranthus palmeri* (S.) Wats.], the most problematic weed in soybean (Van Wychen, 2022), has evolved resistance to 9 different sites of action (SOA) (Heap, 2024) leaving producers searching for new herbicides. Bayer CropScience has announced its intentions to launch Convintro™ brand herbicides, with one being a premixture for use preemergence in soybean. The premixture will contain diflufenican (WSSA group 12), metribuzin (WSSA group 5), and flufenacet (WSSA group 15) allowing producers to use multiple SOAs to help slow the evolution of herbicide resistance (Norsworthy et al., 2012). Additionally, diflufenican would add an additional site of action for soybean producers. Diflufenican is not a new herbicide, as it has been used extensively in Europe since the 1980s. However, it is highly effective against broadleaf weed species in wheat production (Haynes and Kirkwood, 1992). Therefore, an experiment was conducted to evaluate different application timings of the dif lufenican:metribuzin:flufenacet premixture for Palmer amaranth control and soybean tolerance.

Procedures

A field experiment was conducted in 2022 and 2023 at the University of Arkansas System Division of Agriculture's Milo J. Shult Agriculture Research and Extension Center in Fayetteville, Arkansas, to determine if different application timing of a diflufenican:metribuzin:flufenacet premixture affects soybean tolerance and Palmer amaranth control. Trials were drilled seeded with the cultivar AG45XFO (Bayer CropScience, Saint Louis, Mo.) into 4-row plots (12-ft wide) measuring 25-ft in length. The trial was designed as a randomized complete block design with 4 replications and 1 factor. The diflufenican:metribuzin:flufenacet premixture was applied 14-day preplant, 7-day preplant, preemergence, and 3 days after planting at the anticipated 1X rate for a silt loam soil. 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 and weed control ratings were collected 21 and 42 days after planting on a scale of 0% to 100%, with 0% being no injury or weed control and 100% being complete crop death or weed control. Finally, soybean grain yield was collected at maturity in both years. Data were subjected to an analysis of variance in JMP Pro V 17.1 and means were separated using Tukey's honestly significant difference with $\alpha = 0.05$. Site year was considered a fixed effect in the model; therefore, data were analyzed by year when significant.

Results and Discussion

By 21 days after planting, injury ranged from 0% to 6% in 2022 and 2% to 20% in 2023 for the different application

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timing evaluated. In both years, soybean injury increased the closer the application of the diflufenican:metribuzin:flufenacet premixture occurred to planting. Additionally, a total of 4.3 inches of rainfall occurred in the first 14 days after planting in 2023; however, 2.0 inches of rainfall occurred in the same period in 2022 (data not shown). Research has shown that soybean injury from diflufenican was higher when more rainfall occurred (Laplante, 2022), which could correlate to the higher injury observed in 2023. By 42 days after planting, however, soybean injury was less than 3% for all treatments evaluated, with no differences observed indicating a recovery from the early season injury.

Palmer amaranth control ranged from 87% to 99% 21 days after planting in 2022, with the 14-day preplant application timing being the only treatment providing less than 95% control. By 42 days after planting in 2022, control ranged from 65% to 90% with comparable levels of control for the 7-day preplant to 3 days after planting application timings. In 2023, Palmer amaranth control ranged from 90% to 99%, with the preemergence and 3 days after planting application timings being the most effective treatments 21 days after planting. By 42 days after planting, a similar trend was observed as the previous evaluation timing with only the preemergence and 3 days after planting application timings providing >85% control of Palmer amaranth. Soybean grain yield ranged from 26 to 42 bu./ac in 2022 and 50 to 63 bu./ac in 2023 in treatments receiving the diflufenican premixture. In both years, soybean grain yield was reduced when the diflufenican:metribuzin:flufenacet was applied 14-day preplant versus an application that occurred 3 days after planting. Overall, the diflufenican:metribuzin:flufenacet premixture applied at planting is highly effective against Palmer amaranth up to 42 days after planting.

Practical Applications

Soybean producers should apply the diflufenican:metribuzin:flufenacet premixture 7-day preplant to 3 days after planting to maximize weed control and reduce soybean injury. Additionally, the premixture adds a unique site of action that will help soybean producers diversify weed control programs aimed at control of herbicide-resistant Palmer amaranth. Additional research should evaluate commonly used preemergence herbicides used in soybean to compare the length of residual control to the diflufenican:metribuzin:flufenacet premixture.

Acknowledgments

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

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Table 1. Soybean injury, Palmer amaranth (*Amaranthus palmeri* S. Wats.) control, and soybean grain yield from different application timings of a diflufenican:metribuzin:flufenacet premixutre in 2022 and 2023 from the Milo J. Shult Agriculture Research and Extension Center in Fayetteville, Ark.

	Injury			Palmer amaranth control				Yield	
	21 DAP[†]		42 DAP	21 DAP		42 DAP			
Timing	**2022**	**2023**		**2022**	**2023**	**2022**	**2023**	**2022**	**2023**
	--------------------------------------	------	--------------	--%------	-------	-------	-------	-------bu./ac--------	
Nontreated	-	-	-	-	-	-	-	6 c	27 c
14 DPP	0 b[‡]	2 b	0[§]	87 b	92 b	65 b	70 b	26 b	50 b
7 DPP	3 ab	3 b	0	96 a	90 b	86 a	65 b	33 ab	57 ab
Pre	4 ab	20 a	1	99 a	99 a	90 a	89 a	34 ab	62 a
3 DAP	6 a	20 a	2	99 a	99 a	90 a	92 a	42 a	63 a
P-value	0.007	<0.001	0.149	0.002	0.003	0.008	<0.001	0.002	0.008

[†]Abbreviations: DAP, days after planting; DPP, day preplant; Pre, preemergence; DAP, days after planting.

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

[§] Data averaged over years.

PEST MANAGEMENT: WEED CONTROL

Economic Analysis and Effectiveness of Enlist E3 Soybean Herbicide Programs in Arkansas

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Abstract

Arkansas soybean [*Glycine max* (L.) Merr.] producers face many challenges throughout the growing season. One of the most important is weed control, particularly the control of herbicide-resistant populations of Palmer Amaranth (*Amaranthus palmeri* S. Wats.). With a limited number of herbicide options and newer trait technologies with greater seed costs, producers must make difficult decisions in choosing effective herbicide programs while remaining profitable. Enlist® E3 soybean is an attractive option to producers competing with herbicide-resistant populations of Palmer amaranth and allows for the utilization of 3 additional modes of action (MOA) to control weeds. However, many questions arise regarding the number of applications required and herbicide combinations needed to optimize both weed control and economic returns.

Introduction

Palmer Amaranth (*Amaranthus palmeri* S. Wats.) is the number one most problematic weed involved in mid-South soybean production today (Ward et al. 2013). In addition, there are only a limited number of herbicide modes of action (MOA) that producers can use on their soybean acres to stay ahead of this weed. Battling weeds can be costly as well as ineffective if done at the wrong time or if the chemical doesn't have the rainfall to get the residuals activated. Weed resistance issues and difficult-to-control species have necessitated the identification of novel strategies and herbicides for continued successful pre-plant weed management in these production systems (Flessner et al. 2019; Johanning et al. 2016; Vollmer et al. 61 2019; Westerveld et al. 2021; Zimmer et al. 2018). The purpose of this study was to evaluate the cost, in terms of return on investment, and the success rate of the selected herbicide programs. The objectives of this research were to assess the effectiveness of labeled rate applications of both pre- and postemergence in the Enlist® E3 System as well as the cost and return on investment in terms of yield for those applications. The data from this experiment will include weed control ratings, costs of applications, and yield.

Procedures

Field experiments were conducted near Marianna, Newport, and Rohwer, Arkansas, in 2023. The experiment was set up in a randomized complete block design consisting of 17 total treatments with 4 replications. Treatment timings included preemergence (A), early postemergence (B), and late postemergence or 2-4 weeks after the "B" timing (C) (Table 1). All herbicide applications were made using a CO_2-pressurized backpack sprayer with AIXR110015 nozzles calibrated to deliver a spray volume of 10 gallons per acre. Location was considered a random effect for all analyses; therefore, the data presented were averaged across locations ($P = 0.05$). Plots were evaluated season long; however, only the final weed control ratings and yield are presented. Weed control was evaluated using a visual scale of 0% to 100%, where 0 equals no control and 100 equals complete control or complete reduction in biomass.

The study was designed to evaluate the necessity of 1. multiple preemergence (PRE) MOA, 2. multiple application timings (2 vs. 3), 3. an overlapping residual herbicide, and 4. order in which glyphosate and glufosinate were applied (Table 1).

Results and Discussion

The economic analysis was conducted using 2023 herbicide and application costs from a local retailer, and the 2023 USDA-Risk Management Agency soybean harvest price of $12.84 per bushel. There was no difference in soybean yield across treatments as all yields were within a range of 4 bushels (Fig. 1). As a result, the economic analysis revealed that the greatest return on investment $580.33 occurred from the simplest herbicide program (Dual Magnum® PRE followed by (fb) Enlist One® and Roundup® applied early postemergence (EPOST)]. However, greater than 95% visual Palmer amaranth control 4 weeks after final application (WAFA) was only achieved in the treatments that received 3 herbicide applications, while the lowest Palmer amaranth control (81%) at 4 WAFA was observed in the 2 simplest herbicide programs Dual Magnum fb Enlist one plus Roundup or Liberty®) (Fig. 2).

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The lowest return on investment, $480.37, occurred from the herbicide program consisting of a multi-MOA PRE of Boundary® fb an EPOST of Enlist one + Roundup, fb a late postemergence (LPOST) of Enlist one + Roundup, which was approximately double the cost of the herbicide program with the greatest return (Figs. 1, 3, and Table 1). The herbicide program with the second lowest return on investment also relied upon sequential applications of Enlist one and Roundup with no overlapping residual (Table 1). This would indicate that although multiple MOAs and overlapping residuals did not provide the greatest return on investment, they do provide an advantage over comparable programs that do not include overlapping residuals or rotate MOAs. Although one of the simpler herbicide programs provided the greatest return on investment, the 14-percentage point reduction in visual control compared to the top herbicide programs could significantly increase the soil seedbank, affecting harvest efficiency and crop quality, thereby potentially impacting some short- and long-term economic returns.

Practical Applications

Overall, this research highlighted that the greatest economic returns occurred in minimalist herbicide programs; however, overlapping residuals and alternating MOAs in sequential applications also provided economic benefits. Future research should evaluate the long-term economics of reduced herbicide programs that allow for additions to the soil seedbank.

Acknowledgments

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Table 1. Enlist Soybean Treatment Applications and Cost.

Treatment	Herbicides	Application Rate	Application Timings[a]	Cost
		(oz/ac)		($/ac)
1	Untreated	-	-	-
2	Dual Magnum	24	A	
	Enlist One	32	B	
	Roundup Powermax	32	B	45.53
3	Dual Magnum	24	A	
	Enlist One	32	B	
	Liberty	32	B	52.10
4	Dual Magnum	24	A	
	Enlist One	32	B	
	Roundup Powermax	32	B	
	Zidua	3.25	B	46.64
5	Dual Magnum	24	A	
	Enlist One	32	B	
	Liberty	32	B	
	Zidua	3.25	B	54.22
6	Boundary	32	A	
	Enlist One	32	B	
	Roundup Powermax	32	B	59.76
7	Boundary	32	A	
	Enlist One	32	B	
	Liberty	32	B	65.35
8	Boundary	32	A	
	Enlist One	32	B	
	Roundup Powermax	32	B	
	Zidua	3.25	B	61.88
9	Boundary	32	A	
	Enlist One	32	B	
	Liberty	32	B	
	Zidua	3.25	B	67.45
10	Dual Magnum	24	A	
	Enlist One	32	B	
	Roundup Powermax	32	B	
	Enlist One	32	C	
	Roundup Powermax	32	C	76.79
11	Dual Magnum	24	A	
	Enlist One	32	B	
	Liberty	32	B	
	Enlist One	32	C	
	Roundup Powermax	32	C	80.58
12	Dual Magnum	24	A	
	Enlist One	32	B	
	Roundup Powermax	32	B	
	Zidua	3.25	B	
	Enlist One	32	C	
	Roundup Powermax	32	C	77.20

Table 1. Continued.

Treatment	Herbicides	Application Rate	Application Timings[a]	Cost
		(oz/ac)		($/ac)
13	Enlist One	32	B	
	Liberty	32	B	
	Zidua	3.25	B	
	Enlist One	32	C	
	Roundup Powermax	32	C	82.65
14	Boundary	32	A	
	Enlist One	32	B	
	Roundup Powermax	32	B	
	Enlist One	32	C	
	Roundup Powermax	32	C	88.08
15	Boundary	32	A	
	Enlist One	32	B	
	Liberty	32	B	
	Enlist One	32	C	
	Roundup Powermax	32	C	93.53
16	Boundary	32	A	
	Enlist One	32	B	
	Roundup Powermax	32	B	
	Zidua	3.25	B	
	Enlist One	32	C	
	Roundup Powermax	32	C	90.16
17	Boundary	32	A	
	Enlist One	32	B	
	Liberty	32	B	
	Zidua	3.25	B	
	Enlist One	32	C	
	Roundup Powermax	32	C	95.66

[a] A = preemergence, B = early postemergence, and C = late postemergence or 2–4 weeks after the B timing.

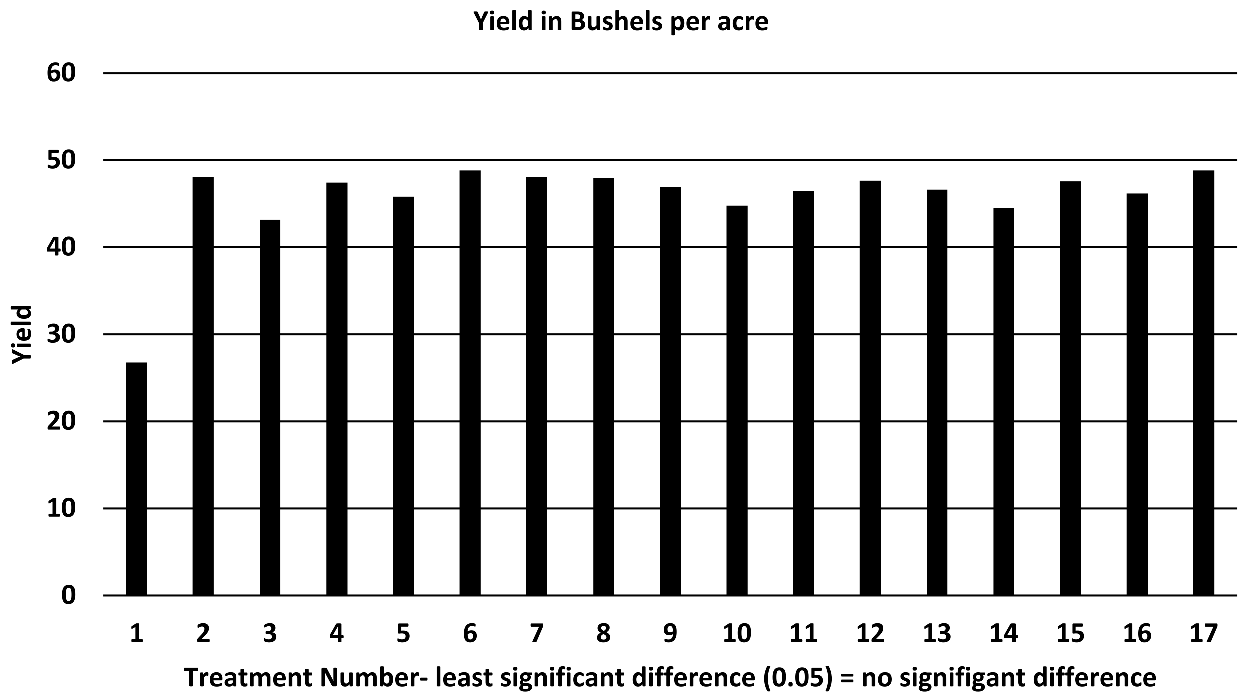

Fig. 1. Yield in bushels per acre averaged across locations.

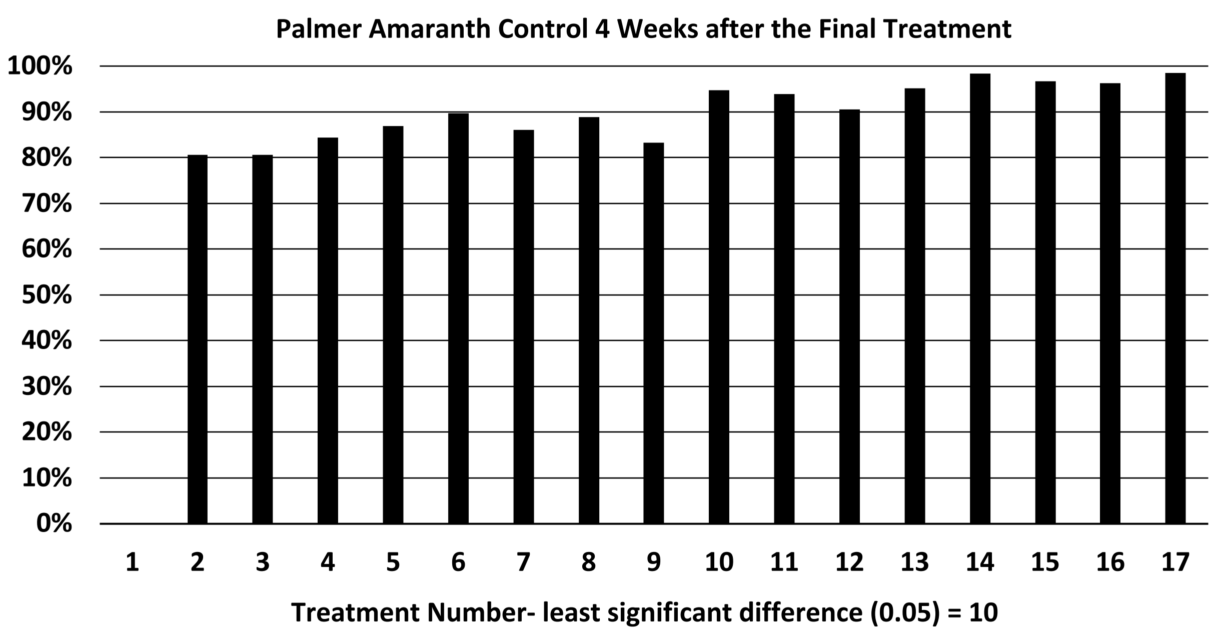

Fig. 2. Palmer amaranth (*Amaranthus palmeri* S. Wats.) control with the various herbicide treatments was averaged across locations. Plots were evaluated on a scale of 0% to 100% control.

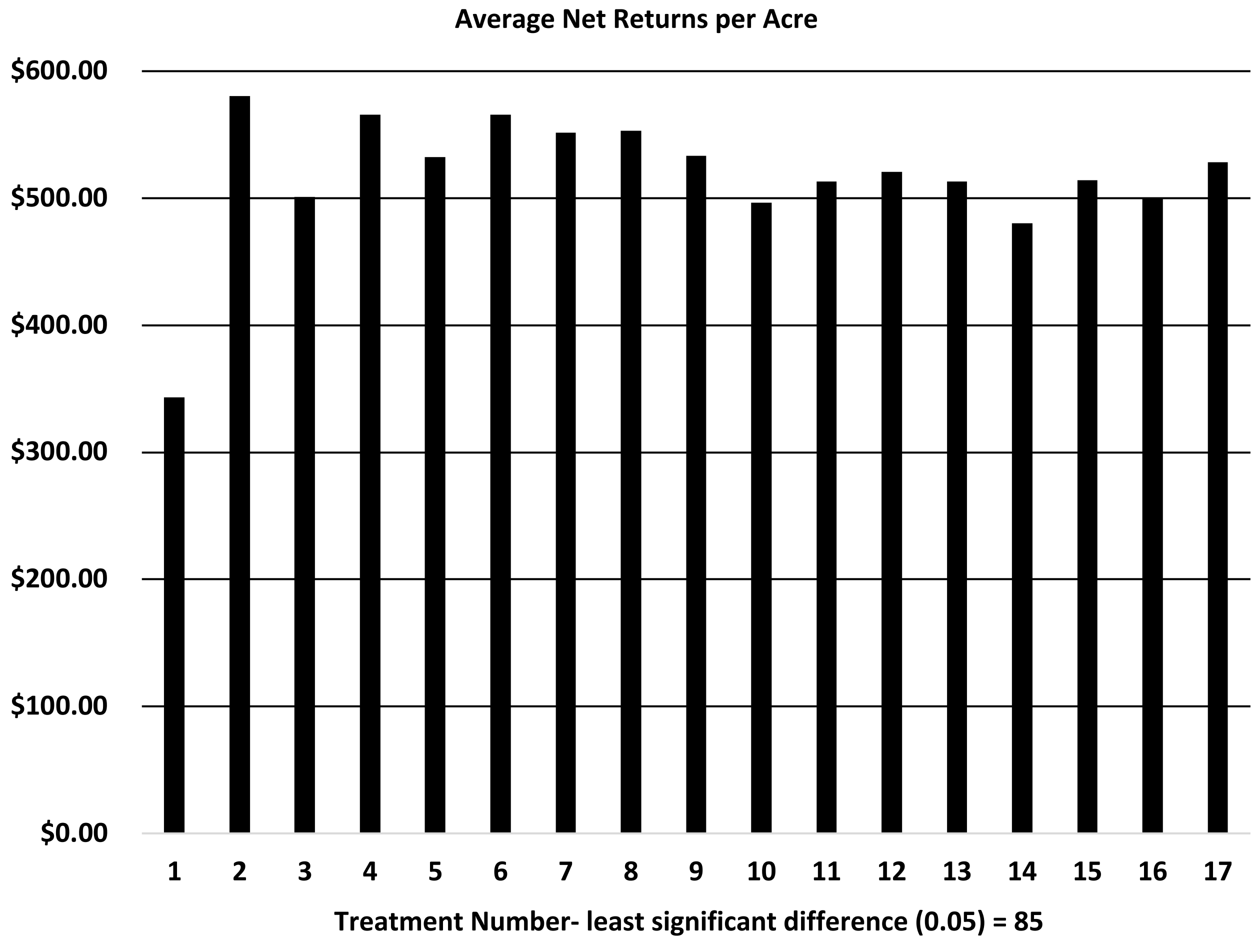

Fig. 3. Net returns per acre for the specified expenses and herbicide treatments, averaged across locations. Net returns were generated based on yield and application cost.

ECONOMICS

Soybean Enterprise Budgets and Production Economic Analysis

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Abstract

Crop enterprise budgets have been developed to be amendable for representing alternative production practices and cropping systems of Arkansas producers. Interactive budget programs apply methods that are consistent over the top of field crops grown in Arkansas. Production practices for base budgets represent the University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) recommendations from the Soybean Research Verification Program and crop specialists. Unique budgets can be customized by users based on either CES recommendations or information from producers utilizing their individual production practices. The budget program is used to conduct economic analysis of field data from various soybean research plots as well as the research verification trials. The crop enterprise budgets are designed to enable producers to estimate the types of costs associated with production as well as potential returns. Costs and returns analysis within the budgets are used to investigate factors impacting farm profitability by allowing users to update various field activities associated with one's unique farming techniques and operations. Currently, a total of 28 soybean budgets are released each winter, with updates in the following spring. Soybeans are divided into 7 groups: conventional, Enlist E3™, Liberty Link®, LLGT27, Roundup Ready, RR2Xtend®, and RR2XtendFlex®. Soybeans are further classified by irrigation practice: flood, furrow, pivot, and no irrigation.

Introduction

The 2023 production season saw its fair share of challenges for Arkansas producers. Volatility seems to be here to stay, albeit with a steadier price trend, but with supply availability issues recurring. Profitability fades away with a rental situation, and ownership of land is a cost many growers find hard to withstand. Commodity prices have recouped some of the losses witnessed during the last 2 years. Fuel and fertilizer costs have waned from global issues faced in 2021 and 2022. A top concern is China's ability to decrease exports as their population growth has stalled. With volatility and weariness growing in profitability potentials, it is essential that producers have a tool to calculate costs and returns for various production techniques and alternatives to estimate potential net profitability scenarios. This profitability measure also needs to encompass changes in input costs as well as production practices producers seek to adopt on-farm. The objective of this project is to develop an interactive, computational program that will enable the stakeholders of the Arkansas soybean industry to evaluate production methods for comparative costs and returns.

Procedures

Methods employed for developing crop enterprise budgets include input prices that are estimated directly from information available from suppliers, producers, and knowledgeable sources, as well as costs calculated from engineering formulas developed by the American Society of Agricultural and Biological Engineers. Input costs for fertilizers and chemicals are estimated by applying prices to typical input rates. Input prices, custom hire rates, and fees are estimated using information from industry contacts as well as bids from local suppliers. Methods of estimating these operating expenses presented in crop enterprise budgets are identical to producers obtaining cost information for their specific farms. These prices, however, fail to factor in discounts from buying products in bulk, preordering items for a lower price, and other promotions that may be available at the point of purchase.

Ownership costs and repair expenses for machinery are estimated by applying engineering formulas to representative prices of new equipment (Givan, 1991; Lazarus and Selly, 2002). Repair expenses in crop enterprise budgets should be regarded as value estimates of full-service repairs. Repairs and maintenance performed by hired farm labor will be partially realized as wages paid to employees. Machinery performance rates of field activities utilized for machinery costs are used to estimate time requirements of an activity, which is applied to an hourly wage rate to determine labor costs received from surveying producers. Labor costs in crop enterprise budgets represent time devoted. Recently, labor costs associated with irrigation have been added to all budgets utilizing information received from Mississippi State University, (MSU, 2023) CES specialists, and local producers.

Ownership costs of machinery are determined by the capital recovery method, which determines the amount of money that should be set aside each year to replace the value of equipment used in production (Kay and Edwards, 1999).

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This measure differs from typical depreciation methods, as well as actual cash expenses for machinery. Amortization factors applied for capital recovery estimation coincide with prevailing long-term interest rates (Edwards, 2005). Interest rates in this report are from Arkansas lenders, as reported in the fall of 2023. Representative prices for machinery and equipment are based on contacts with Arkansas dealers, manufacturer's suggested retail prices (MSRP), and reference sources (Deere & Company 2023; MSU 2023). Revenue in crop enterprise budgets is the product of expected yields from following Extension practices under optimal growing conditions combined with actual yield data from research verification plot trials and commodity price data from the National Agricultural Statistics Service (NASS).

Results and Discussion

The Department of Agricultural Economics and Agribusiness (AEAB) and Agriculture and Natural Resources (ANR) are both part of the University of Arkansas System Division of Agriculture and together develop annual crop enterprise budgets to assist Arkansas producers and other agricultural stakeholders in evaluating expected costs and returns for the upcoming field crop production year. Production methods represent typical field activities as determined by consultations with producers within the state, County Agents, agronomists, weed scientists, plant pathologists, entomologists, and information from the Soybean Research Verification Program Coordinators in the Department of Crop, Soil, and Environmental Sciences. Actual production practices vary greatly among individual farms due to management preferences believed to be the best methods for achieving the greatest success. Analyses are for generalized circumstances with a focus on consistent and coordinated application of budget methods for all field crops. This approach results in meaningful costs and returns comparisons for decision-making related to acreage allocations among field crops. Results should be regarded only as a guide and a basis for individual farmers developing budgets for their production practices, soil types, and various circumstances unique to local production.

Table 1 presents an example of the 2023 budget developed for furrow irrigated soybeans utilizing field activities associated with a Roundup Ready 2 XtendFlex® production system in Arkansas. Costs are presented on a per-acre basis with an assumed 1,000 acres. Program flexibility gives users the ability to change all the variables, allowing them to develop budgets tailored to represent many unique farming operations and needs. Table 1 shows returns to operating expenses are \$249.04/ac. Net returns for 2023 were estimated to be \$119.25/ac compared to \$150.25/ac in 2022. The price received for 2023 was set at \$12.70/bu. compared to \$12.10/bu. previously. Table 1 represents only furrow irrigated Roundup Ready 2 XtendFlex soybeans. However, the budget program includes similar capabilities for flood, center pivot irrigated, and non-irrigated soybean production, as well as providing evaluation of various seed technologies utilized in Arkansas soybean production.

Practical Applications

Copies of the current crop enterprise budgets are available to the public at, www.uaex.uada.edu. Once on the webpage, enter the term "crop budgets" in the search box and the first option available is the crop enterprise budget page. It is here, on the Crop Enterprise Budgets for Arkansas website, that users can find a list of the available crop budgets in their most recent form. The interactive budgets utilize Microsoft® Excel®. An updated interactive tool is under development and will be made available once it is complete. The benefits provided by the economic analysis of alternative soybean production methods provide a significant reduction in financial risk faced by producers. Arkansas producers have the capability, with this budget program, to develop economic analyses of their individual production activities. Unique crop enterprise budgets developed for individual farms are useful for determining credit requirements and for planning production methods with the greatest potential for financial success. Flexible budgets enable farm financial outlooks to be revised during the production season as input availability, input prices, yields, and commodity prices change. For the 2023 crop budgets, a spring update of fuel and fertilizer prices was made. The update also includes updates to commodity prices with an increase in expected net revenue. Incorporating changing information and circumstances into budget analysis assists producers and lenders in making decisions that manage financial risks inherent in agricultural production.

Acknowledgments

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Table 1. Soybean Enterprise Budget, RR2XtendFlex®, Furrow Irrigation

Crop Value	Grower %	Unit	Yield[a]	Price/Unit	Revenue
Crop Value, Enter Expected Farm Yield & Price	100%	bu.	60.00	12.70	762.00
OPERATING EXPENSES		**Unit**	**Quantity**	**Price/Unit[b]**	**Costs**
Seed, per acre	100%	thous.	150	0.61	91.50
Nitrogen (Urea, 46-0-0)	100%	lb	0	0.40	0.00
Phosphate (0-46-0)	100%	lb	90	0.45	40.05
Potash (0-0-60)	100%	lb	100	0.42	41.50
Ammonium Sulfate (21-0-0-24)	100%	lb	0	0.24	0.00
Boron 15%	100%	lb	0.00	1.28	0.00
Other Nutrients, Including Poultry Litter	100%	acre	1.00	0.00	0.00
Herbicide	100%	acre	1	96.49	96.49
Insecticide	100%	acre	1	24.75	24.75
Fungicide	100%	acre	1	30.50	30.50
Other Chemical	100%	acre	1	0.00	0.00
Other Chemical	100%	acre	1	0.00	0.00
Custom Chemical & Fertilizer Applications					
Ground Application: Fertilizer & Chemical	100%	acre	0	8.00	0.00
Air Application: Fertilizer & Chemical	100%	acre	2	8.00	16.00
Air Application: lb	100%	lb	0	0.080	0.00
Other Custom Hire, Air Seeding	100%	acre	0	8.00	0.00
Machinery and Equipment					
Diesel Fuel, Pre-Post Harvest	100%	gallons	4.209	4.50	18.94
Repairs and Maintenance, Pre-Post Harvest	100%	acre	1	7.65	7.65
Diesel Fuel, Harvest	100%	gallons	2.027	4.50	9.12
Repairs and Maintenance, Harvest	100%	acre	1	7.76	7.76
Irrigation Energy Cost	100%	ac-in.	12	5.32	63.78
Irrigation System Repairs & Maintenance		ac-in.	12	0.24	2.88
Supplies (e.g., polypipe)	100%	acre	1	3.88	3.88
Levee Gates	100%	acre	1	0.00	0.00
Labor, Field Activities	100%	hours	0.818	12.45	10.18
Scouting/Consultant Fee	100%	acre	1	6.50	6.50
Other Expenses	100%	acre	1	0.00	0.00
Crop Insurance	100%	acre	1	4.80	4.80
Interest, Annual Rate Applied for 6 Months	100%	rate %	7.00	476.28	16.67
Custom Harvest	100%	acre	0.00	0.00	0.00
Post-Harvest Expenses					
Drying	100%	bu.	60.00	0.00	0.00
Hauling	100%	bu.	60.00	0.27	16.20
Check Off, Boards	100%	bu.	60.00	0.06	3.81
Cash Land Rent		acre	1	0.00	0.00
Total Operating Expenses					**$512.96**
Returns to Operating Expenses					**$249.04**
CAPITAL RECOVERY & FIXED COSTS					
Machinery and Equipment		acre	1	103.45	103.45
Irrigation Equipment		acre	1	21.17	21.17
Farm Overhead[c]		acre	1	5.17	5.17
Total Capital Recovery & Fixed Costs					**$129.79**
TOTAL SPECIFIED EXPENSES					**$642.75**
NET RETURNS					**$119.25**

[a] Yield and inputs are based on Extension research data. Enter expected farm yield and inputs.

[b] All price estimates do NOT include rebates, bulk deals, or discounts available through suppliers.

[c] Estimate based on machinery and equipment.

Economic Analysis of the 2023 Soybean Research Verification Program

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

Abstract

Economic and agronomic results of a statewide soybean research verification program can be a useful tool for producers making production management decisions prior to and within a crop-growing season. The 2023 season results provide additional economic relationship insights among seasonal, herbicide, and irrigation production systems. Early-season production system fields had yields that exceeded full-season yields by 4.27 bu./ac and exceeded late-season yields by 5.24 bu./ac. Early-season returns to land and management were $100.68 per acre higher than full-season returns and $165.25 per acre higher than late-season system fields. Roundup Ready 2 Xtend® (RRX) herbicide production system fields had an 8.80 bu./ac yield advantage over Roundup Ready 2 Flex® (RRF) fields, a 0.85 bu./ac advantage over Enlist E3® system fields, and a 25.70 bu./ac advantage over conventional fields, leading to a $156.32 or more per acre advantage in returns to land and management across all program fields. The pivot-irrigated field was superior to the furrow-irrigated fields in terms of yield, but furrow-irrigated fields had an average return that exceeded that of the pivot-irrigated field. Average total cost savings of $221.31 per acre and the difference of $192.51 per acre returns to land and management associated with the furrow-irrigated system fields overcame the 2.14 bu./ac yield advantage of the pivot-irrigated field.

Introduction

The Arkansas Soybean Research Verification Program (SRVP) originated in 1983 with a University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) study consisting of 4 irrigated soybean fields. Records have been compiled each succeeding year from the fields of participating cooperators until over 500 individual fields now comprise the state data set. Among other goals, the program seeks to validate CES standard soybean production recommendations and demonstrate their benefits to state producers. Studies of the annual program reports have shown that SRVP producers consistently exceed the state average soybean yields, even as both measures have trended upward (Stark et al., 2008). Specific production practice trends, such as herbicide use rates, have 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 receives timely management guidance from state SRVP coordinators on a regular basis and from state extension specialists as needed. Economic analysis has been a primary focus of the program from the start. The SRVP coordinators record input rates and production practices throughout the growing season including official yield measures at harvest. A CES state extension economist compiles the data into the spreadsheet used for an annual cost of production budget development. Measures of profitability and production efficiency are calculated for each cooperator's field and then grouped by soybean production system.

Results are stated for use as discussion only. Readers should note that 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, 2023; MSU, 2022; Becks Hybrids, 2024). Herbicide classification titles correspond with the 2023 season Arkansas soybean crop enterprise budgets published by Watkins (2023).

Procedures

Fifteen cooperating soybean producers from across Arkansas provided input quantities and production practices utilized in the 2023 growing season. A state average soybean market price was estimated by compiling daily forward booking and cash market prices for the 2023 crop. The collection period was 1 January through 31 October 2023. These prices are the same as those used for the weekly soybean market reports published on the Arkansas Row Crops Blog (Deaton, 2024). Data was entered into the 2023 Arkansas

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soybean enterprise budgets for each respective production system (Watkins, 2023). Input prices and production practice charges were primarily estimated by the budget values. Missing values were estimated using a combination of both industry representative quotes and values taken from the Mississippi State Budget Generator program for 2023 (Laughlin and Spurlock, 2016). Summary reports, by field, were generated and compiled to generate system results.

Results and Discussion

The 15 fields included in the 2023 Arkansas Soybean Research Verification Program report (Norton et al., 2023) had an average yield of 62.50 bu./ac, generating an average revenue of $840.00 per acre. Producers required $356.56 per acre of variable costs, $84.87 per acre of fixed costs, or a total cost per acre of $441.43 per acre resulting in a return to land and management of $398.57 per acre. The fields spanned 8 different production systems based on combinations of seasonal, herbicide, and irrigation characteristics (Table 1). Two system combinations were the most common with 4 fields each: early-season, Roundup Ready Xtend® technology seed, with furrow-irrigation and full-season, Enlist® seed, with furrow-irrigation. Two fields used early-season, Roundup Ready 2 Xtend Flex® seed, with furrow-irrigation systems. 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 2023 crop reported by Deaton in weekly market reports (Deaton, 2024). The soybean forward book and cash market price for the 2023 crop averaged $13.44 per bushel over the period of 1 Jan.–31 Oct. 2023. 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 such items as 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 15 fields spanned 7 early-season, 7 full-season, and 1 late-season system. Early-season plantings had a 4.27 bu./ac yield advantage over full-season and a 5.24 bu./ac yield advantage over late-season systems (Table 2). Revenue for the early-season fields was also higher than for full- or late-season fields ($871.49 vs. $814.08 and $801.02, respectively). The late-season field had higher total costs than either early- or full-season fields; the high total costs were primarily due to higher variable costs. The full-season fields had the highest average fixed costs. Returns to land and management for early-season fields were by far the highest: $100.68 per acre higher than full-season fields and $165.25 per acre higher than late-season fields.

Herbicide Comparisons

The Enlist® (E3) herbicide system was most frequently used in 6 of the 15 fields (Table 3). The Roundup Ready 2 Xtend® (RRX) and Roundup Ready 2 Xtend Flex® (RRF) systems were both used in 4 fields. One field used a conventional (CON) system. Yield comparisons by herbicide showed the RRX fields had a 0.85 bu./ac advantage over the E3 fields, an 8.80 bu./ac advantage over the RRF fields, and a 25.70 bu./ac advantage over the CON field. E3 fields had higher total costs than either of the other systems ($50.05/ac or more higher), whereas RRX fields had the lowest ($40.08/ac or more lower). The RRX fields had the highest average returns to land and management ($156.32/ac or more higher). The CON field had moderately high total costs and much lower average returns to land and management ($172.37/ac or more lower) than the other fields.

Irrigation Comparisons

All 15 fields in the 2023 program were irrigated. Fourteen fields were furrow-irrigated, and 1 field was irrigated by center pivot. The pivot-irrigated field had a small yield advantage (2.14 bu./ac higher) over the furrow-irrigated fields. The total costs of the center-irrigated field, however, were much higher ($221.31/ac higher) than the furrow-irrigated fields. This led to the furrow-irrigated fields having an advantage in average returns to land and management ($192.51/ac higher) over the pivot-irrigated field.

Overall Comparisons

The 2023 Arkansas Soybean Research Verification Program fields had a 62.50 bu./ac statewide average yield. This was 2.68 bushels less than in 2022, but it was 8.5 bushels above the 2023 Arkansas state average yield of 54 bushels/ac (USDA, 2024). Revenue averaged $840.00 from this production and market price. The revenue mark represents a decrease of $159.16/ac compared to 2022. Total variable costs averaged $356.56, a $20.46 increase, and total fixed costs averaged $84.87, a $14.39 decrease, for an average total cost per acre of $441.43, a $6.07 increase over 2022. These revenue and cost averages left producers with an average per acre return to land and management of $398.57 across all production systems, and a decrease per acre of $165.22 compared to 2022.

Practical Applications

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

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Table 1. Production System Combinations of the seventeen fields participating in the 2023 University of Arkansas System Division of Agriculture's Soybean Research Verification Program.

Production System	Early	Early	Early	Full	Full	Full	Full	Late
Herbicide	E3	RRX	RRF	E3	CON	E3	RRF	RRF
Irrigation	Fur	Fur	Fur	CP	Fur	Fur	Fur	Fur
Number of Fields	1	4	2	1	1	4	1	1

Production Systems: Early = Early-Season; Full = Full-Season; Late = Late-Season.
Herbicide: CON = Conventional; E3 = Enlist®; RRF = Roundup Ready 2 Xtend Flex®; RRX = Roundup Ready 2 Xtend®.
Irrigation: CP = Center Pivot Irrigation; Dry = Non-Irrigation; Fur = Furrow Irrigation.
Source: 2023 Arkansas Soybean Research Verification Program Report.

Table 2. Economic Results by Seasonal Production System for the 2023 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	7	7	1	15
Yields (bu./ac)	64.84	60.57	59.60	62.50
Revenue ($/ac)	871.49	814.08	801.02	840.00
Total Variable Costs ($/ac)	340.28	362.23	430.81	356.56
Total Fixed Costs ($/ac)	74.64	95.96	78.89	84.87
Total Costs ($/ac)	414.92	458.19	509.70	441.43
Returns to Land and Management ($/ac)	456.57	355.89	291.32	398.57

Source: 2023 Arkansas Soybean Research Verification Program Report.

Table 3. Economic Results by Herbicide System for the 2023 University of Arkansas System Division of Agriculture's Soybean Research Verification Program.

Herbicide Production System	Conventional	Enlist E3	Roundup Ready 2 Xtend	Roundup Ready 2 Xtend Flex	All Fields
Number of Fields	1	6	4	4	15
Yields (bu./ac)	41.20	66.05	66.90	58.10	62.50
Revenue ($/ac)	553.73	887.71	899.14	780.86	840.00
Total Variable Costs ($/ac)	302.12	401.17	282.73	377.09	356.56
Total Fixed Costs ($/ac)	93.47	99.24	72.78	73.27	84.87
Total Costs ($/ac)	395.59	500.41	355.51	450.36	441.43
Returns to Land and Management ($/ac)	158.14	387.31	543.63	330.51	398.57

Source: 2023 Arkansas Soybean Research Verification Program Report.

Table 4. Economic Results by Irrigation System for the 2023 University of Arkansas System Division of Agriculture's Soybean Research Verification Program.

Irrigation Production System	Furrow	Pivot	All Fields
Number of Fields	14	1	15
Yields (bu./ac)	62.36	64.50	62.50
Revenue ($/ac)	838.08	866.88	840.00
Total Variable Costs ($/ac)	345.01	518.20	356.56
Total Fixed Costs ($/ac)	81.67	129.79	84.87
Total Costs ($/ac)	426.68	647.99	441.43
Returns to Land and Management ($/ac)	411.40	218.89	398.57

Source: 2023 Arkansas Soybean Research Verification Program Report.

ECONOMICS

Economic Considerations of In-Season Potassium Applications to Soybean

C.C. Ortel,[1] T.L. Roberts,[1] M. Popp.[2] W.J. Ross,[3] N.A. Slaton,[4] and M.R. Parvej[5]

Abstract

Potassium (K) deficiency is a common yield-limiting factor in Arkansas soybean [*Glycine max* (L.) Merr.] production that can be addressed with innovative supplemental fertilizer applications. An established leaf sampling protocol and dynamic critical concentration allow accurate diagnosis of a K deficiency with corresponding recommendations for corrective, in-season fertilizer-K applications at site-specific rates and times to reach anticipated yield goals. However, the profitability of in-season fertilizer-K applications to irrigated soybean remains unclear. Research was conducted in Arkansas from 2021 to 2023 to evaluate multiple rates of in-season applications of muriate of potash (MOP) fertilizer to soybean applied at 15 days after first flower (DAR1). The economic ramifications associated with in-season K application were quantified by calculating yield averages, partial returns (PR), and regret, each assuming 5-year average prices for MOP fertilizer and soybean grain. Significant yield responses to in-season potash fertilizer were found. These yield increases translated to large increases in PR and regret in comparison to no in-season fertilization. Corrective applications of 80 to 120 lb K_2O/ac at 15 DAR1 were considered optimal, with risk assessments provided to allow informed decisions for individual situations. Results were summarized by category of leaf-K concentration, and treatment averages were provided in the payoff matrix. Treatment average information on yields subject to fertilizer use was organized in a payoff matrix that accounts for soybean grain price and fertilizer cost. The payoff matrix can thus serve as a spreadsheet-based decision support tool as price and cost information change and materially impact the optimal fertilization strategy.

Introduction

Potassium (K) fertilizer prices have recently experienced extreme volatility, applying additional financial stress to soybean [*Glycine max* (L.) Merr.] producers. Record high prices of muriate of potash (MOP; 0-0-60), the most used source of fertilizer-K in Arkansas, were recorded in 2022 (Y Charts, 2023). High fertilizer input costs have directly impacted soybean production, resulting in reduced rates of fertilizer-K to maximize profitability (Popp et al., 2020). However, when lower rates of fertilizer-K are applied to soils that measure low in plant-available K, the likelihood of K deficiency increases. Potassium deficiency in soybean can result in large potential yield loss with as much as 41% confirmed in Arkansas (Slaton et al., 2021). In addition to uncertain cost, a large range in soybean yields across varying levels of soil fertility warrants risk and relative profitability analyses of K fertilizer management in soybean.

While the preplant fertilizer recommendations are reliable, in-season K deficiencies may still occur and result in yield loss, especially if preplant rates were reduced or eliminated. Potassium-deficient soybean may show no visible symptoms, known as hidden hunger, or symptoms may not appear until very late in the season when yield loss is permanent. Widespread hidden hunger was confirmed in production soybean fields in Arkansas, indicating yield loss from K deficiencies is a common problem even in seemingly healthy soybean fields (Ortel et al., 2023). Therefore, proactive and routine tissue sampling may be the best way to monitor nutrient status and identify potential hidden hunger before significant yield loss is unavoidable. The recent development of a dynamic critical K concentration curve for soybean improves the diagnostic ability for in-season deficiencies by providing an exact critical concentration of leaf-K required to maintain 95%, 85%, and 75% relative grain yield goals at any given point during the reproductive growth stages of soybean (Slaton et al., 2021). When a K deficiency is confirmed, an in-season application of granular MOP may correct the deficiency and minimize the yield loss (Slaton et al., 2020).

A payoff matrix is a way of expressing the risks associated with different management options. For in-season K applications to soybean, this is considering the likelihood of deficiency (measured by the leaf-K; Slaton et al., 2021), and then the subsequent likelihood of partial returns (PR) and regret for each rate of K fertilizer. Regret in this context is defined as the loss in soybean revenue net of fertilizer-K cost experienced, or the PR associated with making a fertilizer rate decision at a particular point in time, that is non-optimal

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when compared to PR of alternative fertilizer application rates (Popp et al., 2010). Comparisons of yield and economic outcomes within ranges of leaf-tissue K and across fertilizer rates thus delineate the risks associated with each fertilizer rate choice across a range of leaf-tissue K levels observed in the study. The primary objective is to provide this information to growers in a simple format, allowing them to make an informed decision about the yield and profit risks involved with applying in-season K, as well as the potential risk of not applying a corrective in-season application.

Procedures

Irrigated soybean response to in-season K application rate was evaluated in 10 field trials conducted from 2021 to 2023 on silt-loam soils with access to irrigation located across the primary soybean-producing regions of Arkansas. Varying levels of STK were selected between sites in anticipation that the soybean would express different levels of K deficiency, allowing more robust conclusions to be drawn from the results. Within two days of the targeted 15 DAR1, treatments of granular MOP were applied at rates of 0, 40, 80, 120, and 160 lb K_2O/ac and irrigation was applied to the site. Except for K fertilization, soybean management closely followed recommended guidelines for full-season soybean production as outlined by the University of Arkansas System Division of Agriculture's Cooperative Extension Service (Ross, 2000).

At 15 DAR1, a composite sample of 12 to 16 trifoliolate leaves (no petiole) was collected from the uppermost fully expanded trifoliate leaves within the middle rows of each plot. The leaves were dried, ground, and digested with concentrated HNO3 and 30% H_2O_2 (Jones and Case, 1990) and analyzed by ICP-AES for K concentration. The measurement of leaf-K concentration was used to describe the level of K deficiency experienced by the soybean and was categorized into four uncertain states of nature. Categories of deficiency were determined using the dynamic critical tissue-K concentration values known for each leaf sampling time and each of 95%, 85%, and 75% expected RGY (Slaton et al., 2021). The categories for each leaf sampling time are marked by these thresholds to describe leaf-K concentrations < 75% sufficiency, between 75% and 85% sufficiency, between 85% and 95% sufficiency, and above 95% sufficiency. The likelihood of occurrence for each of the defined leaf-K categories was calculated from the data collected across the 10 site-years of research considered. Within each leaf-K category, the yield response was analyzed as a randomized complete block design in RStudio.

The PR were calculated for each treatment and within each leaf-K category across all site-years of research, defined as revenue earned by the soybean yield minus the fertilizer expenses (cost of fertilizer and application charge $7.50/ac). The PR values by leaf-K category and fertilizer application amount were then used to calculate the regret a producer would experience in a particular leaf-K category in comparison to the least profitable result across application amounts, which typically occurred without fertilizer except in situations where leaf-K was already high. Hence, when the best-performing fertilizer rate was selected, the regret was 0. The expected value of each fertilizer treatment was calculated by considering the likelihood of occurrence of PR. Said likelihood was determined as the ratio of observations falling within a leaf-K category to the total number of leaf-K observations at DAR1 across all plots considered. Similarly, the expected regret for each fertilizer rate option was calculated by considering the regret and the likelihood of occurrence; the optimal choice for expected regret is the fertilizer rate with the least expected regret.

The maximax algorithm is an optimist's approach and the maximin approach is the pessimist's approach. The decision maker assumes either the best (maximax) or the worst (maximin) outcome across leaf-K categories for each fertilizer rate choice and chooses the fertilizer rate choice with the highest outcome. The minimum range algorithm calculates the potential PR difference across leaf-K categories for each fertilizer rate choice, with the lowest range as the optimal choice. Finally, the maximum regret algorithm identifies the fertilizer rate choice with the least maximum regret across all leaf-K categories for each fertilizer rate applied in-season. All the above calculations were computed to build a payoff matrix that can be used as a decision support tool to allow producers to adjust the price of fertilizer and value of soybean grain to match their situation. The ideal fertilizer strategy was identified for all choice algorithms (expected PR, maximax, maximin, minimum range, minimum of maximum regret, and expected regret) using bold lettering. In this manner, the producer could choose the fertilization strategy using either a single algorithm or a combination of algorithms to assess profitability and risk implications of in-season K application.

Results and Discussion

The average yields achieved from soybean with leaf-K less than 0.97% K at 15 DAR1 were less than the Arkansas state average soybean yield (52 bu./ac), except when 120 lb K_2O/ac was applied at 15 DAR1 as a corrective application (Table 1; USDA, 2023). This leaf-K category describes severe K deficiency, and soybean yield is likely to respond to an in-season application of fertilizer-K within 20 DAR1 (Slaton et al., 2020). When the 5-year averages were considered for soybean grain ($11.80/bu.) and fertilizer-K ($416/ton), the PR ranged from $398 to $731/ac, with the highest regret when no fertilizer-K was applied, and the K deficiency remained severe (Table 1). The large regret can be attributed to the large potential yield loss from severe K deficiency and the ability to increase the average yield by 36% with a corrective application of 120 lb K_2O/ac (Table 1). Meanwhile, the average yields achieved from soybean with leaf-K of 1.89% or greater are considered sufficient and consistently measured above the state average yield regardless of the fertilizer-K rate applied (USDA, 2023).

The expected value was the highest when 80 lb K_2O/ac was applied, valued at $731/ac (Table 1). The decision to apply 80 lb K_2O/ac also had the lowest expected regret compared to all other fertilizer rate options and would be selected by an optimist, as it produced the highest overall PR (Table 1). However, the management decision to apply 120 lb K_2O/ac may also be a sound decision and would be selected by the pessimist as it produced the highest of the minimum PR among fertilizer rates. Similarly, 120 lb K_2O/ac also measured the lowest minimum range of PR and the least maximum regret, indicating a strategy that would reduce the risk of this fertilizer rate selection (Table 1). Ultimately, these calculations are appropriate if the likelihood of what leaf-K category and the prices are not known. Further results are subject to change with changes in soybean price and fertilizer cost. Ideally, producers would collect a leaf sample to measure the leaf-K and then use their cost of MOP and the expected value of soybean grain to make an informed decision, although uncertainty about spatial distribution in leaf-K remains with a single field sample.

When 160 lb K_2O/ac was applied to a soybean crop at 15 DAR1, the raw yield was statistically similar to those achieved with lower rates of fertilizer-K across all leaf-K categories (Table 1). However, the cost of potash has increased, and there is no guarantee that the additional K will remain available for a subsequent crop. Loss of fertilizer-K via runoff is more likely when large volumes of fertilizer are applied to a field (Daniels et al., 2023). Soybean is a luxury consumer of K and will continue to take up plant-available K from the soil when the plant already has sufficient levels of K nutrition. The grain is a sink for excess K nutrition and a portion of the K that is luxury consumed will be removed from the cropping system at harvest (Parvej et al., 2016). Therefore, caution is advised when considering the application of high rates of fertilizer-K to soybean in-season because of the evidence of no statistical yield increase combined with the potential for losses from the cropping system, either by runoff or crop removal.

Practical Applications

Results of 10 site-years of research were summarized using treatment averages when applied to soybean by measuring in various categories of leaf-K concentrations, representing various levels of deficiency. It was consistently profitable to correct an in-season K deficiency when it occurred. Producers should rely on leaf samples to measure the leaf-K concentration and use this information to make the best possible management decision, as this is the only scientific way to confirm a yield-limiting K deficiency. The fertilizer rate choice is impacted by relevant prices for both fertilizer-K and soybean grain to facilitate the best decision possible. When 5-year averages were considered, 80 to 120 lb K_2O/ac were the most profitable management decisions at 15 DAR1. When higher rates were applied, no significant yield response was observed at any time for this level of deficiency, but an increase in fertilizer costs impacted profitability. The most profitable scenario of all was when no K deficiency occurred, but in-season corrective application of 80 lb K_2O/ac had the lowest expected regret and highest expected value, a result that could change under alternative soybean price and fertilizer cost values. The importance of preplant nutrient management is underscored by this research as preplant nutrient management impacts the likelihood of leaf-K categories a producer finds in their field.

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Table 1. Payoff matrix of partial returns (PR) for soybean, which received corrective applications of fertilizer-K at 15 days after first flower (DAR1), divided as categories of leaf-K concentrations (LK) and considering the 5-year average prices of muriate of potash fertilizer ($416/ton) and soybean grain ($11.80/bu.).

Payoff Matrix			Controllable Action				
			0 lb K_2O/ac	40 lb K_2O/ac	80 lb K_2O/ac	120 lb K_2O/ac	160 lb K_2O/ac
	Leaf-K (% K)[†]	**Probability of LK occurrence**	**Yield Least Square Means in bu./ac[‡]**				
Uncertain State of Nature	LK < 0.97	17.3%	33.7 b	45.5 a	48.3 a	54.6 a	51.5 a
	0.97 ≤ LK < 1.32	18.2%	41.0 b	45.9 a	53.1 a	52.8 a	52.2 a
	1.32 ≤ LK < 1.89	44.2%	55.8 a	55.3 a	58.2 a	55.4 a	55.2 a
	LK ≥ 1.89	20.3%	61.0 a	58.0 a	64.9 a	62.4 a	65.8 a
			Partial Return in $/ac[§]				
	LK < 0.97	17.3%	$398	$516	$535	$595	$545
	0.97 ≤ LK < 1.32	18.2%	$484	$520	$591	$574	$553
	1.32 ≤ LK < 1.89	44.2%	$658	$631	$652	$605	$588
	LK ≥ 1.89	20.3%	$720	$663	$731	$687	$713
			Regret (High - Low within Row) in $/ac[¶]				
	LK < 0.97	17.3%	$198	$80	$60	$0	$50
	0.97 ≤ LK < 1.32	18.2%	$108	$71	$0	$17	$38
	1.32 ≤ LK < 1.89	44.2%	$0	$27	$7	$54	$70
	LK ≥ 1.89	20.3%	$11	$68	$0	$43	$17
Decision Algorithms[¶]	Expected Value		$594	$597	**$636**	$614	$600
	Maximax		$720	$663	**$731**	$687	$713
	Maximin		$398	$516	$535	**$574**	$545
	Min. Range		$322	$148	$196	**$113**	$169
	Max. Regret		$198	$80	$60	**$54**	$70
	Exp. Regret		$56	$52	**$14**	$36	$50

[†] Dynamic critical concentration used to delineate leaf-K categories to align with <75%, 75 to 85%, 85 to 95% and above 95% sufficiency (Slaton et al., 2021).

[‡] Letter separation indicates statistically significant differences within each LK category at *P* < 0.05.

[§] Partial returns are calculated as yield*soybean price less fertilizer rate*fertilizer cost and fertilizer application charges of $7.50 A^{-1} if any. Partial returns do not indicate profit of soybean production. Instead, PR can be compared to assess profit changes across fertilizer rate choices and leaf-K levels.

[¶] See Procedures section in text for a description. Bold numbers indicate optimal choice for each algorithm.

IRRIGATION

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

C.G. Henry[1] *and Russ Parker*[1]

Abstract

The University of Arkansas System Division of Agriculture Irrigation Yield Contest was conducted from 2018 until 2023. The contest was designed to promote better use of irrigation water and record data on water use and water use efficiency (WUE) for various crops. Unlike yield contests, where winners are decided by yield alone, irrigation contest results are decided by the highest total water use efficiency calculated 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. Irrigation water was recorded using 6-in., 8-in., 10-in., and 12-in. portable mechanical flow meters. Rainfall totals were calculated using Farmlogs™. The contest average WUE for soybeans from 2018 through 2023 was 3.29 bu./in. The winning WUE was 5.05 bu./in. for 2023, 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. The adoption of irrigation water management (IWM) practices by participants such as CHS, Surge irrigation, and soil moisture sensors is increasing. Soybean contest participants from 2018–2023 reported using, on average, 9.8 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 dropped in water levels between 2009 and 2019 (Arkansas Department of Agriculture Natural Resource Division, 2019).

Bryant et al. (2017) studied computerized hole selection, surge irrigation, and soil moisture monitoring compared to traditional irrigation practices in 20 paired grower soybean fields. They reported no significant difference in yield (69 BPA) between the IWM and control fields, a reduction of irrigation water applied by 21% ($P = 0.0198$), and a 36% increase in water use efficiency ($P = 0.01$). No difference in net returns was found between the practices, indicating that the water savings recovered the costs of implementing IWM.

The University of Arkansas System Division of Agriculture Irrigation Yield Contest was designed to encourage the use of water-saving methods for Arkansas Producers. The competition aims to promote irrigation water 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 WUE in multiple crop types under irrigated production in Arkansas, and by recognizing producers who achieved a high water use efficiency.

Procedures

Rules for an irrigation yield contest were developed in 2018. The rules were influenced by existing yield contests (Arkansas Soybean Association, 2014; National Corn Growers Association, 2015; National Wheat Foundation, 2018; the University of California Cooperative Extension, 2018). They 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 of 60 bu./ac must be achieved to qualify for the contest.

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 to be 7 days after the planting date provided on the entry form. The seed companies' published days to maturity are used for physiological maturity. Rainfall is adjusted for extreme events.

A third-party observer, often an Extension agent, NRCS employee, or other staff member from the University of Arkansas System Division of Agriculture, must be present during the harvest operations. For the yield estimate, a minimum of 3 acres were 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

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IRR = Irrigation application in ac-in./ac. Statistical analysis was performed using Microsoft Excel and JMP 15 (SAS Institute, Inc., Cary, N.C.).

Results and Discussion

For each contest year, detailed results are published on the contest website (https://www.uaex.uada.edu/environment-nature/water/). Over the 6 years that the competition has been conducted, 84 soybean fields have been entered. The average WUE over the 6 years was 3.23 bu./in. By year, the average WUE was 3.49 bu./in. for 2023 with 19 contestants, 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 18 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 in 2023 was the second-highest of the 6 years of the contest, with 2021 being the highest. The winning WUE for each year was 5.05 bu./in. for 2023, 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. 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. 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 that 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). In the 2015 survey, 40% reported using computerized hole selection, and 66% of the Arkansas growers reported using computerized hole selection. Meanwhile, 24% of respondents said they used soil moisture sensors 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 85% across all 6 years, with 88% in 2018, 72% in 2019, 100% in 2020, 97.5% in 2021, 79% in 2022, and 92% in 2023. Sixty percent of respondents from all 6 years said they used soil moisture sensors on their farm, with 50% in 2018, 40% in 2019, 100% in 2020, 87% in 2021, 81% in 2022, and 86% in 2023. 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, 12% in 2022, and 43% in 2023 (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. Such direct feedback from Arkansas soybean farmers will likely give many a competitive advantage when water resources become more scarce. It provides a mechanism for soybean farmers to evaluate the potential for water savings by adopting water-saving techniques or management changes.

Across 6 years of the contest, soybean growers averaged using 9.8 ac-in./ac of water applied and a total water use of 24.3 inches of total water for soybean.

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Table 1. Maximum, average, and minimum for 2018, 2019, 2020, 2021, 2022, and 2023 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.)
2023	Maximum	5.05	88.00	17.10	18.80	29.60
	Average	3.49	77.00	12.00	10.70	22.70
	Minimum	1.95	54.00	8.10	5.40	17.50
2022	Maximum	4.25	100.00	17.80	16.70	29.16
	Average	3.16	82.00	14.30	11.90	26.20
	Minimum	2.33	68.00	10.40	8.00	21.39
2021	Maximum	5.23	101.00	21.40	19.00	32.00
	Average	3.53	84.00	14.50	9.90	24.50
	Minimum	2.45	64.00	10.40	5.10	17.40
2020	Maximum	4.34	105.00	15.90	20.80	34.10
	Average	3.48	80.00	13.40	10.20	23.70
	Minimum	1.81	44.00	9.80	4.30	15.50
2019	Maximum	4.31	112.00	26.60	13.10	19.80
	Average	2.94	74.00	19.20	6.00	26.00
	Minimum	1.80	46.00	14.30	2.00	19.80
2018	Maximum	3.92	103.00	17.60	17.40	30.60
	Average	2.86	72.00	15.00	10.30	25.30
	Minimum	2.24	53.00	11.60	4.90	19.30
6 year	Average	3.22	77.30	15.00	10.10	24.70

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

	Computer Hole Selection	Moisture Sensors	Surge Valve
	----------------------	(%)	----------------------
2023	92	86	43
2022	79	81	12
2021	98	87	35
2020	100	100	25
2019	72	40	28
2018	88	50	44

IRRIGATION

Insights into Soil Water Retention Curves: A Comparison of Traditional and Modern Laboratory Techniques

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Abstract

Understanding soil water retention curves (SWRCs) is critical for effective agricultural practices, particularly crop irrigation water management. While traditional laboratory techniques, such as pressure plates, have been used for measuring SWRCs, they are often time-consuming. Technological progress has emerged in newer laboratory techniques employing precision mini-tensiometers (HYPROP) and dewpoint water potential meters (WP4C). This study investigates the disparities between SWRCs measured using traditional (pressure plate) and newer methods (HYPROP+WP4C) across 8 soil series of varying textures that are commonly irrigated in Arkansas. Our results showed that both methods exhibited a low mean absolute error (MAE) in volumetric water contents ranging from 0.02 to 0.09 $in.^3$ $in.^{-3}$, indicating minimal variability between soil series and high precision in measurements. The maximum difference in volumetric water content between the 2 methods occurred at the wet end (0 to -4.8 psi, approximately 0 to -33 kPa) and the mid-range (-4.8 to -72.5 psi, approximately -33 to -500 kPa) of the curve across all soil series. Additionally, plant available water for most soil series was higher under the HYPROP+WP4C method compared to the pressure plate method, except for Dubbs Silt Loam, which showed a 5% reduction (0.05 $in.^3$ $in.^{-3}$) and Bosket Fine Sandy Loam, which showed no differences between the 2 methods. Conducting field experiments to validate these results would enhance the applicability of the findings for more precise irrigation schedules tailored to specific soil conditions.

Introduction

A soil water retention curve (SWRC) represents the relationship between soil matric potential and volumetric soil water content (Parker and Patrignani, 2023). This relationship is inherently unique to each soil type (Miller and Gardiner, 2001). The SWRC offers valuable insights for quantifying and enhancing our understanding of soil water redistribution dynamics (Feki et al., 2018; Garg and Gupta, 2015; Geroy et al., 2011), potential groundwater recharge rates below the root zone (Jiménez-Martínez et al., 2009; Wyatt et al., 2017), solute transport (Gärdenäs et al., 2005; Vogel et al., 2000), soil respiration rates (Ghezzehei et al., 2019; Orchard and Cook, 1983), plant available water (Groenevelt et al., 2001; Minasny and McBratney, 2003), and determining optimal soil moisture conditions for tillage events in agricultural fields (Dexter and Bird, 2001; Mueller et al., 2003).

Soil water retention curves have traditionally been determined in laboratory settings by establishing the hydraulic equilibrium of a soil-water system using tension tables (ranging from 0 to -10 kPa) (Stackman et al., 1969), pressure cells (ranging from 0 to 200 kPa) (Richards and Fireman, 1943), and pressure plate apparatus (ranging from 100 to 1500 kPa) (Richards, 1948). Newer laboratory methods for determining SWRC include the HYPROP laboratory evaporation method, which uses mini-precision tensiometers (ranging from 0 to -80 kPa) (Schindler and Muller, 2006; Schindler et al., 2010), and the WP4 dewpoint potentiometer (ranging from -100 kPa to -300,000 kPa) (Campbell et al., 2007).

A key difference between traditional and newer methods for determining SWRC is that traditional methods typically involve periodic manual checks to ensure hydrostatic equilibrium, while newer methods often allow for continuous and automated monitoring through computer interfaces, enabling more detailed and unattended observations of soil properties. Another key difference between traditional and newer methods for measuring SWRC is that traditional methods typically require a longer time span, ranging from several weeks to several months, to determine a full range SWRC. As a result, they are best suited for processing a large number of samples but may only provide a few data points along the SWRC (Parker and Patrignani, 2023; Roy et al., 2018).

In contrast, newer methods enable a shorter time frame, typically several days to a few weeks, to determine a full-range SWRC. They also allow researchers to make detailed measurements along the SWRC, capturing nonlinearities, especially on the wet end of the curve (Parker and Patrignani, 2023; Roy et al., 2018).

Although newer methods are becoming increasingly popular, research studies on traditional pressure plate methods still dominate. This prevalence is partly attributed to legacy instrumentation in soil physics laboratories and the

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inherent capacity of traditional pressure plate methods to process larger batches of soil samples compared to newer methods, especially when determining soil water retention at specific matric potentials such as field capacity and permanent wilting point (Parker and Patrignani, 2023).

However, some previous studies have indicated that the pressure plate apparatus may be susceptible to significant errors, particularly at low matric potentials in fine-textured and swelling soils. For example, Cresswell et al. (2008) demonstrated that while the pressure plate apparatus yielded accurate estimates of volumetric water content at -1500 kPa for non-swelling soils, it failed to do so for soils with a modified linear shrinkage exceeding 5%. Another study comparing the SWRC of silt loam soil samples using both a pressure plate apparatus and a dew point water potential meter showed up to 81% higher matric potential values when using the pressure plate apparatus, particularly at -1500 kPa (Bittelli and Flury, 2009). A study investigating potential errors associated with the pressure plate apparatus revealed that in fine-textured soils, this apparatus tended to overestimate volumetric water content by up to 40% compared to values obtained using a dew point water potential meter (Solone et al., 2012).

The errors associated with the pressure plate apparatus at low matric potentials are commonly attributed to several factors. These include the loss of hydraulic contact between soil samples and the ceramic plate due to soil shrinkage (Campbell, 1988), water reabsorption by the soil after releasing pressure on the plate (Richards and Ogata, 1961), and the failure to reach equilibrium within a reasonable period, typically spanning from a few weeks to a few months, owing to the inherently low hydraulic conductivity of soils at low matric potentials (Campbell, 1988; Gee et al., 2002). However, despite these challenges, some studies on peat soils have determined that pressure plates are suitable for estimating the permanent wilting point. These studies found no evidence of loss of contact with the ceramic plate (Bechtold et al., 2018).

A study considering the entire soil moisture range revealed that while the hanging-water column method and the evaporation method yielded similar observations within the wet to moderate range of the SWRC, retention data obtained from the pressure plate apparatus tended to overestimate water contents compared to those obtained using a dew point water potential meter (Schelle et al., 2012).

The relationship between soil water content and soil matric potential is complex and difficult to describe by a simple modeling approach (Hillel, 1998). Over the years, numerous models and equations have been developed to fit soil water retention curves (Leong and Rahardjo, 1997). The van Genuchten (1980) equation is widely accepted and extensively employed for characterizing SWRCs (Roy et al., 2018).

In this study, we developed soil water retention curves for 8 soil series with varying textures, including Bosket Fine Sandy Loam, Beulah Fine Sandy Loam, Dewitt Silt Loam, Commerce Silt Loam, Dubbs Silt Loam, Dundee Silt Loam, Henry Silt Loam, and Tunica Clay. We utilized the pressure plate method as a traditional approach and the HYPROP combined with WP4C as a newer method. Subsequently, we fitted the van Genuchten equation to the developed SWRCs. This study aims to quantify the differences in SWRCs determined using traditional and newer laboratory techniques. Based on previous studies, we hypothesize that SWRCs from traditional and newer methods are similar at the wet end of the SWRC. Additionally, we hypothesize that the newer methods tend to overestimate the plant's available water content in soils.

Procedures

Studied Soils

The study examined 16 undisturbed soil series with 6 replications, each featuring varying textures, including Bosket Fine Sandy Loam, Beulah Fine Sandy Loam, Dewitt Silt Loam, Commerce Silt Loam, Dubbs Silt Loam, Dundee Silt Loam, Henry Silt Loam, and Tunica Clay. These series represent the soil's top 5.91 in. (15 cm), identified as the effective root zone for plants in the Arkansas Delta region, USA. Eight of these series were chosen for pressure plate studies, while the other 8 were chosen for HYPROP + WP4C studies. Table 1 shows each selected soil series's taxonomy class, coordinates, county, and recent land-use data. Figure 1 illustrates the distribution of soil textural classes used in this study.

HYPROP and WP4C Dewpoint Potentiometer Method

A complete soil water retention curve was determined using a combination of the HYPROP and WP4C methods for 8 soil series, each with 6 replications. The HYPROP system (Hydraulic Property Analyzer, METER Group, Inc., Pullman, Wash., USA) was used to measure soil water content across a soil matric potential range from 0 to approximately -500 kPa, based on the extended evaporation method (Schindler et al., 2012). This system employs an undisturbed soil core placed in a stainless steel cylinder 15.26 in.^{3} (250 cm^3) to monitor soil matric potential and gravimetric soil water content over time. Prior to measurement, samples were saturated for 48 hours. Two holes were drilled in the core's bottom using an auger-like insertion tool to install 2 vertically aligned mini-tensiometers. The core, with its bottom sealed for the duration of the experiment, was placed in the tensiometer assembly, allowing the upper end to remain open to the atmosphere for evaporation. Following a week of soil core drying, the final gravimetric water content was obtained by oven-drying the samples at 221 °F (105 °C) for 48 hours and reweighing to determine dry mass. All sample collection, soil core preparation, and measurement procedures followed the guidelines outlined in the HYPROP manual (UMS, 2015).

The WP4C Dewpoint PotentiaMeter (METER Group, Inc., Pullman, Wash., USA) was used to determine the gravimetric water content at the soil matric potential of -1500 kPa, considered the wilting point (Θ_{PWP}). After analyzing 8 soil core samples, each with 6 replications (48 soil cores in total) on the HYPROP, approximately 0.35 oz (10 g) of oven-dried and ground soil were added to small stainless-steel cups and wetted with various amounts of distilled water using an eyedropper. The mixture was manually mixed with a spatula to achieve a range of gravimetric water contents. The cups were then placed on a table covered with plastic overnight in a temperature-controlled room (i.e., approximately 77 ˚F (25 ˚C). Following temperature and water equilibration, the soil water potential was measured using the WP4C device and calibrated with a standard potassium chloride solution. Subsequently, each cup was weighed and oven-dried at 158 ˚F (70 ˚C) for 48 hours. Following this, the cups were reweighed to determine the gravimetric water content. Volumetric water content was calculated by multiplying the gravimetric water content by the bulk density obtained from each HYPROP soil core. Plant available water (Θ_{PAW}) was determined as the difference between Θ_{FC} obtained from the HYPROP method and Θ_{PWP} from the WP4C method (Prass Pimentel, 2023).

Pressure Plate Method

Using the pressure plate method, SWRCs were developed for 8 soil series, each with 6 replications, totaling 48 soil cores. A standard commercial pressure plate apparatus (Soil Moisture Equipment Corp., Goleta, Calif.) was utilized to apply specific pressures to the samples. Intact soil cores and ceramic pressure plates were pre-soaked in distilled water before measurement. Each sample was prepared by placing a 2.36 in. (6-cm) diameter paper filter (Soil Moisture Equipment Corp.) on saturated plates, followed by a 2.36 in. (6-cm) diameter, 1.18 in. (3-cm) high soil ring placed over the filter. This assembly was then sealed inside the pressure plate Extractor at a pressure of -33 kPa. Equilibrium was reached within 3 to 5 days. Subsequently, the soil cores were extracted from the chamber and weighed. This procedure was repeated at pressures of 0, -4.8, -14.5, -43.5, -72.5, and -220 psi, respectively, (approximately 0, -33, -100, -300, -500, and -1500 kPa). It is essential to note that while pressure was applied to the chamber and equilibration was considered complete when no drainage was observed, complete cessation of outflow might not have been achieved. Extended exposure of samples on plates could lead to less accurate measurements due to potential evaporation loss and biological growth in the soil, water, and plates (Bittelli and Flury, 2009).

Fitting SWRCs Using the van Genuchten Equation

Soil water retention curves were proposed by van Genuchten (1980) with the equation below:

$$\Theta = \Theta_r + \frac{(\Theta_s - \Theta_r)}{[1 + (\alpha|h|)^n]^m} \qquad \textit{Eq. 1}$$

Where Θ is the volumetric water content (in.^{3} in.$^{-3}$), Θ_r is the soil residual water content (in.^{3} in.$^{-3}$), Θ_s is the soil saturated water content (in.^{3} in.$^{-3}$), α is a scale parameter inversely proportional to the mean pore diameter (in.$^{-1}$), h is soil water potential (kPa), n and m are shape parameters of soil water characteristics, $m = 1 - \frac{1}{n}, 0 < m < 1$

This equation was used to assess how well the measured data obtained using the pressure plate and HYPROP + WP4C methods align with the curve determined by the van Genuchten equation.

Optimizing van Genuchten's parameters began with an initial guess of the parameters. Subsequently, the volumetric water content (Θ) corresponding to each soil matric potential was estimated. Then, the sum of squared errors was utilized as an objective function, which was minimized using the Generalized Reduced Gradient (GRG) nonlinear method. This approach involved refining the parameter estimates to converge towards an optimal solution that best fits the observed data. This process was run using Excel Solver (Wraith and Or, 1998).

Evaluation statistics included the mean absolute error (MAE) as the primary statistic to quantify the difference between SWRCs obtained using the pressure plate and HYPROP + WP4C methods. This was achieved by comparing the volumetric water contents corresponding to each soil matric potential, which was conducted separately for each soil series.

$$MAE = \frac{1}{n}\sum_{i=1}^{n}|\theta_{HW} - \theta_{PP}| \qquad \textit{Eq. 2}$$

Where n is the total number of data points, θ_{HW} is the ith volumetric water content from the HYPROP + WP4 data points (in.^{3} in.$^{-3}$), θ_{PP} is the ith volumetric water content from the pressure plate data points (in.^{3} in.$^{-3}$).

Results and Discussion

Our results showed that pressure plate and HYPROP + WP4C methods yielded SWRCs with a mean absolute error (MAE) ranging from 0.02 to 0.09 in.^{3} in.$^{-3}$ for the analyzed soil series (Table 2), indicating minimal variability between soil series and overall precision in the measurements. The largest discrepancy between methods was observed in the Commerce Silt Loam with an MAE of 0.09 in.^{3} in.$^{-3}$, while the Dewitt Silt Loam exhibited the lowest errors with an MAE of 0.02 in.^{3} in.$^{-3}$ (Table 2).

Contrary to our initial hypothesis, the maximum difference in soil water content between the two methods for all soil series occurred in the wet end (0 to -4.8 psi, approximately 0 to -33 kPa) and mid-range (-4.8 to -72.5 psi, approximately -33 to -500 kPa) of the SWRCs (Fig. 2). Specifically, for the Henry Silt Loam, Dundee Silt Loam, Beulah Fine Sandy Loam, and Tunica Clay, the maximum difference in the curve shape was observed when the soil was fully saturated (0 psi, 0 kPa), and for the Dewitt Silt Loam, it also fell in the wet end (-4.35 psi, approximately -30 kPa). For the remaining soils, including Commerce Silt Loam, Dubbs Silt Loam, and Bosket Fine Sandy Loam, the maximum difference in curve shape between the 2 methods occurred in the mid-range. According to Schindler et al. (2010), one factor contributing to the discrepancies between traditional and newer methods in the wet end of the SWRC is the hydraulic gradient within the soil sample when using the HYPROP system, potentially caused by rapid evaporation rates. This divergence may lead to the top and bottom tensiometers no longer accurately representing the average soil column's matric potential. To mitigate this, a screen can be added on top of the sample to reduce evaporation rates and decrease the hydraulic gradient. In a similar study comparing traditional and newer methods conducted by Parker and Patrignani (2023), the largest difference was observed between the two methods in the mid-range of the SWRCs. They suggested that this discrepancy could be attributed to using long soil samples combined with low hydraulic conductivity or large hydraulic gradients in the soil samples analyzed by the HYPROP system. These conditions could lead to high evaporation rates, causing the average values of the precision mini-tensiometers to no longer accurately represent the average soil matric potential.

According to our findings, the pressure plate method only estimated more water content at field capacity for Bosket Fine Sandy Loam, Commerce Silt Loam, and Dubbs Silt Loam. This observation aligns with results from previous studies comparing traditional and new methods, which consistently indicated that the pressure plate apparatus tends to overestimate water content at low soil matric potentials (0 to around -4.8 psi, approximately 0 kPa to -33 kPa) (Bittelli and Flury, 2009; de Jong van Lier et al., 2019; Solone et al., 2012).

In line with the hypothesis posited in this study, suggesting potential overestimation by newer methods, our results demonstrate that plant available water content is generally higher under the HYPROP + WP4C method compared to the pressure plate method for most soil series. However, exceptions were noted, with Dubbs Silt Loam exhibiting a 5% reduction (0.05 $in.^3\ in.^{-3}$) in plant available water content under the HYPROP + WP4C method, while Bosket Fine Sandy Loam showed no difference in plant available water between the two methods.

Practical Applications

Our study investigated the performance of pressure plate and HYPROP + WP4C methods in determining Soil Water Retention Curves across various soil series. Both methods exhibited a small mean absolute error (MAE), indicating minimal variability between soil series for field capacity and wilting points. However, discrepancies were observed, particularly in the Commerce Silt Loam, suggesting the importance of method selection based on soil characteristics. Contrary to expectations, the largest differences between methods occurred in the wet and mid-range of SWRCs, potentially influenced by factors such as hydraulic gradients and evaporation rates. These findings underscore the need for caution when interpreting results from newer methods such as HYPROP + WP4C, especially in conditions prone to rapid evaporation. Our results suggest that exceptions exist while the HYPROP + WP4C method generally overestimates plant available water content compared to the pressure plate. Our study provides valuable insights for researchers in optimizing soil water measurement techniques for accurate irrigation management and crop yield optimization. Understanding how these methods help with management decisions based on retention curves is key to improving irrigation scheduling tools.

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Table 1. Summary of the Taxonomic Class, Coordinates, County, and Most Recent Landuse for the 8 Most Irrigated Agricultural Soil Series in the Arkansas Delta Region.

Soil Series	Taxonomic class	Coordinates	County	Most recent landuse
Bosket Fine Sandy Loam	Fine-loamy, mixed, active, thermic Mollic Hapludalf	35.82°N, -91.19°W	Jackson	Soybean
Beulah Fine Sandy Loam	Coarse-loamy, mixed, thermic Typic Dystrudepts	35.79°N, -91.22°W	Jackson	Cotton
Dewitt Silt Loam	Fine, smectitic, thermic Typical Albaqualf	34.46°N, -91.46°W	Arkansas	Corn
Commerce Silt Loam	Fine-silty, mixed, thermic Fluvaquentic Endoaquepts	35.08°N, -90.31°W	Crittenden	Soybean
Dubbs Silt Loam	Fine-silty, mixed, thermic Typic Hapludalfs	35.28°N, -90.39°W	Crittenden	Corn
Dundee Silt Loam	Fine-silty, mixed, thermic Typic Endoaqualfs	35.17°N, -90.24°W	Crittenden	Corn
Henry Silt Loam	Coarse-silty, mixed, thermic Typic Fragiaqualfs	35.66°N, -90.71°W	Craighead	Soybean
Tunica Clay	Clayey loamy, smectitic, thermic Vertic Epiaquepts	35.82°N, -91.19°W	Crittenden	Corn

Source (Prass Pimentel, 2023).

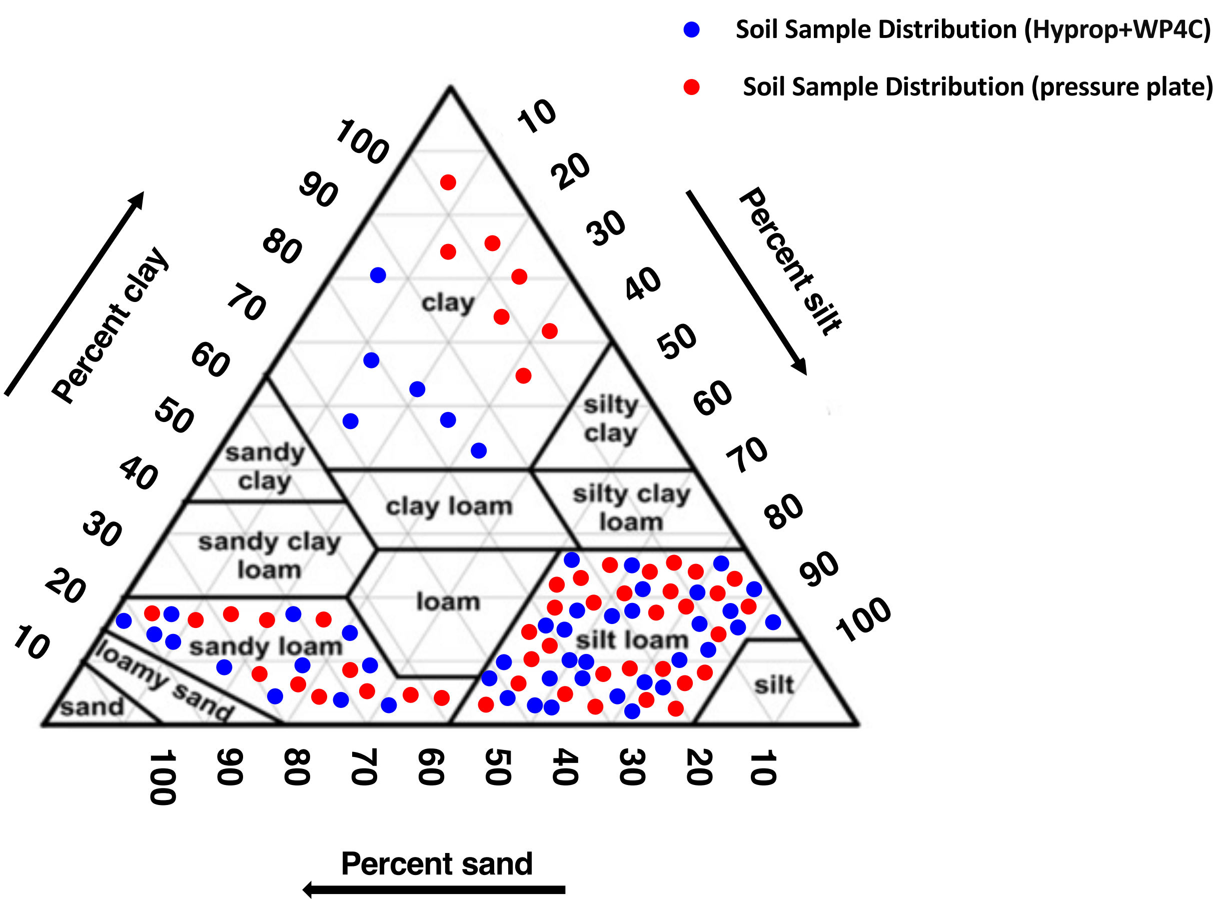

Fig. 1. Soil textural classes of soil samples used in this study

Table 2. Soil water contents at field capacity (θ_{-33}), permanent wilting point (θ_{-1500}), plant available water (PAW), difference in PAW (ΔPAW) relative to the pressure plate method, and mean absolute error (MAE) between pressure plate and Hyprop + WP4C laboratory methods.

	pressure plate			Hyprop + WP4C				
Soil Series	θ_{-33}	θ_{-1500}	PAW	θ_{-33}	θ_{-1500}	PAW	ΔPAW	MAE
	----------	----------	----------	---(in.^{3} in.$^{-3}$)---	----------	----------	----------	----------
Bosket Fine Sandy Loam	0.28	0.15	0.13	0.25	0.12	0.13	0	0.05
Beulah Fine Sandy Loam	0.16	0.10	0.06	0.26	0.11	0.15	0.09	0.05
Dewitt Silt Loam	0.31	0.10	0.21	0.37	0.09	0.28	0.07	0.02
Commerce Silt Loam	0.31	0.20	0.11	0.29	0.09	0.20	0.09	0.09
Dubbs Silt Loam	0.32	0.13	0.19	0.27	0.13	0.14	-0.05	0.06
Dundee Silt Loam	0.32	0.20	0.12	0.39	0.16	0.23	0.11	0.03
Henry Silt Loam	0.30	0.17	0.13	0.35	0.10	0.25	0.12	0.05
Tunica Clay	0.40	0.26	0.14	0.43	0.25	0.18	0.04	0.03

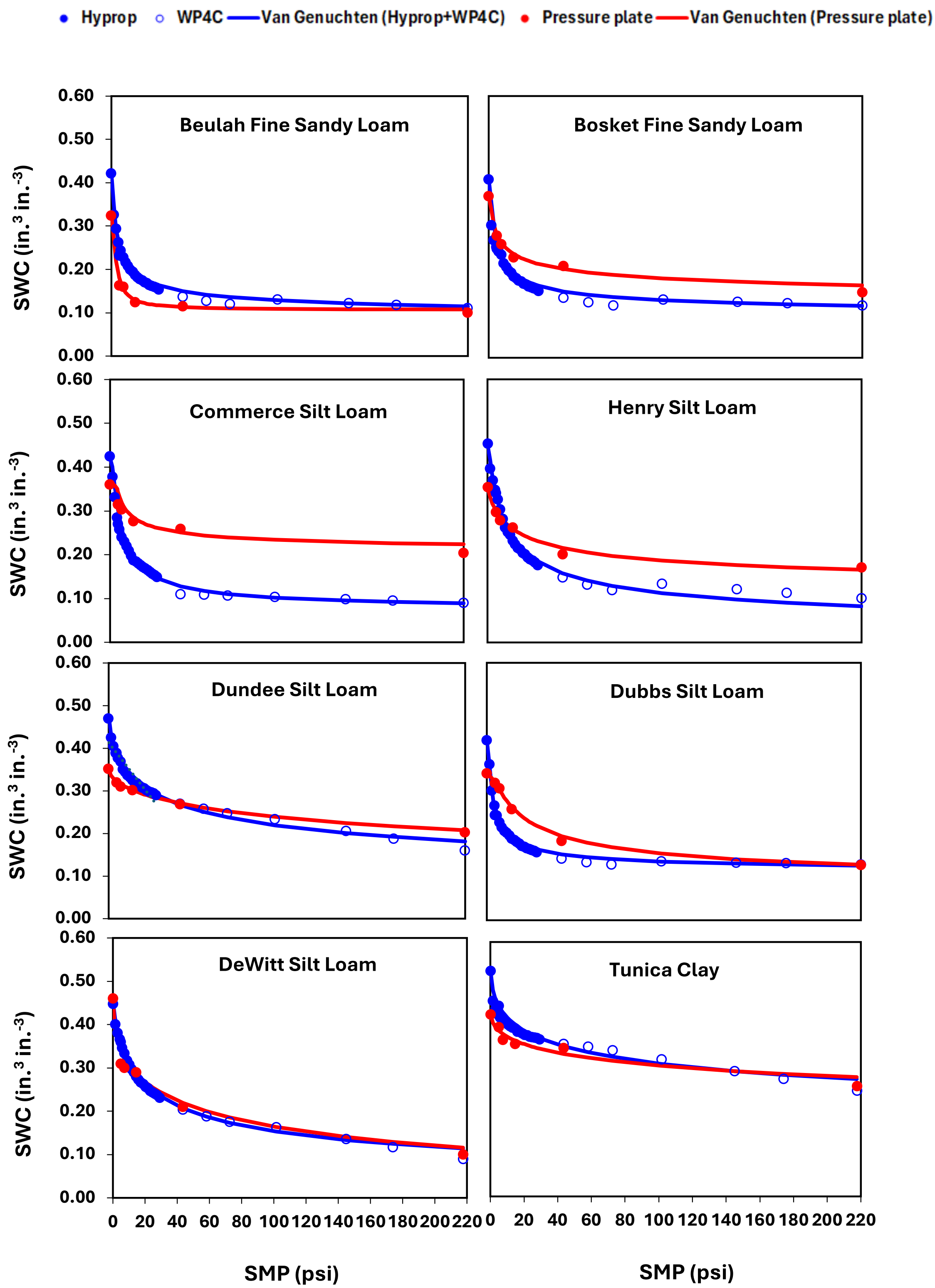

Fig. 2. Fitted soil water retention curves using best-estimated van Genuchten parameters with pressure plate dataset and Hyprop+WP4C dataset for Beulah Fine Sandy Loam, Bosket Fine Sandy Loam, Commerce Silt Loam, Henry Silt Loam, Dundee Silt Loam, Dubbs Silt Loam, Dewitt Silt Loam, and Tunica Clay.

Evaluating Methods for Determining Soil Water Content for Improved Water Retention Curves

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Abstract

The HYPROP (Hydraulic Property Analyzer) system measures the matric potential of a soil core as the soil dries naturally. However, it has been noted from previous analyses that HYPROP soil core dries from the edge to the center, leading to potential inaccuracies in measuring the soil core's average volumetric water content. This study evaluated the accuracy of the HYPROP system in determining average volumetric water content (VWC) within a 250 cm^3 soil core using Dewitt silt-loam soil. Acclima™ Time-domain Reflectometry (TDR) sensors were placed at the edge, center, and between and were simultaneously analyzed using the evaporation method technique used in the HYPROP system. A polynomial model ($P < 0.01$) of y = 8.41 + (1.202*x) - (0.012*x2) with a goodness of fit of 0.99 was measured between the weighted average volumetric water content and the volumetric water content measured by the HYPROP measured VWC. The model's coefficients differed for the three sensor placements, suggesting that the core does not dry uniformly. Even though the sensors did not provide a true estimated water content due to their sensor limitation, it was still possible to observe the drying pattern from the edge to the center of the soil core. These findings suggest that the HYPROP method may tend to overestimate the VWC within a 250 cm^3 soil core and overestimate the field capacity.

Introduction

The soil water retention curve (SWRC) is crucial for understanding soil water content, which is vital for efficient crop management (El Marazky et al., 2011). The SWRC helps monitor irrigation effects on crop yield, quality, and resource conservation (Ali, 2010). Additionally, the SWRC aids in modeling water flow and estimating plant-available water (Hillel, 1971). Irrigation-smart farming utilizes sensors and technology like soil water retention curves to optimize field conditions (Wolfert et al., 2017).

New technologies, like the Hydraulic Property Analyzer (HYPROP), expedite soil water retention curve determination (Schindler et al., 2010). HYPROP uses miniature tensiometers to measure soil matric potential and gravimetrically assess water content as the soil dries naturally (Schindler et al., 2010). However, it has been observed that soil cores dry from the core's edge to the center with the evaporation method (HYPROP). The HYPROP mini-tensiometers are placed at the center of the soil core, so the tension reading may not accurately represent the soil core's average volumetric water content. To address HYPROP's limitations in measuring water content as the soil dries out, using several soil moisture sensors is an alternative technique that needs testing.

Presently, there are several soil moisture sensors available to estimate the water balance in a crop field. Time domain reflectometry, TDR sensors are preferred over these other types of sensors for several reasons, such as their high accuracy, easy installation, and they do not need calibration for each installation (Evett et al., 2002a, 2002b; Kelleners et al., 2005). Here, the Acclima™ TDR soil moisture sensor was used to compare the water content experienced at the edge, middle, and between the HYPROP average water content within a 15.26 $in.^3$ soil core. Therefore, this laboratory experiment aimed to determine differences in soil water content at the center and at the edge of an undisturbed soil core compared to HYPROP's volumetric water content as the soil dries out over time.

Procedures

This study used 4 intact soil cores of a Dewitt silt-loam soil. The 4 samples were collected in a no-tillage-managed field on 4 August 2022 from the top 6 in. at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Ark. Sample collection, soil

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preparation, and measurement procedures were performed according to the HYPROP (Hydraulic Property analyzer, METER Group, Inc., Pullman, Wash., USA) manual guidelines (UMS, 2015). The final gravimetric water content was determined by oven-drying samples at 221 °F or 48 hours and re-weighed to determine dry mass. Volumetric water content was calculated by multiplying gravimetric water content by the bulk density determined from each soil core.

In this study, the Acclima™ Soil Smart Series TDR305N (Acclima™, Inc, Meridian, Idaho, USA) with a 2-in. long waveguide with a rod spacing of 0.45-in. connected to an SDI-12 communication port was used for the volumetric water content (VWC) data recording. For data recording, the TDR probe was connected to a CR3000 Micrologger (Campbell Scientific, Inc, Logan, Utah, USA), and values were retrieved using Excel (Microsoft-version 1808, Redmond, Wash.) after 6 days of continuous measurement. Three TDR sensors were placed in 3 locations in the soil core and analyzed jointly with the HYPROP device (Meter Group, Pullman, Wash., USA). The first sensor was placed at 1.07 in., and the second was placed at 0.45 in. from the center of the core. The third sensor was placed in the middle of the soil core at 1.57 in. from the edge (Fig. 2). It is important to highlight that it was not possible to place the TDR center and between sensors probe exactly vertically due to space limitations and the probes were slightly angled.

It was important to ensure accurate measurements of the volumetric water content within the soil core. The measurement volume of each sensor will vary at different locations, which must be considered. Moreover, some locations may have impacted the overall measurement more than others. A weighted average volumetric water content was calculated to address the measurement variation by location. This approach ensured that all points within the core were weighted based on volume when determining the average measurement. To evaluate the performance of the TDR sensors relative to HYPROP measurements, corresponding 1-hour data were recorded and analyzed using JMP (version 17.0, SAS Institute, Inc., Cary, N.C.). Using the Fit Y by X platform, data from the Acclima™ TDR sensors placed at the edge, center, between, and the weighted average were plotted versus the HYPROP volumetric water content for each core, and a polynomial quadratic equation was fitted to the data.

Results and Discussion

A polynomial model ($P < 0.01$) of y = 8.41 + (1.202*x) – (0.012*x2) with a goodness of fit of 0.99 was measured between the weighted average volumetric water content to the volumetric water content measured by the HYPROP balance. The coefficients of the model were different for the 3 sensor placements, suggesting that the core is not drying uniformly. The inner and outer sensors and the outside sensors dried faster than the inner core (Fig. 1). Since the outside sensor represents the larger volume of the core, the weighted average of the core deviated from the inner sensors over time. It was more pronounced as the soil core dried.

The difference between the Acclima™ TDR estimated VWC and HYPROP was small at saturation. However, as the soil core began to dry out, the HYPROP measured VWC decreased more rapidly than the TDR weighted average estimated VWC. Contrary to expectations, as the soil core transitioned into the evaporation-dominated dry period, the estimated TDR weighted average VWC remained substantially higher (29 % v/v) than the HYPROP measure VWC (20 % v/v). Various unanticipated and anticipated interferences affected the observed experiment's outcome, causing it to deviate from our initial expectations (Fig. 1).

The anticipated interference of the variation in calculating the VWC using the sensors may have played a role. The sensor had to estimate the VWC based on estimating the bulk-soil dielectric constant, which could introduce some level of variability in the measurements. For the unanticipated interferences, according to B. Larson (Acclima™, personal communication, 27 January 2023), 4 factors may have potentially interfered with the sensor readings. First, the 15.26 $in.^3$ HYPROP uses a stainless-steel cylinder soil core, and magnetic interference may have affected the sensors, leading to unpredictable readings. Second, the presence of metal in the bottom of the soil sample from the balance could also have impacted the sensor readings because of the size of the magnetic field. Third, having sensors placed too close to each other may have resulted in mutual interference. For instance, the center one has its neighbor's rods nearby, the middle one has two sets of neighboring rods, and the edge unit has a neighboring sensor and a metal wall within its field (and a significantly different ratio of soil to other material). These differences may show up as changes to the overall permittivity experienced by each pulse in the sensor and cause differences in their readings. Fourth, the moisture gradient between the dry (top) and wet (bottom) parts of the soil might have affected the waveguide, causing variations in the response of the pulse sent through it. This difference in response could have led to overestimating the water content.

In order to apply the findings of this laboratory experiment to a practical scenario, a model adjustment was made to the retention curve developed for the Dewitt silt loam, and is shown in Fig. 2. These retention curves were also compared to a 5-point retention curve developed using the pressure plate method (Dane and Hopmans, 2002). The 3 curves show different soil moisture behavior as the soil dries out from saturation. The soil's VWC at field capacity (FC; -33 kPa) clearly varied among each method (Fig. 2).

The VWC at FC was obtained from the HYPROP, HYPROP adjusted using the sensors model, and pressure plate methods were 35%, 36%, and 30%, respectively (Fig. 2). The standard HYPROP measured VWC results showed a deviation of 5 % v/v from the pressure plate results, while the adjusted HYPROP results deviated even more by 6 % v/v. It is important to highlight that individual TDR sensors accounted for the drying down variability of the soil core; however, the TDR weighted average did follow the HYPROP measured VWC.

These findings suggest that the HYPROP method may tend to overestimate the VWC within a 15.26 in.^{3} soil core and over-estimate the FC. If the FC is over-estimated, it can overestimate the Plant Available Water (PAW), which is the difference between field capacity and permanent wilting point (PWP). Overestimated FC and PAW mean that the soil is perceived to have greater water-holding capacity than it does, leading to delayed irrigation scheduling and potential water stress for plants. Using PWP for the Dewitt silt loam soil (10% v/v), the PAW using HYPROP, and HYPROP adjusted using the sensors model, and the pressure plate method was 25%, 26%, and 20% v/v, respectively. This result suggests that the HYPROP should generally report greater PAW than the pressure plate method in Dewitt silt loam soil.

Generally, the evaporation method assumes the soil core is at uniform soil moisture, which this study found not to be a valid assumption. Although there were variations in the sensor data due to its limitations on this study, it is possible that as the core dries, the outer ring of soil, comprising a large volume, is at a lower soil moisture content than the average weight of the soil core used to determine the gravimetric water content of the sample. The experiment was limited to 1 soil series sample, the Dewitt silt loam. The experiment should be replicated on other soil samples and textures to confirm these results. Additionally, it would be useful to compare these results to pressure plate tests of the same soil samples. Improvement in the HYPROP system is suggested to account for the findings in this study.

Practical Applications

Even though the sensors did not provide a true estimate of water content due to their limitations, it was still possible to observe the drying pattern occurring from the edge to the center of the soil core. Consequently, the model did not provide a useful adjustment to the HYPROP system that can account for bias that occurs in the dry down of the soil core during the development of a retention curve from a soil core sample.

A future study should be repeated with the sensors placed at the edge, between, and at the center in separated cores in non-conductivity and non-magnetic materials. Further testing and work are needed to evaluate this method and how it compares to pressure plate retention curves.

Acknowledgments

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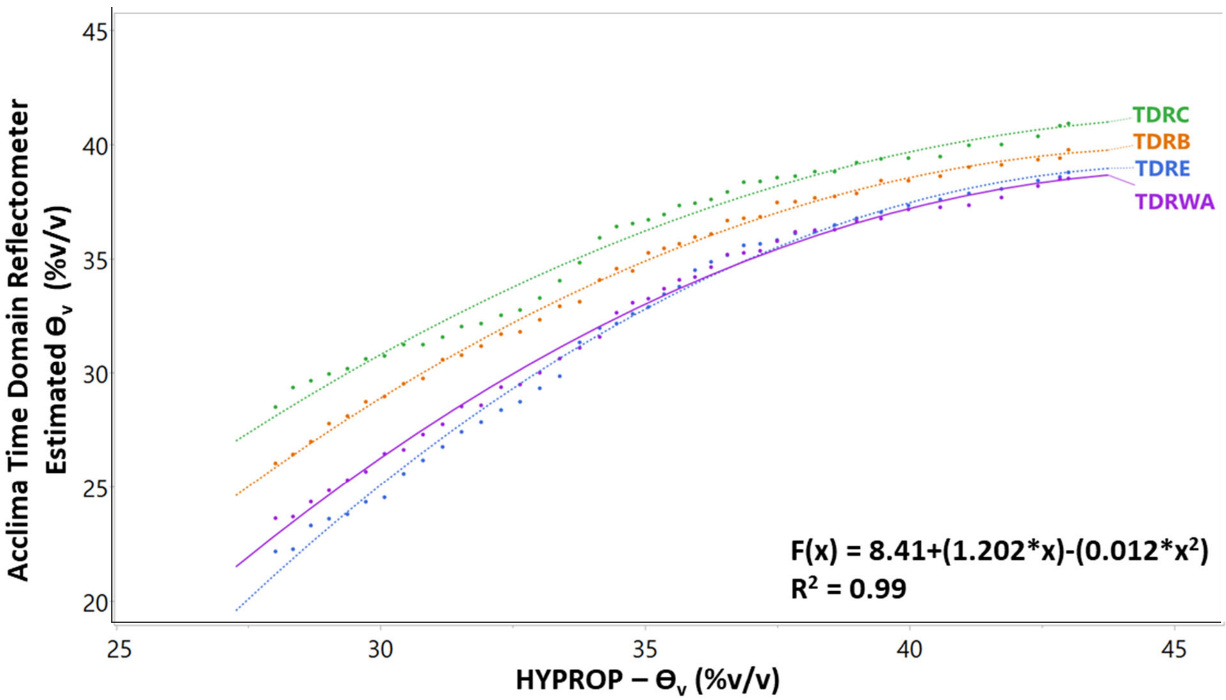

Fig. 1. Polynomial quadratic relationship between the predicted Acclima™ TDR probes placed at the edge (TDRE), between (TDRB), center (TDRC), and the weighted average (TDRWA) volumetric water content (Θv) and HYPROP measured Θv. The equation was obtained from the relationship between TDRWA (F(x)) and water content measured by weight (x, %v/v).

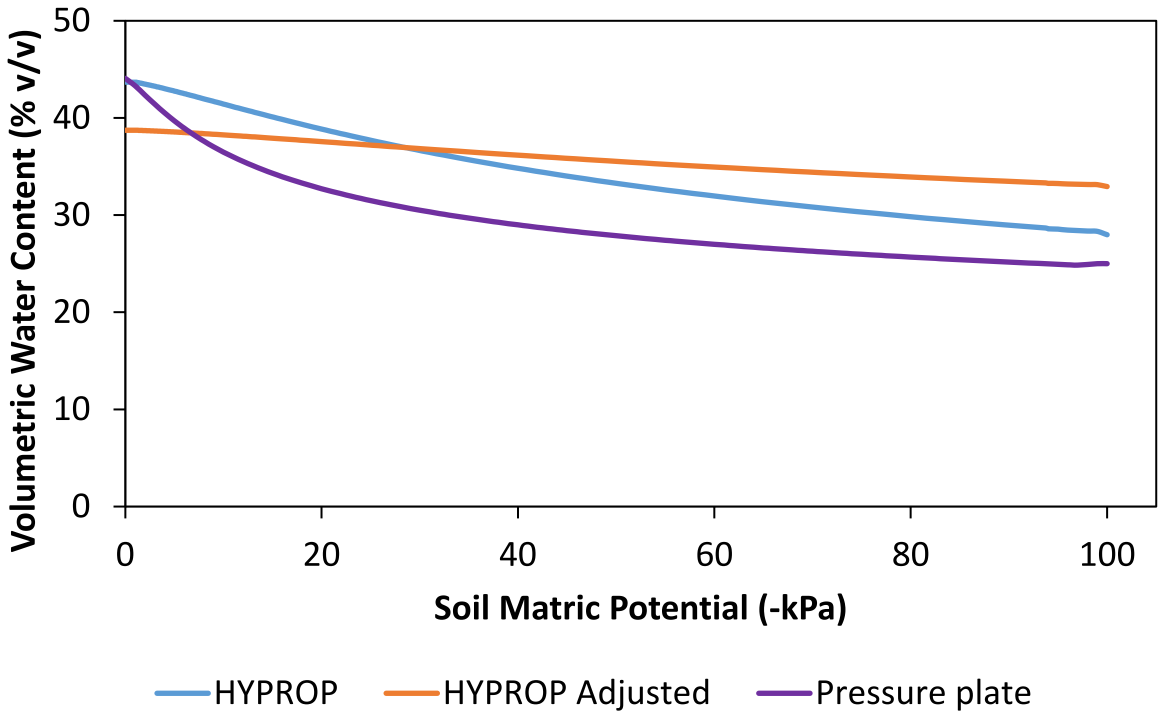

Fig. 2. Soil water retention curves developed through the standard HYPROP method, a proposed HYPROP adjustment using the equation from Fig. 1, and a pressure plate method (Dane and Hopmans, 2002) using an intact soil sample from a Dewitt silt-loam.

Comparison of the Soil Water Characteristic Curve Using the Evaporation and Pressure-Plate Methods for Three Contrasting Soils from the Arkansas Delta Region

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Abstract

Irrigation scheduling plays a key role in crop production and water savings in agriculture. However, irrigation scheduling requires knowledge of the soil water characteristic curve (SWCC) for optimal results. The SWCC relates the soil water content with soil matric potential and has several advantages. The SWCC for several common, irrigated soil series in the Arkansas Delta region has been developed using the pressure-plate method. In contrast, none of the soil series have had a SWCC developed using the evaporation method. Therefore, the objective of this study was to assess the accuracy of the Hydraulic Property Analyzer (HYPROP) evaporation method in developing the SWCC and associated soil properties compared to the standard pressure-plate method. Six undisturbed soil cores were collected from the top 6 in. for each Bosket sandy loam (Mollic Hapludalf), Dewitt silt loam (Typical Albaqualf), and Tunica clay (Vertic Epiaquepts) soil series. Significant differences occurred between methods for field moisture capacity and permanent wilting point for the Dewitt silt loam and Tunica clay soil series. Despite saving time and producing more data points, the HYPROP evaporation method is not an acceptable alternative to the traditional pressure-plate laboratory method for developing a SWCC for irrigation scheduling in the Arkansas delta region. Comparing these methods with more soils may improve results and confidence with the HYPROP evaporation method.

Introduction

Irrigation accounts for the largest groundwater withdrawals by using 94% of the total consumption in Arkansas (Kresse et al., 2014). Irrigation water management seeks to optimize farming water use by varying water application across a field based on variations in soil texture (e.g., clayey, loamy, sandy, and silty) and crop growth stage. Moreover, plant-soil interactions, especially in the rhizosphere, are a path to better water supply for crops, which can lead to high crop production using less water.

Determining the optimal irrigation management practice for crops requires measurements or estimation of the soil water characteristic curve data in the field or laboratory for effective irrigation management. The soil water characteristic curve (SWCC) is the relationship between soil water content and matric potential and is one of the two relevant properties in crop-soil-water management. The SWCC determines the field capacity (FC), permanent wilting point (PWP), and total available water (FC-PWP) in the soil. These are key factors for properly managing irrigation and soil water balance, which can be done using soil moisture sensors.

Several methods have been used to develop the SWCC directly or indirectly. Richards' pressure apparatus is the traditional method to develop the SWCC (Richards, 1948). However, depending on the laboratory, the process is time-consuming and expensive. Currently, another method that has been used to develop the soil water characteristic curve is the evaporation method. The Hydraulic Property Analyzer (HYPROP) laboratory evaporation method (UMS GmbH, Germany) for SWCC construction is new and straightforward. This method uses 2 high-precision miniature tensiometers, sample weight can change with time, and can continuously determine soil matric potentials and corresponding soil water contents (Schindler et al., 2010). However, this method has its limitations, such as the drying pattern, where the soil does not dry uniformly within the soil core as the water evaporates over time (Prass Pimentel, 2023)

Thus, the objective of this study was to assess the accuracy of the evaporation method in developing the SWCC and measuring the soil properties bulk density, porosity, field moisture capacity, permanent wilting point, and plant available water compared to the globally standard pressure plate method.

Procedures

Soil Collection

Six undisturbed soil samples were collected for each soil series at the 6-in. soil depth considered the effective root zone

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for plants in the Arkansas Delta region, USA. Bosket fine sandy loam was collected in Jackson County in a soybean field with a pivot. Dewitt silt loam was collected in Arkansas County in a furrow-irrigated corn (*Zea mays*) field. Tunica clay was collected in a cornfield in Crittenden County. All soil series were previously mapped using the Web Soil Survey (USDA-NRCS, 2024).

Pressure Plate, HYPROP, and WP4C Measurements

Six replicates were performed for each measurement. A standard commercial pressure plate apparatus (Soil Moisture Equipment Corp., Goleta, Calif.) was used to apply the specified pressures to the samples. Plates were prepared by soaking in distilled water overnight before being loaded with soil samples. Six-cm diameter paper filters (Soilmoisture Equipment Corp., Goleta, Calif.) were placed on saturated plates, the undisturbed soil samples were placed over the filter, and the samples were wetted with distilled water from the bottom to achieve good contact between the soil and plate. The samples were allowed to wet until saturation (glistening but not ponding) before being placed in the pressure chamber. Pressure was applied to the chamber, and equilibration was deemed complete after no drainage was observed. Depending on the pressures applied, 4 types of clay-fired ceramic plates were utilized: for 3.3- and 10-m H_2O, plate no. 0675B01M3 (2.5 µ effective pore size; Soil Moisture Equipment Corp.) was used; for 33-m H_2O, plate no. 0675B03M1 (0.7 µ effective pore size; Soil Moisture Equipment Corp.) was used; and for 150-m H_2O, plate no. 0675B15M1 (0.16 µ effective pore size; Soil Moisture Equipment Corp.) was used. A 200-m H_2O commercial air compressor (0505V; Soil Moisture Equipment Corp.) was used to achieve all pressures. The HYPROP system (Hydraulic Property analyzer, METER Group, Inc., Pullman, Wash., USA) was used to measure the equivalent soil water content, and the soil matric potential ranged from 0 to approximately -500 kPa, applying the extended method (Schindler et al., 2012). Sample collection, soil core preparation, and measurement procedures were performed according to the HYPROP manual guidelines (UMS, 2015). The WP4C Dewpoint PotentiaMeter (METER Group, Inc., Pullman, Wash., USA) was used to determine the gravimetric water content at the soil matric potential of -1500 kPa, considered a wilting point.

Fitting the Soil Water Characteristic Curve and Data Analyses

Soil water characteristic curves were developed by using the van Genuchten (1980) model. The soil matric potential (ψ) and volumetric water content (θ) measured for Bosket, Dewitt, and Tunica soil series in the combined HW and PP datasets were plotted as θ vs. ψ. Best fit parameters (α, n, θ_r, and θ_s) were estimated for the van Genuchten model of SWCC using "Excel Solver" (Microsoft, Redmond, Wash., 2016; Wraith and Or, 1998). To measure the goodness of fit between the measured and the predicted datasets, the coefficient of determination (R^2) was obtained for each dataset.

For curves comparison, SWCCs were constructed for a ψ range between 33 and -1500 kPa (permanent wilting point for plants) to use the best fit of the van Genuchten parameters for each combined dataset for Bosket, Dewitt, and Tunica soil series to compare the soil properties (i.e., soil bulk density (ρ_b), total porosity (f_t), soil water content at field moisture capacity (Θ_{FMC}), and the van Genuchten parameters (i.e., α, n, θ_r, and θ_s), obtained from both HW and PP methods, one-factor analysis of variance (ANOVA) was performed. The Tukey test was then used for mean comparisons to determine significant differences ($\alpha > 0.05$). Statistical analyses were conducted using JMP (version 17.0, SAS Institute, Inc., Cary, N.C.).

Results and Discussion

Results comparing the Pressure plate (PP) and HYPROP + WP4C (HW) data set among the soil properties of soil bulk density (ρ_b), total porosity (f_t), soil water content at field moisture capacity (Θ_{FMC}), soil water content at permanent wilting point (Θ_{PWP}), plant-available water (Θ_{PAW}), in the top 15 cm for the Bosket fine sandy loam, Dewitt silt loam, and Tunica clay soils series are shown in Table 1.

The combined HW provided more points of measured θ data between the wet (from 0 to -100 kPa) and the dry (from -1300 to -1500 kPa) ψ ranges, which can get a better estimation for the van Genuchten parameters. The traditional PP method measured values of θ and ψ between -33 and -1500 kPa ranges with 5 measured data points. The HW dataset's estimated fitting parameters differed from those of the PP dataset. The comparison of the fitted SWRCs from the HW and traditional PP datasets for each soil type is shown in Fig. 1.

Bosket Fine Sandy Loam Soil

There was a significant difference in ρ_b, f_t, Θ_{PWP}, and Θ_{PAW} between HW and PP methods, while θFMC did not differ ($P = 0.258$) between the methods. The ρ_b was greater in the PP method (103.63 lb ft^{-3}), which led to a low f_t (0.37 $in.^3$ $in.^{-3}$) compared to ρ_b and f_t obtained from the HW method (91.77 lb ft^{-3} and 0.44 $in.^3$ $in.^{-3}$). This difference can be due to the field being tilled when the soil samples were collected for PP analyses. The Θ_{PWP} obtained from the PP method was greater (0.150 $in.^3$ $in.^{-3}$) compared to the HW method (0.060 $in.^3$ $in.^{-3}$). The HW method had a higher Θ_{PAW} of 0.190 $in.^3$ $in.^{-3}$ compared to the PP method, which had an Θ_{PAW} of 0.120 $in.^3$ $in.^{-3}$. The lower bulk density in the HW method implies greater total porosity than the PP method, consequently leading to a more available pore space that can store more water in the soil. In addition, the differences between the Θ_{PWP} values for the HW and PP methods might be due to the phenomenon known as hysteresis.

According to the van Genuchten equation, the SWCCs were fitted using the best fitting parameters (α, n, θs, and θ_r) with the HW dataset (Fig. 1b) and PP dataset (Fig. 1a). The R^2 between the measured and predicted values was 0.74 for the fitted SWRC with the HW dataset. The Bosket soil PP dataset had a somewhat poorer agreement, with $R^2 = 0.44$.

Dewitt Silt Loam Soil

In contrast to the Bosket Fine Sandy Loam, there was no significant difference in ρ_b, f_t, and Θ_{PWP} between HW and PP methods, while θ_{FMC} and Θ_{PAW} differed between the methods in the Dewitt silt loam soil series. The Θ_{FMC} obtained from HW was greater (0.360 in.^{3} in.$^{-3}$) compared to the PP method (0.310 in.^{3} in.$^{-3}$), which led to a higher Θ_{PAW} of 0.260 in.^{3} in.$^{-3}$ in the HW method compared to the PP method with a Θ_{PAW} of 0.210 in.^{3} in.$^{-3}$. This difference in the θ_{FMC} parameter can be attributed to the non-uniform drying pattern in the HYPROP soil core observed during the analyses. It has been observed that soil cores dry from the core's edge to the center with the evaporation method (HYPROP). The HYPROP mini-tensiometers are placed at the center of the soil core; therefore, the tension reading may not accurately represent the soil core's average volumetric water content. In contrast to the HYPROP, the PP method uses the smallest soil sample ring, which can reduce data variability and apply uniform pressure in the soil sample.

The van Genuchten equation SWCCs were fitted using the best fitting parameters with the PP dataset (Fig. 1c) and HW dataset (Fig. 1d). For the fitted SWRC with the PP dataset, the R^2 between measured and predicted values was 0.92. Compared to the PP method, the R^2 for the Dewitt soil HW dataset was 0.82.

Tunica Clay Soil

In contrast to the Bosket Fine Sandy Loam and similar to the Dewitt Silt Loam soil series, there was no significant difference in ρ_b, f_t, and Θ_{PWP} between HW and PP methods, while θ_{FMC} and Θ_{PAW} differed between the methods in the Tunica Clay soil series. The Θ_{FMC} obtained from HW was greater (0.440 in.^{3} in.$^{-3}$) compared to the PP method (0.400 in.^{3} in.$^{-3}$), which led to a higher Θ_{PAW} of 0.190 in.^{3} in.$^{-3}$ in the HW method compared to the PP method with a ΘPAW of 0.140 in.^{3} in.$^{-3}$. Similar to the results from Dewitt Silt Loam soil, this difference observed in the θ_{FMC} parameter can be attributed to the non-uniform drying pattern in the HYPROP soil core. In addition, the shrink-swell phenomena of the clay soil, which was observed during the analyses, and the larger column size of the HYPROP soil core may have played a role in this difference. The SWCCs for Tunica soil were fitted using the best fitting parameters with the HW dataset (Fig. 1f) and the PP dataset (Fig. 1e). For the fitted SWRC with the HW dataset, the R^2 between measured and predicted values was 0.93. Compared to the HW method, the Tunica soil PP dataset had a slightly lower agreement with $R^2 = 0.73$.

Practical Applications

In this study, the predicted soil moisture content via fitted SWCCs using the van Genuchten model agreed well with the measured data by the combined HYPROP and WP4C pressure plate method for Dewitt silt loam and Tunica Clay soils. However, the predicted SWCCs did not agree for Forestdale sandy loam soil. The van Genuchten best-fitting parameters are more sensitive to fit the data for this soil series. The HW method measured greater θ_{FMC} and Θ_{PAW} soil hydraulic properties compared to the PP method in the Dewitt silt loam and Tunica clay soil series. These findings suggest that HYPROP may be overestimating the θ_{FMC} and consequently overestimating the Θ_{PAW}. For irrigation purposes, the soil is perceived to have greater water-holding capacity than it does, leading to delayed irrigation scheduling and potential water stress for plants.

Several researchers have been comparing the evaporation and equilibrium methods worldwide and across different soil types, validating the evaporation method since it had reliable data compared to the globally standard pressure plate method. In contrast, despite saving time and yielding more data points, in this study, the HYPROP evaporation method might not be an acceptable alternative to the traditional pressure-plate laboratory method for developing an SMCC for irrigation scheduling in the Arkansas Delta region. However, HYPROP can predict soil moisture content via fitted SWCC using the van Genuchten model. Using more soils to compare methods may improve results and confidence in the HYPROP evaporation method.

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Table 1. Summary of standard error, mean of response, and *P*-value resulting from statistical analysis between Richard's pressure plate (PP) and HYPROP+WP4C (HW) data set among the soil properties soil bulk density ($Ꝓ_b$), total porosity ($ʃ_t$), soil water content at field moisture capacity (Θ_{FMC}), soil water content at permanent wilting point (Θ_{PWP}), plant-available water (Θ_{PAW}), in the top 15 cm for the Bosket fine sandy loam, Dewitt silt loam, and Tunica clay soils series collected in the Arkansas delta region, USA.

Soil Series/Method	$Ꝓ_b$	$ʃ_t$	Θ_{FMC}	Θ_{PWP}	Θ_{PAW}
	(lb ft^{-3})	--------------------------------(in.^{3} in.$^{-3}$)--------------------------			
Bosket Fine Sandy Loam					
Pressure Plate	103.63 a†	0.37 b	0.280 a	0.150 a	0.120 b
HYPROP+WP4C	91.77 b	0.44 a	0.250 a	0.060 b	0.190 a
P-value	0.006	0.006	0.258	0.003	0.009
Standard error	2.56	0.015	0.015	0.017	0.014
Dewitt Silt Loam					
Pressure Plate	88.02 a	0.46 a	0.310 b	0.100 a	0.210 b
HYPROP+WP4C	94.27 a	0.42 a	0.360 a	0.100 a	0.260 a
P-value	0.141	0.132	0.002	0.173	<0.001
Standard error	2.75	0.016	0.006	0.002	0.006
Tunica Clay					
Pressure Plate	93.64 a	0.43 a	0.400 b	0.260 a	0.140 b
HYPROP+WP4C	94.26 a	0.46 a	0.440 a	0.250 a	0.190 a
P-value	0.165	0.175	0.020	0.403	<0.001
Standard error	2.56	0.016	0.010	0.009	0.007

†Within the column, means at the same letter are not significantly different according to Tukey's protected least significant difference at $\alpha = 0.05$.

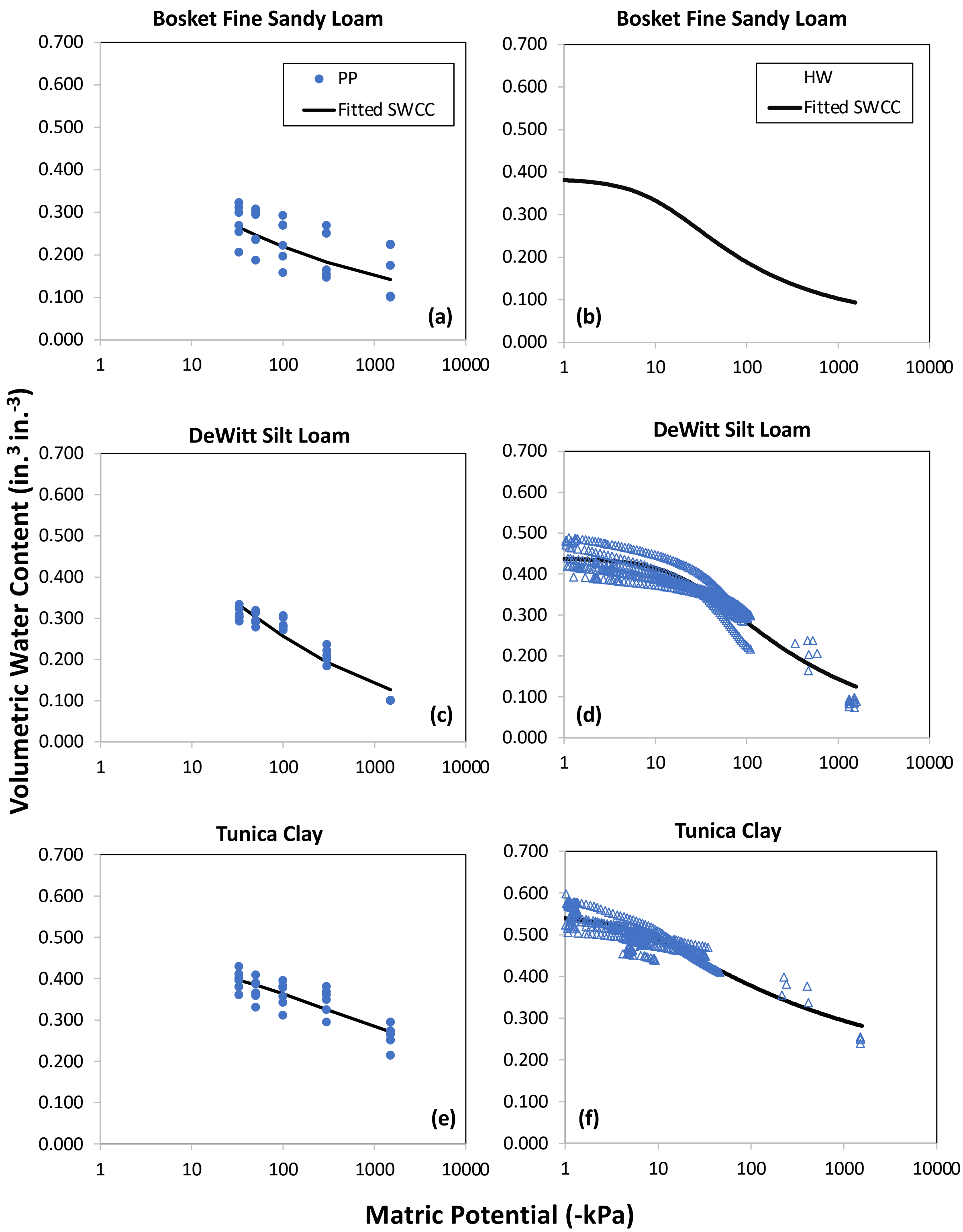

Fig. 1. The soil water characteristic curve was developed using the best-estimated van Genuchten parameters (Fitted SWCC) with Richard's pressure plate (PP) data set for Bosket soil (a), Dewitt soil (c), and Tunica soil (e), and with HYPROP+WP4C (HW) data set for Bosket soil (b), Dewitt soil (d), and Tunica soil (f) collected in the top 6 inches in the Arkansas Delta region, USA.

Soil Health in Arkansas Soybean Production

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Abstract

The utilization of cover crops in Arkansas soybean (*Glycine max*) production systems was evaluated for their viability to grow and thrive, sequester nutrients, and impact soil health over time. Cover crops evaluated include cereal rye (*Secale cereale*), black-seeded oat (*Avena sativa*), barley (*Hordeum vulgare*), Austrian winter pea (*Pisum sativum*), blue lupin (*Lupinus angustifolius*), hairy vetch (*Vicia villosa*), and two different cover crop blends in addition to a fallow treatment. One blend consisted of a mix of black-seeded oats and Austrian winter pea, while the second blend was a mix of cereal rye, crimson clover (*Trifolium incarnatum*), and seven-top turnip (*Brassica rapa*). Cover crops were established starting in the fall of 2017 at three agricultural research stations in Arkansas near Kibler, Colt, and Rohwer. Biomass and soil samples were collected in the spring prior to termination and soybean planting. Soil samples were analyzed for nutrient content, total carbon (C), total nitrogen (N), and C:N ratios. Net changes in soil pH, soil organic matter (SOM), C, N, C:N ratios, and soil respiration (CO_2-C) were analyzed within cover crop treatments at the three field locations across Arkansas.

Introduction

Cover crops have numerous advantages and disadvantages in regard to crop production and soil management. Cover crops can improve soil drainage, eliminate excess water on poorly drained fields, and prevent runoff or sediment loss (Blanco-Canqui et al., 2015). There is also the potential to reduce fertilizer-N inputs to the following crop (Wagger, 1989). Cover crops can keep soil temperatures lower in the spring, which may have a negative impact on cash crop emergence. There may also be increased insect pressure with dense cover crop residues present in the non-crop season. Dense cover crop biomass or residues can result in poor seed-to-soil contact at planting, which may also reduce crop stand or decrease uniformity of crop emergence. The objectives of this study were to evaluate the impact of long-term implementation of various cover crops on soil health and the impact of continued cover crop use on soybean in Arkansas production systems.

Procedures

The cover crop treatments consisted of a winter fallow, cereal rye (*Secale cereale*), black-seeded oat (*Avena sativa*), barley (*Hordeum vulgare*), Austrian winter pea (*Pisum sativum*), blue lupin (*Lupinus angustifolius*) switched to hairy vetch (*Vicia villosa*), Blend 1 (cereal rye, crimson clover [*Trifolium incarnatum*], seven-top turnip [*Brassica rapa*]) in a 96:2:2 ratio respectively, and Blend 2 (Black-seeded oats and Austrian winter pea) in a 50:50 ratio. Blue lupin was replaced with hairy vetch due to the blue lupin not being as well suited for Arkansas as originally thought. Testing locations consisted of the following University of Arkansas System Division of Agriculture field research locations: a silty clay loam (3% sand, 60% silt, and 37% clay) at the Vegetable Research Station (VRS) near Kibler, Ark, which was in a vegetable-soybean rotation prior to this study; a silt loam (1% sand, 77% silt, and 22% clay) at the Pine Tree Research Station (PTRS) near Colt, Ark., which was in a rice (*Oryza sativa* L)-soybean rotation prior to the study; and a silt loam (6% sand, 79% silt, and 15% clay) at the Rohwer Research Station (RRS) near Watson, Ark. which was in a soybean-wheat (*Triticum aestivum* L) double-crop system prior to the study.

The trial was a randomized complete block design with 4 replications. Cover crops were planted beginning in the fall of 2017 and each subsequent fall thereafter. Biomass samples were collected on the day of or the day before chemical termination of each cover crop. This was done at early heading to allow for maximum biomass accumulation of all cover crops. Samples were collected from a 3 ft^2 area at the soil level using a hand sickle. Samples were dried to terminal dryness in a forced-air oven at 140 °F for a minimum of 14 days and weighed. Biomass in lb/ac was extrapolated from weighed biomass per plot.

Initial soil samples were pulled in 2017 as a composite collected from the top 4 in. in each location, with at least 3 cores per rep. Final soil samples were collected in the spring of 2023 as a composite from each cover crop plot from the top 4 in. This was following seven full rotations of each cropping system. Soil samples were analyzed at Ward Laboratories Inc

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(Kearney, Neb.) in 2017 and at the University of Wisconsin in 2023 for soil pH using 1:1 soil: water ratio, soil organic matter (SOM) concentration via loss-on-ignition, total C, total N, and soil respiration (ppm CO_2-C).

Soybeans were seeded at 150,000 seeds/ac using no-tillage practices approximately 2–4 weeks after termination of cover crops each year. The soybean variety P45A40LX was planted in 2023 on 38-in. rows at RRS on 26 May, on 7.5-in. rows at VRS on 30 May, and 15-in. rows at PTRS on 29 May. Soybeans were flat-planted with a drill seeder and flood irrigated at PTRS, flat-planted with a drill seeder and overhead irrigated at VRS, and vacuum planted on raised beds and furrow irrigated at RRS. Soybeans were harvested using a small-plot combine and yields adjusted to 13% moisture. Statistical analyses were performed utilizing JMP Pro 17 (JMP Statistical Discover, LLC, Cary, N.C.) with means separation using Student's T grouping for least square means at $\alpha = 0.05$.

Results and Discussion

There were no significant differences in biomass accumulation for any cover crop treatments in 2023. Cover crop biomass accumulation ranged from 2,427 to 5,120 lb/ac. Cover crop biomass provides an estimate of organic C that is generated and potentially returned to the production system. Higher rates of cover crop biomass accumulation provide a great source of substrate to increase SOM concentrations and also provide a food source for soil micro and macro fauna to aid in nutrient cycling and increased aggregate stability. Cover crop biomass production is largely impacted by termination date but can also be a function of cover crop species and plant density.

Net changes in soil pH, SOM, C, N, C:N ratio, and soil respiration (CO_2-C) were significant amongst locations (Table 1), suggesting that inherent soil properties are a driving force in many of these measurements. Soil pH increased at PTRS across treatments, while it decreased across treatments at RRS and VRS (Table 1). Changes in soil pH can be influenced by a number of factors including irrigation water source and fertilization. Increases in soil pH at the PTRS location were most likely attributed to the alkaline water source used for irrigation, while the soil pH decrease at RRS and VRS could be due to the cover crop residue decomposition (which is most often a net acidic reaction). Carbon concentrations increased at all locations across treatments (Table 1), but the highest rate of change occurred at the VRS. Of the three sites included in the study, the VRS reported the highest clay content, which may have been a driving factor in the greater magnitude of increase in soil C content. Carbon:Nitrogen (C:N) ratios decreased across treatments at VRS and RRS while they increased slightly at PTRS (Table 1). Carbon:Nitrogen ratios are a complicated metric but can shed light on the intricate dynamic of C and N cycling in agroecosystems. A narrower (smaller) C:N ratio suggests an increase in the overall health and performance of a soil system. Increases in N sequestration are required to effectively sequester C in the soil.

Soil organic matter was significantly impacted by cover crop treatments at the PTRS and RRS, but there were no significant differences in SOM at the VRS location (Table 2). Net SOM change at PTRS was more variable across cover crop treatments (Table 2) with the majority of treatments resulting in a net decrease in SOM over time, especially the fallow treatment. The net decrease in SOM at PTRS for the fallow and black-seeded oats treatments (-0.18%) may be attributed to reduced biomass production in either the cover crop or cash crop biomass over the life of the experiment. Austrian winter pea resulted in the highest net change in SOM (+0.22%) at PTRS (Table 2) and may be attributed to the N added from the legume crop, which aided in C sequestration and thus an increase in SOM. The lack of change for the other legume cover crop treatment (blue lupine switched to hairy vetch) may have been due to the failure to establish the blue lupin cover crop in the early years of the trial, and now that hairy vetch is being used, we may begin to see an increase in SOM similar to what was observed with Austrian winter pea. At the RRS, all cover crop treatments resulted in a net increase in SOM over the course of the trial, even in the fallow treatment where no cover crops were grown. The increase in SOM within the winter fallow cover crop treatment and all other treatments can be attributed to the implementation of no-tillage production practices that help preserve organic biomass additions to the soil and increase SOM. The largest net increase in SOM at the RRS was observed in the Blend 1 cover crop treatment and was +0.38%. The hairy vetch and Blend 2 cover crop treatments also provided appreciable increases in SOM with a net increase of 0.33 and 0.23%, respectively.

The impact of winter cover crops on soil N varied across locations with an overall increase in soil N at the VRS and RRS locations with very little change at the PTRS location (Table 1). The impact of winter cover crop treatments on soil N concentration was only significant at the RRS location with the fallow treatment reporting the lowest net N concentration change (0.007%, Table 3). As expected, treatments containing a legume tended to result in the greatest increases in soil N concentration, including Blend 1 and hairy vetch. These treatments also tended to result in greater SOM concentrations, which further supports the notion that added N is required to sequester C as SOM.

Soybean yields were not significantly different between any cover crop treatments at any of the locations in 2023 (Table 4). The use of cover crops did not negatively or positively influence soybean production in 2023. The lack of differences in soybean yield indicates that although there were no negative effects of cover crop use, under the conditions of this study, there were no significant benefits to yield either. Future investigations should focus on collected soil water content data, input requirements (i.e., irrigation, fertilization, and pesticides) and other information related to soybean performance. Previous research has suggested that increases in soil health within irrigated production systems will most likely not result in yield increases. However, increases in soil health associated with irrigated production systems can often lead to significant decreases in production inputs, which leads to increased profitability.

Changes in soil health over this long-term study varied among locations. Positive trends were observed with increased SOM at the RRS and VRS locations across cover crop treatments and increased C concentrations at all locations across the majority of treatments. The irrigation methods could have a potential impact on the net soil health changes given the PTRS location was flooded, the RRS location was furrow irrigated, and the VRS location was overhead irrigated. The interaction of soil conservation practices and irrigation methods warrants further investigation.

Practical Applications

The results presented here indicate that the incorporation of no-tillage practices and winter cover crops can have a significant impact on soil health metrics. Although the time required to see significant changes in soil health parameters may require >5–10 years, it is apparent that increases in SOM, soil C, and soil N are attainable with consistent implementation of these practices. Future work should focus on the net reduction in input costs associated with increased soil health in Arkansas soybean production systems.

Acknowledgments

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Table 1. Change in soil characteristics at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS), Rohwer Research Station (RRS), and Vegetable Research Station (VRS) from 2017 to 2023.

	Net change in soil characteristic at testing location			
Soil Characteristic	**PTRS†**	**VRS**	**RRS**	***P*-value**
Delta pH	0.34a‡	-0.41c	-0.3b	<0.0001
Delta OM	-0.05c	0.41a	0.17b	<0.0001
Delta %C	0.03b	0.34a	0.098b	<0.0001
Delta %N	-0.001c	0.046a	0.014b	<0.0001
Delta C:N	0.04a	-0.61b	-0.45b	0.0014
Delta CO_2-C (ppm)	-4.4b	13.8a	-29.6c	<0.0001

† PTRS = Pine Tree Research Station, Colt, Ark.; RR = Rohwer Research Station, Rohwer, Ark.; VRS = Vegetable Research Station, Kibler, Ark.

‡ Means followed by the same letter within a row are not significantly different at $P = 0.05$.

Table 2. Influence of cover crops use on soil organic matter at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS), Rohwer Research Station (RRS), and Vegetable Research Station (VRS) from 2017 to 2023.

	Net change in soil organic matter		
Cover Crop	**PTRS**[†]	**VRS**	**RRS**
	------------------------------- (%) -------------------------------		
Fallow	-0.18b[‡]	0.48	0.06ab
Cereal Rye	0.02ab	0.48	0.18ab
Black Oats	-0.18b	0.38	0.11ab
Barley	-0.13b	0.25	0.06ab
Austrian Winter Pea	0.22a	0.48	0.03b
Hairy Vetch	-0.03ab	0.33	0.33ab
Blend 1	-0.13b	0.58	0.38a
Blend 2	0.07ab	0.30	0.23ab
P-value	0.0118	NS	0.0152

[†]PTRS = Pine Tree Research Station, Colt, Ark.; RR = Rohwer Research Station, Rohwer, Ark.; VRS = Vegetable Research Station, Kibler, Ark.

[‡]Means followed by the same letter within a row are not significantly different at $P = 0.05$.

Table 3. Influence of cover crops use on soil Nitrogen at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS), Rohwer Research Station (RRS), and Vegetable Research Station (VRS) from 2017 to 2023.

	Net change in soil nitrogen		
Cover Crop	**PTRS**[†]	**VRS**	**RRS**
	------------------------------- (%) -------------------------		
Fallow	-0.004	0.038	0.007b[‡]
Cereal Rye	0.001	0.050	0.012ab
Black Oats	-0.013	0.051	0.012ab
Barley	0.000	0.034	0.009ab
Austrian Winter Pea	0.009	0.050	0.010ab
Hairy Vetch	0.001	0.044	0.020ab
Blend 1	0.001	0.057	0.026a
Blend 2	-0.003	0.041	0.015ab
P-value	NS	NS	0.0214

[†]PTRS = Pine Tree Research Station, Colt, Ark.; RR = Rohwer Research Station, Rohwer, Ark.; VRS = Vegetable Research Station, Kibler, Ark.

[‡]Means followed by the same letter within a row are not significantly different at $P = 0.05$.

Table 4. Influence of cover crops on the grain yield of soybean at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS), Rohwer Research Station (RRS), and Vegetable Research Station (VRS) during 2023.

	Grain Yield		
Cover crop	**PTRS**†	**RRS**	**VRS**
	---------------- (bu./ac) ----------------		
Fallow	51.8‡	60.8	42.5
Cereal Rye	53.2	61.3	42.3
Black Oats	51.7	60.5	41.5
Barley	50.6	60.3	40.0
Austrian Winter Pea	50.8	60.8	42.5
Hairy Vetch	50.2	62.8	38.3
Blend 1	49.3	63.3	38.5
Blend 2	48.6	61.0	41.5

†PTRS = Pine Tree Research Station, Colt, Ark.; RR = Rohwer Research Station, Rohwer, Ark.; VRS = Vegetable Research Station, Kibler, Ark.

‡ Average grain yields were not significantly different between treatments.

Interaction of Drought Stress and Potassium Deficiency on Soybean Potassium Uptake

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Abstract

Potassium (K) nutrition and drought stress affect soybean (*Glycine max* (L.) Merr.) vigor and productivity through the combined impacts on water regulation. A study was conducted with soybean grown in 5-gal buckets under a rain-out shelter to determine how the interaction between these crop stresses at various growth stages influences the crop total K uptake (TKU). Treatments included soybean grown with and without preplant fertilizer-K, soil moisture at 50% (drought) or 80% (well-watered) field capacity, imposed drought during vegetative growth (V3–V7), flowering (R1–R3), pod development (R4–early R6), and seed development (R5–mid R6) on 2 different silt loam soils. Widespread K deficiencies were observed during the study across all treatments. Drought stress significantly ($P < 0.05$) reduced the TKU. The crop growth stage when drought stress was imposed was a significant factor, with greater reductions in TKU when stress was imposed during reproductive growth. Preplant fertilizer-K increased TKU in drought conditions. Results emphasize the complexity of the interactions between K nutrition and drought stress in soybean, as drought stress impeded K uptake.

Introduction

Drought stress is arguably the most important yield-limiting factor in global soybean (*Glycine max* (L.) Merr.) production (Desclaux et al., 2000), coupled with potassium (K) deficiency as a major yield-limiting factor in Arkansas production systems. Potassium (K) is one of the 14 plant essential mineral elements and is needed in large amounts, second only to nitrogen (N) in total plant uptake, and is the highest demand related to fertilization (Bender et al., 2015). Potassium is responsible for several critical physiological and metabolic functions of the plant, including photosynthesis, transpiration, water and nutrient translocation, and disease susceptibility through enzyme regulation (Prajapati and Modi, 2012). Several of these functions involve water regulation within the plant, emphasizing the importance of K for plant health and tolerance to abiotic stresses, including drought. Water is a common cause of agricultural disasters and can result in major yield loss (Daryanto et al., 2016). Overall plant health is dependent on both plant-available water and plant-available K, with intertwined benefits and consequences.

The primary research objective was to delineate the relationship and potential interaction between K deficiency and drought stress on soybean total K uptake (TKU) at various growth stages in Arkansas soybean. Based on the intricate nature of K nutrition and water relations, we hypothesized that drought stress would exacerbate K deficiency because of the impaired K uptake when soil moisture is limited. Additionally, we hypothesized that adequate K nutrition would alleviate some level of drought stress because of the plant's ability to manage transpiration and water loss pathways by allocating ample K between the stomata guard cells and maximizing water use efficiency. Hence, we predicted that (a) K deficiency and drought would reduce plant TKU, and (b) the severity of crop impact depends on the growth stage in which the crop is stressed, and more loss associated with later reproductive growth stages.

Procedures

Soybean was grown in 5-gal buckets under a rain-out shelter to completely manage the soil moisture in a typical Arkansas environment (humidity, temperature, day length, etc.) from May to September 2021. Two silt loam soils were collected from Colt, Ark., mapped as Calloway silt loam (Fine-silty, mixed, active, thermic Aquic Fraglossudalfs) and Calhoun silt loam (Fine-silty, mixed, active, thermic Typic Glossaqualfs) soil series. The Calhoun soil measured very low (≤60 ppm) soil test K (STK) with a field history of K deficiency, while the Calloway soil measured medium (91–130 ppm) STK and had no history of crop K deficiencies in the last 5 years (Slaton et al., 2013). The soil texture, organic matter content, and the SPAW (Soil, Plant, Atmosphere, and Water) program (Saxton, 2017) were used to determine the amount of water to add to each bucket to achieve the desired soil moisture targets.

All soil was dried, sieved, and evenly distributed as 35 lb of soil into each 5-gal bucket with drainage holes drilled into the bottom. Fertilizer-K treatments were applied as granular muriate of potash (0-0-60) at 125% of the recommended rate based on the Mehlich-3 soil reports and the current Arkansas recommendations, calculated by soil mass. Both soils mea-

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sured in the medium category of P and received 125% of triple super phosphate (0-46-0) to ensure P was not a limiting factor as the plants grew in a confined bucket with limited soil volume. All fertilizer was incorporated approximately 3 in. deep before planting. A foliar application of boron (B) was applied at the V4 growth stage and pests were routinely controlled with insecticides. High populations of white flies (*Trialeurodes vaporariorum*) were routinely found and sprayed, resulting in sooty mold (*Capnodium citri*) during late reproductive growth.

Treatments included preplant fertilizer-K and no fertilizer-K at the time of planting, followed by either no drought stress or drought stress held for 18 consecutive days at key growth stages. Each treatment was replicated 4 times in each soil. The growth stages targeted for treatment were vegetative growth (V3–V7), anthesis (R1, R2), pod development (R3, R4), and seed fill (R5, R6) (Table 1). However, the pod development drought stress was disrupted by an extreme rain event that occurred 4 days into the treatment, flooding the rain-out shelter and providing water to the soybean and soil through the bucket's drainage holes. After the excess moisture was removed, the drought stress treatment was restarted at the R4 growth stage. Drought stress was defined as 50% field capacity of the soil, while no drought stress was defined as 80% field capacity (Samarah et al., 2004). All buckets were watered to the exact desired weight every other day during drought stress. For growth stages when plants were not under drought treatment, equal amounts of water were applied to each bucket based on the weights of a representative subsample.

Plants were harvested at the R7 growth stage to investigate the aboveground nutrient uptake and nutrient partitioning within seeds and biomass at the peak of nutrient accumulation (Bender et al., 2015). At harvest, plants were clipped at the soil surface, measured, and digested with HNO_3 and 30% H_2O_2 (Jones and Case, 1990) and analyzed by ICP-AES for K concentration. The combination of grain and aboveground biomass and their relative K concentrations were used to calculate the TKU within each experimental unit.

The experiment was established as a 2×2×2×4 factorial design with the following factors: soil series, preplant fertilizer-K rate, drought stress, and drought timing. Buckets were blocked by drought timing within the rain-out shelter, with 4 replications of all soils, drought, and fertilizer-K rate treatments included in each. Block placement in the rain-out shelter was considered a random variable. Any data points above or below 1.5 times the interquartile range were identified as outliers and excluded from the analysis. Data were subjected to linear mixed effect analysis and post-hoc analysis and means separation was conducted using Tukey's honestly significant difference test. Assumptions of linearity, homogeneity of variance, and normality of residuals for each model were tested and verified.

Results and Discussion

Total aboveground TKU ranged from 0.00113 to 0.00375 lb K/ft across all treatments. Soybean that received preplant fertilizer-K measured an average of 0.00216 and 0.00271 lb K/ft with and without drought stress, respectively. Soybean that did not receive preplant fertilizer-K measured an average of 0.00177 and 0.00212 lb K/ft with and without drought stress, respectively. The average aboveground TKU measured was lower than the 0.003277 lb K/ft average reported in previous research (Bender et al., 2015; Sallam et al., 1985), confirming K deficiencies occurred within this trial. Interactions between the addition of preplant fertilizer-K, soil, drought, and time of drought are significant influencers on the aboveground TKU. These include the significant interactions between drought, soil, and time of drought ($P < 0.0001$, Fig. 1), drought, fertilizer-K, and soil ($P < 0.0001$, Fig. 2), and drought, fertilizer-K, and time of drought ($P < 0.0001$, Fig. 3). These interactions provide insight into the K uptake and water regulation mechanisms of the crop across various growth stages.

The significant interaction between drought, soil, and time of drought is evidence that drought stress impeded crop K uptake from the soil (Fig. 1). The treatments that were drought-stressed resulted in a lower TKU in all soil and drought timing pairs except for the Calloway soils with drought stress during vegetative growth, at which time drought did not result in a significant TKU difference. The overall trend of reduced aboveground TKU after drought stress occurred agrees with the understanding of crop K uptake and soil K availability, requiring water for K+ diffusion and uptake from the soil (de Bang et al., 2021). Additionally, drought conditions imposed during the reproductive development stages resulted in a greater decrease in TKU than the drought conditions imposed during the vegetative stages (Fig. 1). Bender et al. (2015) found soybean peak K uptake to occur between the R1 and R4 growth stages, explaining why drought conditions during these growth stages had a larger influence on the crop TKU.

The importance of preplant fertilizer-K and drought stress on crop TKU is clear in Fig. 2, which investigates the interaction between preplant fertilizer-K, drought, and soil. In all situations, well-watered soybean resulted in a significantly higher TKU than drought-stressed soybean. Within the Calhoun soil, treatments that received preplant fertilizer-K had a higher TKU regardless of water treatment. However, in the Calloway soil, the preplant fertilizer-K only increased the crop TKU when under drought stress, with no increase seen in the well-watered soybean. This may be explained by the higher STK and plant available K in the Calloway soil, which was accessible to the crop with adequate water.

Regardless of the soil, the timing of drought stress is a significant factor in TKU, with slight differences in TKU between water regimes during vegetative growth followed by a significant reduction in TKU when the drought stress occurred during reproductive growth (Fig. 3). Within each pair of drought stress and time treatments, all soybean treatments that received preplant fertilizer-K measured a significantly higher TKU than those that did not receive any preplant fertilizer-K, except for the R1 drought treatments, which were not significantly different between fertilizer-K treatments. The crop K uptake peaks during these reproductive stages, defined as R2 through R4 by Bender et al. (2015), explaining why drought during these growth stages significantly affects the crop TKU.

Practical Applications

The complex relationship between crop K nutrition, drought stress, and timing of drought stress has significant impacts on TKU ($P < 0.05$). Widespread K deficiency was confirmed across all treatments, limiting conclusions with specific K nutrition effects. Drought stress consistently reduced the productivity of the crop. When drought stress occurred during reproductive growth stages, the reductions in TKU were much more pronounced. Results emphasize the importance of adequate K nutrition and soil moisture on soybean TKU, as drought stress was a major influencer of soybean TKU, especially during reproductive growth stages when peak K uptake occurs.

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Table 1. Schedule of drought treatments and corresponding growth stages.

Planned growth stage	Start date	Beginning growth stage	End date	Final growth stage
Vegetative	04-June	V3	21-June	V7
Anthesis	05-July	R1	22-July	R3
Pod development	18-July [a]	R3 [a]	26-July [a]	R3 [a]
	27-July	R4	13-Aug	R6
Seed fill	03-Aug	R5	20-Aug	R6

[a]Pod development drought was restarted after a severe rain flooded the rain-out shelter and provided water to the soybean and soil through the bucket's drainage holes.

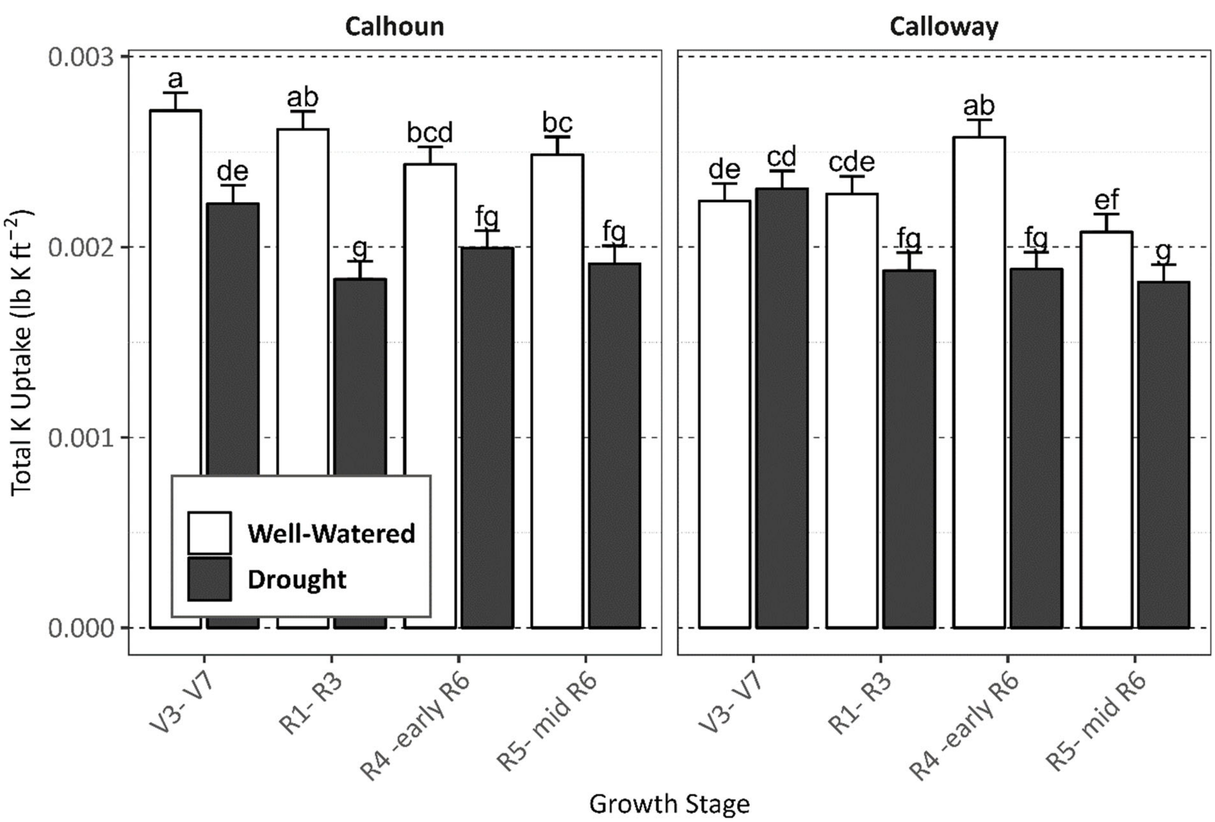

Fig. 1. Soybean total potassium (K) uptake (lb K/ft) by drought treatment with well-watered as white and drought as dark grey at various growth stages across the x-axis grouped by soil across the top. Means (columns) averaged over fertilizer-K treatments and standard error (error bars) are presented with different letters indicating significant differences (*P* < 0.05) between means within treatments based on Tukey's post-hoc test.

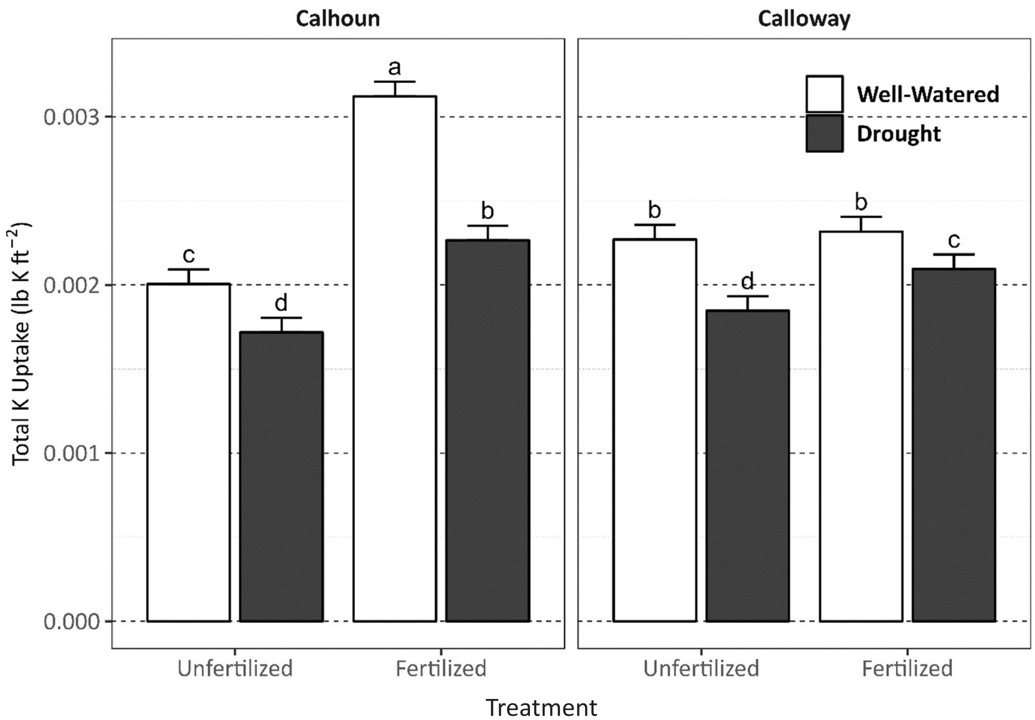

Fig. 2. Soybean total potassium (K) uptake (lb K/ft) by drought treatment with well-watered as white and drought as dark grey by preplant fertilizer-K added across the x-axis grouped by soil across the top. Means (columns) averaged over drought stress timing and standard error (error bars) are presented with different letters indicating significant differences (*P* < 0.05) between means within treatments based on Tukey's post-hoc test.

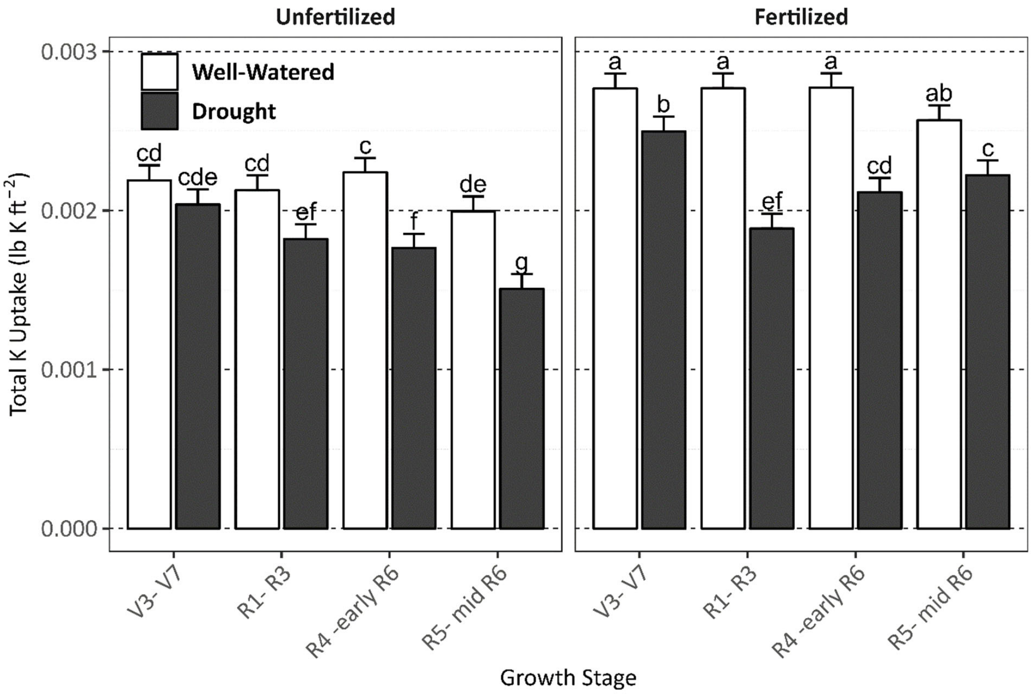

Fig. 3. Total soybean potassium (K) uptake (lb K/ft) by drought treatment with well-watered as white and drought as dark grey at various growth stages across the x-axis grouped by the addition of preplant fertilizer-K, labeled on the top. Means (columns) averaged over soil and standard error (error bars) are presented with different letters indicating significant differences (*P* < 0.05) between means within treatments based on Tukey's post-hoc test.

The Effects of the Inclusion of Soybean Oil in Beef Heifer Diets on Reproductive Performance

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Abstract

Angus crossbred heifers (n = 80; BW = 546 ± 47 lb) were sorted randomly into 1 of 8 pastures (n = 10 heifers/pasture) and pastures were assigned randomly to 1 of 2 treatment groups (n = 4 pastures/treatment): 1) control group fed an isonitrogenous and isocaloric grain supplement with no soy product (CON); and 2) treated group fed grain supplemented with soybean oil at 2% of estimated total diet dry matter intake (SBO). Supplements were offered beginning approximately 30 days after weaning and continued through the breeding season. Body weights and body condition scores were recorded monthly. When heifers weighed > 650 lb, rectal palpation was performed, and an ultrasound was used to determine reproductive tract scores. At 7-day intervals beginning on day 56, blood samples were collected via jugular venipuncture to measure serum progesterone concentrations. Heifers were classified as pubertal when serum progesterone concentrations were greater than 1 ng/mL. Heifers that maintained progesterone concentrations ≥ 1 ng/mL for 2 consecutive samples were classified as cyclic. Heifers were bred by artificial insemination (AI) at approximately 14 months of age. Treatment did not affect body weight ($P = 0.42$) or body condition scores ($P = 0.13$). The percentage of females pubertal ($P = 0.39$) and cyclic ($P = 0.34$) by day 147 were numerically greater for the CON treatment (89.3% and 90.1%, respectively) than the SBO treatment (80.5% and 75.2%, respectively). Heifers supplemented with SBO had numerically greater, but not statistically different ($P \geq 0.24$), AI conception and overall pregnancy rates compared to CON-supplemented heifers (52.6% and 95% vs. 42.5 % and 87.5%, respectively). Potential revenue was greater for cattle supplemented with SBO than CON, despite increased input costs for SBO. Further research will gather additional data for AI and overall pregnancy rates, effects on uterine blood flow, and resulting calf performance.

Introduction

Soybean co-products are a staple among poultry and swine diets, with limited amounts used in the cattle industry (ASA, 2021). Much of the cattle industry is focused on the cost of inputs and the revenue that producers receive, ultimately determining if producers have the additional funds to supplement cattle during the year. Supplementation with additional fats like soybean oil may be more economical for increasing energy and performance when the prices of grains are high and have positive effects on reproduction in cattle (Funston et al., 2004). For developing heifers, proper management and nutritional plans are crucial for proper growth and development to attain puberty at an early age and conceive early in the breeding season (Shike et al., 2013). Early establishment of puberty in heifers (ideally ≈ 12 to 13 months of age) may influence the heifer's ability to conceive at breeding, as there is a likelihood that a heifer's first few estrous cycles after puberty may be less fertile (Byerley et al., 1987a; 1987b). Therefore, the need for heifers to become pubertal earlier is important for conception rates.

Some studies have investigated how the inclusion of soybean oil in developing heifer diets affects body condition scores, attainment of puberty and cyclicity, and conception rates, but few have combined these measures with economic revenue/losses from potential offspring from successful pregnancies. We hypothesize that the inclusion of soybean oil in developing heifer diets will improve overall pregnancy rates and successful artificial insemination rates in beef heifers. The objectives of this study are to determine the effects of including soybean oil in supplemental diets for developing heifers on growth performance, time of cyclicity and puberty, successful artificial insemination and overall pregnancy rates, and economic viability.

Procedures

Angus crossbred heifers (having no previous births; n = 80 heifers) were sorted randomly into 1 of 8 pastures (n = 10 heifers/pasture) and pastures (6-acre mixed grass) were assigned randomly to 1 of 2 treatment groups (n = 4 pastures/treatment), being 1) control group fed an isonitrogenous and isocaloric grain supplement with no soy product (CON); and 2) treated group fed grain supplemented with soybean oil at 2% of total diet dry matter intake (SO2). Supplements (Table 1) were offered beginning approximately 30 days after wean-

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ing (June 2023, when heifers are approximately 8 months old) and continued through the breeding season (February 2024).

Each month, heifers had body weights and body condition scores (BCS) recorded. Beginning when heifers weighed ≥ 650 lb, rectal palpation was performed, and an ultrasound was used to determine reproductive tract scores (data not included). At 7-day intervals beginning on day 56, blood samples were collected via jugular venipuncture. Samples were used for serum progesterone concentrations and allowed for determination of the percentage of heifers cyclic and pubertal. Samples were analyzed via commercial radioimmunoassay. Heifers were classified as pubertal when serum progesterone concentrations were ≥ 1 ng/mL. Heifers that maintained progesterone concentrations ≥ 1 ng/mL for 2 consecutive samples were classified as cyclic. Cyclic heifers were not sampled further.

When heifers reached ≈ 14 months of age (day 160), controlled intravaginal drug release devices (CIDRs) were placed, and an intramuscular injection of PGF was given. Approximately 7 days later, cattle received an intramuscular injection of GnRH. All CIDRs were removed 7 days after GnRH injection, and an estrus detection patch (Estrotect® patch) was placed on all cattle. After 3 days, cattle that received an intramuscular injection of GnRH were bred by artificial insemination (AI) using a single sire, and patch score was recorded. A blood sample was collected for progesterone analysis. Ten days following AI, bulls were introduced and remained with heifers for 56 days. Confirmed pregnancy was determined on days 204 and 278 by transrectal ultrasound.

Costs associated with the development of beef heifers were recorded. Costs of bulls (2 bulls/treatment group) were calculated and included in the input costs for each treatment. Revenue was calculated using the latest USDA market reports, with revenue calculated for potential calves born to dams that successfully maintained an AI pregnancy and calves born to naturally-serviced dams.

Statistical analyses were performed using SAS 9.4®, with PROC MIXED used for body weight, average daily gain, and body condition scores. Body weights were analyzed with the repeated measure of day and for treatment, day, and treatment by day interaction. The PROC GLIMMIX procedure was used for puberty, cyclicity, AI pregnancy rate, and overall pregnancy rates.

Results and Discussion

Body weights did not differ due to dietary treatment throughout the entirety of the study (treatment × day; P = 0.42). Additionally, average daily gain was not different between treatment groups throughout the study ($P \geq 0.29$). There was no treatment × day interaction (P = 0.96) or main effect of treatment (P = 0.13) for body condition scores, which averaged a BCS of 5.5 for CON heifers and a BCS of 5.4 for SBO heifers.

There was no effect of treatment for either puberty ($P \geq 0.15$) or cyclicity ($P \geq 0.15$) at any point during the study, so further results describe numerical differences for the percentage of females determined pubertal and cyclic. There were 90% of heifers that consumed the CON supplement that were pubertal by day 147, with 89.6% determined cyclic. Conversely, 85% of the heifers were pubertal that consumed the SBO supplement by day 147, and 82.1% determined cyclic. Four heifers on the CON supplement did not reach puberty or cyclicity. Six heifers on the SBO supplement did not reach puberty, and 7 did not reach cyclicity during this sampling period. Still, there was no difference in pubertal (P = 0.33) or cyclicity status (P = 0.51) by day 147 in heifers consuming different treatments. Research has shown contradictory results for including dietary fats in supplements for developing heifers. Whitney and colleagues (2000) determined that the inclusion of soybean oil at 3% of a forage-based diet decreased time to conception in females compared to diets supplemented with hay, corn-soybean meal supplement, or soybean oil inclusion at 6%. However, Garcia and others (2003) reported a delayed estrous response and delayed time of estrus in females fed 3 lb/day (4% added fat) whole soybeans in a total mixed diet compared to the control diet. Authors mentioned that the analysis of extracted soybeans revealed the presence of phytoestrogens, which can lower progesterone levels, impair ovulation, and increase infertility rates in females fed a chronic soy diet (Adnan et al., 2022). Because only numerical differences in puberty and cyclicity were noticed between supplemental treatments, it is unclear whether phytoestrogens were present in the SBO supplement for this study.

Estrus behaviors were not different between heifers supplemented with CON or SBO (85% vs. 80%, respectively; P = 0.55). Pregnancy rates for AI conception were not different between supplemental treatment groups (P = 0.38) but were numerically greater for heifers supplemented with SBO compared to CON (52.6% vs. 42.5%, respectively). Similarly, a numerically greater percentage of females consuming SBO were confirmed pregnant by AI at the 2nd pregnancy check compared to CON-supplemented heifers (50% vs. 40%, respectively), but was not statistically different between treatment groups (P = 0.39). Overall pregnancy rates were also numerically greater in SBO-supplemented heifers compared to the CON-supplemented heifers (95% vs. 87.5%, respectively), but there was not a statistical difference between supplemental groups (P = 0.24). A study in 2003 found that 1st-service conception rates were not different in heifers supplemented with whole soybeans, whole cottonseed, or pelleted soybean hulls, but a numerical 20% increase in first-service conception rates was noted in the soybean fed group compared to controls (Howlett et al., 2003). There were no differences in AI or overall conception rates, or other reproductive performance parameters in this study, but numerical increases in conception rates of the SBO-supplemented heifers compared to the CON-supplemented heifers warrant further investigation.

The actual cost per ton of supplement was greater for the SBO supplement compared to the CON supplement. This, in turn, created a more expensive cost per head per day for SBO compared to CON (Table 2). While supplement costs per heifer were increased, the actual breeding cost per heifer on the SBO supplement was lower than CON-supplemented heifers ($129.49/heifer vs. $132.97/heifer, respectively). Potential returns on resulting calves born to dams bred by AI and natural service in each treatment group were greater for calves born to dams from the SBO-supplement compared to the CON-supplement; thus, the gross value from the sale of potential calves was approximately $136.28/head greater for the SBO-supplemental treatment. Despite increased input costs, the potential revenue for SBO-supplemented cattle was $36.60/heifer greater than CON-supplemented cattle.

Practical Applications

There were no differences between body weights, body condition scores, pubertal or cyclicity status, estrus behavior, and detection, or AI and overall pregnancy rates. There were numerical differences for the control-supplemented heifers to have a greater percentage of females pubertal and cyclic. The soybean oil-supplemented heifers had a greater percentage of heifers that were pregnant at the 1st ultrasound to determine artificial insemination conception and for overall pregnancy rates. The total revenue captured by the soybean oil treatment was still greater than control-supplemented cattle. Soybean co-products did not negatively affect reproductive performance, but did slightly increase potential revenue that may be obtained; still, numerical differences seen for artificial insemination and overall pregnancy rates warrant further investigation to confirm potential differences.

Acknowledgments

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Table 1. Ingredient composition of dietary supplements used for developing heifer study.

Ingredient	Control	SBO[a]
	------------------(%)------------------	
Corn	83.9	74.2
Soybean meal	--	4.53
Distillers grain plus soluble, dry	10.2	11.8
Urea	0.41	--
Salt, white	0.64	0.74
Limestone	3.08	3.10
Vitamin A, D, E[b]	0.05	0.051
Corn/Rumensin premix[c]	0.267	0.276
Trace mineral premix	0.05	0.051
Choice white grease	0.52	--
Soybean oil	--	4.04
Molasses	0.96	1.1

[a] SBO = supplement containing soybean oil.

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

[c] Provided 160 mg monensin/day.

Table 2. Actual costs of inputs and projected revenue for developing heifers on a supplement containing soybean oil.

Item[a]	Control	SBO[b]
Cost per head per day ($/heifer)	0.97	1.41
Total Supplement Cost ($/heifer)	227.36	330.52
Total AI Cost ($/heifer)[c]	96.37	92.89
Total Bull Cost ($/heifer)[d]	36.60	36.60
Total Breeding Cost ($/heifer)[e]	132.97	129.49
Gross Value of Calves ($/heifer)[f]	1,448.09	1,584.37
Total Input ($/heifer)	360.33	460.01
Total Output ($/heifer)	1,448.09	1,584.37
Total Revenue ($/heifer)	1,087.76	1,124.36

[a] Each item listed is based on cost per heifer, with each treatment group totaling 40 heifers/treatment.

[b] SBO = supplement containing soybean oil.

[c] Total AI Cost = sum of fixed-time AI protocol drugs (gonadotropin-releasing hormone, prostaglandin), CIDR, semen costs, AI technician labor, and total labor (4 farm workers paid at $8/hour, with total hours through chute totaling 4.5 hours).

[d] Total Bull Cost = calculated using purchase price, number of years of expected use, expected salvage value, annual care, number of heifers exposed, and percentage of heifers that wean a calf.

[e] Gross Value of Calves = calculated using AI breeding date and expected date of pregnancy for naturally-serviced heifers (confirmation of days of pregnancy by AI technician), expected due date, expected wean date, expected age at weaning, and projected weights of calves once weaned.

[f] Price per pound from USDA Market Reports was used to determine projected calf price for potential returns of all calves for each treatment group.

The Impact of Supercritical Carbon Dioxide Processing on the Aroma and Physicochemical Properties of Soybean Flour

S. Kaur[1] *and A. Ubeyitogullari*[1]

Abstract

Soybeans [*Glycine max* (L.) Merr.] are rich in protein but have limited food applications due to undesirable volatile compounds, negatively affecting flavor and consumer acceptance. Supercritical carbon dioxide (SC-CO_2) extraction can extract lipids and volatile compounds, offering advantages over traditional methods while promoting sustainable practices. This study aimed to extract lipids and volatile compounds from soybean flour using SC-CO_2 and investigate the impact of extraction conditions on the properties of soybean flour, including particle size distribution, composition, color, and rheological properties. The volatile compound concentration of the soybean flour was reduced after SC-CO_2 extraction compared to untreated soybean flour. The results showed that SC-CO_2-treated soybean flour had smaller particle sizes, improved protein purity upon protein extraction, and brighter color than hexane-extracted flour. Overall, this research contributes to understanding the potential of SC-CO_2 extraction in enhancing soybean flour's aroma and functional properties, addressing challenges related to off aromas.

Introduction

Soybean [*Glycine max* (L.) Merr.], a widely cultivated legume crop in the United States, accounts for more than 50% of global production (Medic et al., 2014; Thrane et al., 2017). Soybeans are widely known for their high protein (35%–40%) and oil (~20%) contents, and they consist of 35% carbohydrates and 5% of other compounds (e.g., vitamins and minerals) (Sherif, 2013). Soybean oil consists of ~15% saturated fatty acids, ~22% monosaturated fatty acids, and ~57% polyunsaturated fatty acids, whereas soybean protein contains glycinin and beta-conglycinin as 2 small storage proteins (Agyenim-Boateng et al., 2023; Medic et al., 2014). Interestingly, only the oil content of soybean flour is mainly used for food applications. Despite the high nutritive value, soybean protein is limited to animal feed (98%), and only 2% contributes to human food applications (Agyenim-Boateng et al., 2023; Kumar et al., 2022; Thrane et al., 2017). The presence of undesirable volatile compounds results in a restricted consumption of soybean flour (Friedman and Brandon, 2001; Thrane et al., 2017). These off-flavors are attributed to volatile compounds, including aldehydes, alcohols, and ketones, which can negatively impact the overall sensory attributes of soybean flour-based foods due to their beany, grassy flavors.

Supercritical carbon dioxide (SC-CO_2) extraction has emerged as a safe and environmentally friendly method for extracting bioactive compounds with high selectivity, purity, and minimal degradation. Carbon dioxide (CO_2) is a green solvent that exhibits mild critical conditions (88 °F and 1073 psi), and, in addition, it is non-toxic, inexpensive, abundantly available, and non-flammable (Kaur and Ubeyitogullari, 2023; Tuhanioglu and Ubeyitogullari, 2022). The conventional method for extracting lipids from soybean flour involves organic solvents, e.g., hexane, ethanol, and propanol. Hexane is the most commonly used solvent for commodity oil extraction from oilseeds. While effective, hexane has drawbacks, including its high flammability, toxicity concerns, and requirements for solvent recovery.

Therefore, this study aims to enhance the soybean flour aroma profile using a single-step SC-CO_2 extraction process to extract lipids and undesired volatile compounds. The properties of soybean flours treated with SC-CO_2 were compared with those of soybean flours treated with hexane.

Procedures

SC-CO_2 and hexane treatments

First, the soybeans, provided by Riceland Foods (Stuttgart, Ark. USA), were ground to form flour using a grinder. The soybean flour was used for extractions using a lab-scale SC-CO_2 extractor (SFT-120, Supercritical Fluid Technologies, Inc., Del., USA) (Kaur and Ubeyitogullari, 2023). Briefly, 0.63 oz. of flour sample was loaded in a stainless-steel high-pressure vessel and mixed with 2.1 oz. of glass beads to avoid packing and enhance mass transfer properties during extraction. Prior to extraction, the system was flushed with CO_2 for 5 seconds to remove any air trapped in the system, and the micrometer valve temperature was adjusted to 176 °F to prevent freezing due to the Joule-Thomson effect. Then, static extraction was carried out for 20 minutes prior to each run at set pressure and temperature. After the static extraction, a CO_2 flow rate of 1.35 oz./min (measured at the ambient condition: 73 °F and 14.5 psi) was maintained throughout the run. The extraction vial was kept in an ice bath to prevent degradation. The extraction conditions were determined based on our previous studies and literature (Jokić et al., 2012; Kang et al., 2017). The extraction

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condition of 5801 psi and 140 °F at 1.35 oz./min for 4 h (S1) was selected based on the optimization study conducted by Jokić et al. (2012), where the extraction of lipids from soybean flour was optimized. Additionally, a continuous extraction for 4 h at 5801 psi and 140 °F followed by an additional 2 h extraction at 2176 psi and 140 °F with a constant CO_2 flow rate of 1.35 oz./min (S2) was carried out (Tuhanioglu et al., 2023). Finally, the extracted samples were flushed with nitrogen and stored at -4 °F until further analysis.

For the conventional extraction, the defatting of soybeans was performed using hexane (Dey et al., 2022). Briefly, 3.5 oz. of soybean flour was mixed with 13.5 fl oz of hexane at room temperature (73 °F) (H1) and 140 °F referred to as H2, according to the industrial-level extraction process (Valduga et al., 2011).

Gas Chromatography/Mass Spectrometry Analysis

The volatile compounds were identified using a Shimadzu Nexis GC-2030 system equipped with a triple-quadruple mass selective detector, ZB-5MSplus capillary column, and AOC-6000 Autosampler equipped with a 0.39-in.-long SPME fiber coated with Divinylbenzene/Carboxen/Polydimethylsiloxane (DVB/CAR/PDMS). The method of Tuhanioglu et al. (2023) was followed for the volatile compound analysis.

Functional Properties

The USA Standard Test Sieves of different openings (0.0394 in., 0.0167 in., 0.0098 in., 0.0083 in., 0.0071 in., and 0.0059 in.) were fixed in with Meinzer Sieve Shaker (Va. USA) to determine the particle size distribution of flours.

For the lipid content analysis, thimbles carrying 0.35 oz. of the sample were placed into the Soxhlet apparatus, and the extraction was carried out for 12 h using hexane.

According to Dey et al. (2022), the proteins were extracted using alkaline extraction. The nitrogen content was measured according to the Dumas method and converted into crude protein using a conversion factor of 6.25.

The color parameters (i.e., L^*, a^*, and b^* values) were determined using a calorimeter (Minolta CR-300, Konica Minolta, N.J., USA). Prior to analysis, the colorimeter was calibrated via a white calibration plate. The total color change (ΔE^*) and whiteness index were measured according to Eqs. 1 and 2, respectively (Gupta et al., 2021; Sadaf et al., 2024).

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad \text{(Eq. 1)}$$

$$\text{Whiteness index} = 100 - \sqrt{(100 - L^*)^2 + (a^*)^2 + (b^*)^2}$$

The rheological properties of soybean flour samples were analyzed according to Kong et al. (2008) using a modular compact rheometer (model MCR 302e, Anton Paar, Graz, Austria) equipped with a PP50 parallel plate geometry.

Statistical Analysis

The statistical analysis was performed in JMP Pro 17.0 (SAS Institute, N.C., USA) using analysis of variance and Tukey's test with a 5% significance level. The results were expressed as the mean±standard deviation with 3 replicates per sample.

Results and Discussion

Extraction Conditions

This study investigated soybean flours treated with SC-CO_2 and hexane extractions and compared them with the untreated (i.e., full-fat) soybean flour as a control (C). Among these treatments, 2 relied on conventional techniques: hexane extraction conducted at room temperature (73 °F) (H1) and hexane extraction at 140 °F, referred to as H2, mimicking the industrial-level extraction process (Valduga et al., 2011). The other 2 treatments were performed using a green and sustainable approach based on SC-CO_2 extraction. The first SC-CO_2 treatment (S1) involved 5801 psi and 140 °F extraction for 4 hours with a constant CO_2 flow rate of 1.35 oz./min. This specific condition was selected based on a previous optimization study, where SC-CO_2 extraction (i.e., pressures of 4351 to 7252 psi and temperatures of 104 to 140 °F) of lipids from soybean flour was optimized for the maximum lipid yield (Jokić et al., 2012). The second SC-CO_2 treatment (S2) consisted of continuous extraction for 4 h at 5801 psi and 140 °F (Jokić et al., 2012), followed by an additional 2 h extraction at 2176 psi and 140 °F with a constant CO_2 flow rate of 1.35 oz./min (Tuhanioglu et al., 2023). In this condition, 5801 psi and 140 °F were selected based on the optimization conducted to maximize the lipid yield, while 2176 psi and 140 °F were chosen according to our previous study on the optimization of volatile compound removal from sorghum flour (Tuhanioglu et al., 2023).

The effects of extraction methods on the lipid and protein yields. Soybean flour used for extraction consisted of 22.74 ± 0.69% of lipids as determined using Soxhlet extraction. The lipid extraction yields were 19.19 ± 0.68% and 22.17 ± 1.47% for the conventional hexane extraction (H1 and H2, respectively), while the extraction yields were not significantly different when SC-CO_2 extraction (19.75 ± 0.08% for S1 and 20.16 ± 0.39% for S2) was used (Table 1). Similar lipid extraction yields under these conditions were reported by Kang et al. (2017).

After lipid extraction, the proteins were extracted from the hexane- and SC-CO_2-treated flour samples. The protein extraction yields were 33%–34% using H1 and H2 and ~36% using the SC-CO_2 defatting method. However, the protein recovery was relatively higher in SC-CO_2 extraction (S1 and S2) and hexane extraction (H1) than in hexane extraction at higher temperatures (H2).

Volatile Compound Analysis

The major volatile organic compounds identified were aldehydes (e.g., pentanal, hexanal, heptanal), alcohols (e.g., 1-pentanol, 3-hexanol, 1-hexanol), ketones (e.g., 2-hexanone, 5-methyl-; 3-octanone, 2-methyl-), and hydrocarbons (e.g., undecane; nonane; decane, 4-methyl-). The treated samples significantly reduced or eliminated the volatile compounds compared to the untreated soybean flour ($P < 0.05$).

Functional Properties

The particle size distributions of untreated and treated soybean flours are illustrated in Table 2. The untreated soybean flour revealed significantly larger particle sizes compared to the soybean flour treated using hexane and SC-CO_2 extractions ($P < 0.05$) (Fig. 1).

Table 3 shows the effect of different treatments on the color parameters of soybean flour compared to untreated soybean flour. This analysis evaluated the L^* (lightness), a^* (red-green), b^* (yellow-blue), and ΔE^* (color difference), as well as the whiteness index. The untreated soybean flour exhibited a lower L^* value (87.09 ± 0.02) compared to all defatted flours, indicating a darker color. In terms of the a^* and b^* values, H1 resulted in the lowest a^* value among defatted samples, suggesting a decrease in redness, while the control group exhibited the highest b^* value (20.73 ± 0.04), indicating increased yellowness. Additionally, the whiteness index was higher for H1 (88.50 ± 0.64) and S2 (88.11 ± 0.24), suggesting superior whiteness compared to the industrial hexane extraction method (H2) and control (C) (Fig. 1).

Figure 2 shows the viscosity measurements of untreated (C), hexane extracted (H1 and H2), and SC-CO_2 extracted (S1 and S2) soybean flours. The control, untreated soybean flour sample, showed the lowest viscosity compared to other samples (Fig. 2) (Ahmadzadeh and Ubeyitogullari, 2023).

Practical Applications

Soybean flour's undesired aromas restrict its widespread use in manufacturing food products, especially plant protein applications. Therefore, this study investigated the impact of a green extraction method based on SC-CO_2 on soybean flours' properties. This study highlights the potential of SC-CO_2 extraction as a sustainable method for improving the aroma attributes and functional properties of soybean flour while eliminating the use of toxic organic solvents for processing soybeans.

Acknowledgments

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Table 1. The lipid and protein extraction yields (% dry basis) of untreated (C), hexane extracted (H1 and H2), and SC-CO_2 extracted (S1 and S2) soybean flours.

Samples	Lipid extraction yield from untreated soybean flour	Protein extraction yield from defatted soybean flour	Protein extract purity
	(% w/w)		
H1	19.19 ± 0.68 b[†]	33.28 ± 1.18 a	92.20 ± 1.20 a
H2	22.17 ± 1.47 a	34.76 ± 0.18 a	87.97 ± 0.35 b
S1	19.75 ± 0.08 ab	36.26 ± 1.64 a	93.34 ± 0.78 a
S2	20.16 ± 0.39 ab	36.50 ± 1.45 a	92.57 ± 0.11 a

[†]Means that do not share a common letter within the same column are significantly different ($P < 0.05$). SC-CO_2 = supercritical carbon dioxide. H = hexane.

Table 2. The particle size distributions of untreated (C), hexane extracted (H1 and H2), and SC-CO_2 extracted (S1 and S2) soybean flours.

Particle size	C	H1	H2	S1	S2
(in.)	(%)				
>0.0394	0.05 ± 0.00 a[†]	0.03 ± 0.00 b	0.03 ± 0.00 b	0.02 ± 0.00 bc	0.01 ± 0.00 c
0.0394 – 0.0167	32.83 ± 0.45 a	15.88 ± 0.00 b	15.97 ± 0.00 b	14.49 ± 0.00 b	14.69 ± 0.00 b
0.0167 – 0.0098	41.44 ± 0.00 a	15.53 ± 0.00 d	15.53 ± 0.00 d	17.11 ± 0.00 b	17.07 ± 0.00 c
0.0098 – 0.0083	12.59 ± 0.26 a	3.75 ± 0.00 b	3.64 ± 0.00 b	4.51 ± 0.00 b	4.63 ± 0.00 b
0.0083 – 0.0071	7.42 ± 0.26 a	4.66 ± 0.00 b	4.75 ± 0.00 b	1.90 ± 0.00 c	1.94 ± 0.00 c
0.0071 – 0.0059	0.86 ± 0.02 c	5.56 ± 0.00 a	5.48 ± 0.00 a	4.27 ± 0.00 b	4.34 ± 0.00 b
<0.0059	0.78 ± 0.03 d	40.57 ± 0.00 c	40.67 ± 0.00 c	44.83 ± 0.00 b	45.19 ± 0.00 a

[†]Means that do not share a common letter within the same column are significantly different ($P < 0.05$). SC-CO_2 = supercritical carbon dioxide. H = hexane.

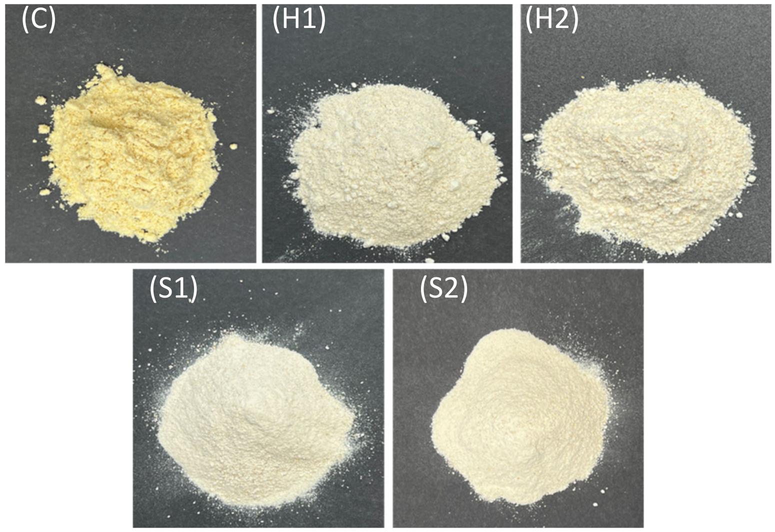

Fig. 1. Photos of soybean flour samples: untreated (C), hexane extracted (H1 and H2), and SC-CO_2 extracted (S1 and S2). SC-CO_2 = supercritical carbon dioxide. H = hexane.

Table 3. The color analysis of untreated (C), hexane extracted (H1 and H2), and SC-CO_2 extracted (S1 and S2) soybean flours.

Color	*L**	*a**	*b**	*ΔE**	Whiteness index
C	87.09 ± 0.02 c[†]	-0.82 ± 0.02 c	20.73 ± 0.04 a	N/A	75.56 ± 0.03 c
H1	93.76 ± 0.63 a	-0.60 ± 0.07 b	9.72 ± 0.36 c	8.28 ± 0.35 a	88.50 ± 0.64 a
H2	93.05 ± 0.19 ab	-0.48 ± 0.06 a	10.22 ± 0.12 b	12.09 ± 0.19 b	87.63 ± 0.20 b
S1	92.77 ± 0.09 b	-0.55 ± 0.03 ab	10.16 ± 0.10 b	7.69 ± 0.02 b	87.54 ± 0.13 b
S2	93.45 ± 0.24 ab	-0.55 ± 0.02 ab	9.95 ± 0.13 bc	8.12 ± 0.16 ab	88.11 ± 0.24 ab

[†]Means that do not share a common letter within the same column are significantly different ($P < 0.05$).
N/A = not applicable. SC-CO_2 = supercritical carbon dioxide. H = hexane.
*L** = lightness; *a** = red-green; *b** = yellow-blue; and *ΔE** = color difference.

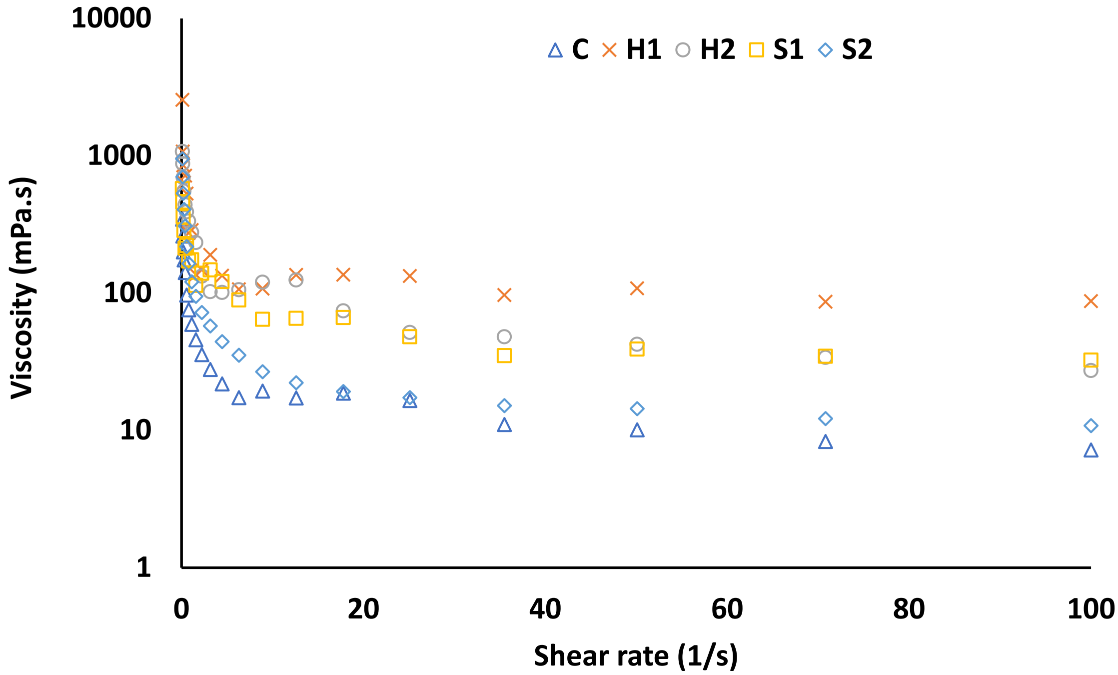

Fig. 2. Viscosities of untreated (C), hexane extracted (H1 and H2), and SC-CO_2 extracted (S1 and S2) soybean flour samples. SC-CO_2 = supercritical carbon dioxide. H = hexane.

APPENDIX

2023-2024 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

2023-2024 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**