Arkansas Soybean Research Studies 2018

Jeremy Ross, Editor

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Preface

The 2018 Arkansas Soybean Research Studies Series includes research reports on topics pertaining to soybean across several disciplines from breeding to post-harvest processing. Research reports contained in this publication may represent preliminary or only a single year or 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.

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

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

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

Acknowledgments

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The Arkansas Soybean Promotion Board

Introduction

Arkansas is the leading soybean-producing state in the mid-southern United States. Arkansas ranked 11th in soybean production in 2018 when compared to the other soybean-producing states in the U.S. The state represents 3.7% of the total U.S. soybean production and 3.7% of the total acres planted in soybean in 2018. The 2018 state soybean average was 50.5 bushels per acre, half a bushel lower than the state record set in 2017. The top five soybean-producing counties in 2018 were Mississippi, Desha, Phillips, Arkansas, and Poinsett Counties (Table 1). These five counties accounted for 33.7% of soybean production in Arkansas in 2018.

Environmental conditions during the 2018 soybean growing season were almost ideal for soybean growth and development, which is reflected by the near-record soybean yield. The early planting progress was in line with the 5-year average planting progress, but with favorable planting conditions during May 2018, soybean producers were able to plant 95% of the acreage three weeks earlier than the 5-year average. Starting in mid-August and extending into December, wet and rainy conditions hampered harvest for the entire State. Many late-season foliar diseases such as aerial web blight, Cercospora leaf blight, anthracnose, pod and stem blight, Frogeye leaf spot, and target spot developed late in the season. With the presence of plant diseases and wet conditions throughout the entire harvest period, many producers had very poor seed quality. Most producers incurred higher than normal dockage at elevators due to the damaged soybean grain. In addition to late-season disease issues, many fields in the state were treated for several insect pests including corn earworm, other caterpillar species, and stinkbugs. Most soybean-producing counties in Arkansas have some level of PPO-resistant Palmer amaranth. Many of these Palmer amaranth populations now have multiple herbicide resistance, and soybean production in these fields is becoming very difficult due to the loss of many herbicides. The 2018 growing season was the second year where the use of dicamba was labeled for over-the-top applications on dicamba-tolerant soybean. With over 1,000 complaints from individuals with dicamba symptomology on non-dicamba soybean to the Arkansas State Plant Board (ASPB) in 2017, the ASPB elected to ban dicamba application from April 16 to October 31. Even with these new regulations, few dicamba complaints were filed with the ASPB, but still, over 400 complaints were filed for soybean fields showing dicamba symptomology.

Table 1. Arkansas soybean acreage, yield, and production by County, 2017–2018[a]

	Acres Planted		Acres Harvested		Yield		Production	
County	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**	**2017**	**2018**
	(acres)		(acres)		(bu./ac)		(bu.)	
Arkansas	187,300	172,800	186,900	171,400	53.7	60.4	10,040,000	10,358,000
Ashley	61,800	57,500	61,400	56,500	56.8	55.9	3,490,000	3,157,700
Chicot	169,700	166,000	168,900	165,400	51.2	52.8	8,647,000	8,734,000
Clay	120,500	110,000	120,100	109,300	54.8	51.3	6,583,000	5,608,000
Conway	19,200	20,100	18,900	19,850	39.4	37.6	745,000	747,000
Craighead	116,700	97,000	115,700	96,550	53.1	50.5	6,147,000	4,874,000
Crittenden	231,300	*	230,700	*	52.7	*	12,165,000	*
Cross	170,900	152,000	170,200	150,500	51.1	53.5	8,696,000	8,058,000
Desha	176,300	181,700	176,000	181,200	56.7	60.4	9,975,000	10,938,000
Drew	40,400	39,400	40,200	39,000	54.5	57.6	2,190,000	2,245,800
Faulkner	8600	7600	8000	7550	42.0	43.3	336,000	327,000
Franklin	2000	*	1900	*	35.5	*	67,500	*
Greene	73,800	73,800	73,600	72,400	51.0	42.1	3,755,000	3,050,000
Independence	32,700	*	32,500	*	43.4	*	1,410,000	*
Jackson	147,500	121,500	141,000	120,800	42.2	40.5	5,949,000	4,892,000
Jefferson	118,700	110,000	117,500	108,250	53.1	57.0	6,240,000	6,169,000
Lawrence	60,300	62,300	58,800	61,800	42.0	41.0	2,467,000	2,533,000
Lee	148,500	139,600	147,700	137,300	48.5	45.0	7,165,000	6,181,000
Lincoln	77,300	70,400	76,500	70,050	57.8	56.1	4,422,000	3,926,500
Lonoke	121,900	*	121,500	*	42.5	*	5,158,000	*
Mississippi	291,500	270,100	290,200	269,200	56.7	51.1	16,442,000	13,747,000
Monroe	119,400	98,500	118,500	97,300	47.2	48.0	5,597,000	4,669,500
Phillips	235,100	207,500	233,400	206,100	52.9	51.2	12,340,000	10,560,000
Poinsett	202,700	178,700	202,400	177,300	55.5	57.0	11,240,000	10,100,000
Prairie	108,000	103,500	107,600	102,800	50.9	54.3	5,482,000	5,584,000
Pulaski	19,500	22,300	19,200	21,250	46.7	44.3	896,000	941,000
Randolph	39,600	*	39,400	*	48.2	*	1,900,000	*
St. Francis	156,100	151,000	155,000	148,900	49.7	46.5	7,703,000	6,923,000
White	29,700	*	27,000	*	42.6	*	1,150,000	*
Woodruff	126,000	129,500	123,500	127,700	44.6	46.3	5,512,000	5,910,000
Yell	5900	*	5800	*	42.6	*	247,000	*
Other Counties	111,100	537,200	110,000	521,600	44.6	41.6	4,343,500	25,006,000
State Totals	3,530,000	3,280,000	3,500,000	3,240,000	51.0	51.0	178,500,000	165,239,500

[a] Data obtained from USDA-NASS, 2019.

*Included in Other Counties.

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2018 Soybean Research Verification Program

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Abstract

The 2018 Soybean Research Verification Program (SRVP) was conducted on 21 commercial soybean fields across the state. Counties participating in the program included; Arkansas, Ashley, Chicot, Clark, Clay, Conway, Crawford, Crittenden, Cross (2), Desha (2), Greene, Jackson, Jefferson, Lincoln, Lonoke, Miller, Randolph, St. Francis and Washington Counties for a total of 1277 acres. Grain yield in the 2018 SRVP averaged 62.8 bu./ac ranging from 34.2 to 83.5 bu./ac. The 2018 SRVP average yield was 12.8 bu./ac greater than the estimated Arkansas state average of 50 bu./ac. The highest yielding field was in Clark County with a grain yield of 83.5 bu./ac. The lowest yielding was in Jackson County and produced 34.2 bu./ac. Due to extremely delayed harvest and subsequent unfavorable weather conditions, Miller County was deemed unmarketable and is not included in average yield.

Introduction

In 1983, the University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) established an interdisciplinary soybean educational program that stresses management intensity and integrated pest management to maximize returns. The purpose of the Soybean Research Verification Program (SRVP) is to verify the profitability of CES recommendations in fields with less than optimum yields or returns.

The goals of the SRVP are to 1) educate producers on the benefits of utilizing CES recommendations to improve yields and/or net returns, 2) conduct on-farm field trials to verify research-based recommendations, 3) aid researchers in identifying areas of production that require further study, 4) improve or refine existing recommendations which contribute to more profitable production, 5) incorporate data from SRVP into CES educational programs at the county and state level. Since 1983, the SRVP has been conducted on 642 commercial soybean fields in 33 soybean-producing counties in Arkansas. The program has typically averaged about 10 bu./ac better than the state average yield. This increase in yield over the state average can mainly be attributed to intensive cultural management and integrated pest management.

Procedures

The SRVP fields and cooperators are selected before the beginning of the growing season. Cooperators agree to pay production expenses, provide expense data, and implement CES recommendations in a timely manner from planting to harvest. A designated county agent from each county assists the SRVP coordinator in collecting data, scouting the field, and maintaining regular contact with the producer. Weekly visits by the coordinator and county agents are made to monitor the growth and development of the crop, determine what cultural practices need to be implemented and to monitor type and level of weed, disease and insect infestation for possible pesticide applications.

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

In 2018 the following counties participated in the program: Arkansas, Ashley, Chicot, Clark, Clay, Conway, Crawford, Crittenden, Cross (2), Desha (2), Greene, Jackson, Jefferson, Lincoln, Lonoke, Miller, Randolph, St. Francis, and Washington counties. The 21 soybean fields totaled 1277 acres enrolled in the program. Two Roundup Ready® varieties (Pioneer P47T89R and Terral REV 48A26), six Roundup Ready Extend® varieties (Armor 46-D08, Armor 48-D24, Asgrow AG43X7, Asgrow AG46X6, Morsoy 4846RXT, and Pioneer 54A54X), and eight Liberty Link® varieties (Armor 44L21, Bayer CZ 4540LL, Bayer HBK LL4953, Cropland LC5215, Delta Grow 4967LL, Pioneer 50A78L, Progeny 4930LL, and Stine 41LF32) were planted in the 21 fields and CES recommendations were used to manage the SRVP fields. Agronomic and pest management decisions were based on field history, soil test results, variety, and data collected from

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individual fields during the growing season. An integrated pest management philosophy is utilized based on CES recommendations. Data collected included components such as stand density, weed populations, disease infestation levels, insect populations, rainfall, irrigation amounts, and dates for specific growth stages.

Results and Discussion

Yield. The average SRVP yield was 62.8 bu./ac with a range of 34.2 to 83.5 bu./ac. The SRVP average yield was 12.8 bu./ac more than the estimated state yield of 50 bu./ac. This difference has been observed many times since the program began and can be attributed in part to intensive management practices and utilization of CES recommendations. The highest yielding field yielded 83.5 bu./ac and was seeded with Pioneer 54A54X in Clark County. Due to extremely delayed harvest and subsequent unfavorable weather conditions, Miller County was deemed unmarketable and is not included in average yield.

Planting and Emergence. Planting began with Jefferson County on 21 March and ended with Washington County planted 22 June. An average of 146,500 seeds/ac was used for planting. An average of 7 days was required for emergence. Refer to Table 1 for agronomic information.

Fertilization. Fields enrolled in the SRVP were fertilized according to the University of Arkansas System Division of Agriculture's Soil Test Laboratory results. Refer to Table 2 for detailed fertility information.

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

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

Insect Control. Fields were scouted weekly and CES recommendations were utilized for insect control programs. Refer to Table 4 fungicide and insecticide applications.

Irrigation. All the fields that were irrigated were enrolled in the CES Irrigation Scheduler Computer Program and utilized computerized hole selection programs such as PHAUCET or PipePlanner. Irrigations were recommended based on information generated from the program. Eighteen of the 21 fields in the 2018 SRVP were furrow irrigated and 3 were dry land.

Practical Applications

Data collected from the 2018 SRVP reflected slightly higher soybean yields, as was the state average, and maintained above-average returns in the 2018 growing season. Analysis of this data showed that the average yield was higher in the SRVP compared to the state average and the cost of production was equal to or less than the Cooperative Extension Service-estimated soybean production costs.

Acknowledgments

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

Table 1. Agronomic information for the 2018 Soybean Research Verification Fields.

County	Variety	Field Size	Previous Crop	Production System	Seeding Rate	Stand Density	Planting Date	Emergence Date	Harvest Date	Yield Adjusted to 13% Moisture
		(ac)			(1000 seeds/ac)	(1000 plants/ac)				(bu./ac)
Arkansas	Asgrow AG46X6	37	Corn	FSI	140	105	5/19	5/25	10/29	70.1
Ashley	Terral REV 48A26	67	Corn	ESI	140	105	4/20	4/30	9/17	68.8
Chicot	Armor 48-D24	33	Rice	FSI	140	96	4/30	5/9	10/6	63.8
Clark	Pioneer P54A54X	73	Corn	FSNI	141	115	5/9	5/15	10/6	83.5
Clay	Morsoy 4846RXT	40	Corn	FSI	141	129	5/12	5/21	10/24	49.3
Conway	Pioneer P50A78L	43	Corn	FSI	150	110	5/8	5/15	10/8	66.8
Crawford	Pioneer P50A78L	65	Corn	FSI	150	114	5/17	5/24	11/13	56.9
Crittenden	Bayer HBK LL4953	28	Soybeans	FSNI	151	138.5	4/30	5/9	10/3	63.0
Cross 1	Pioneer P47T89R	37	Rice	FSI	160	135	5/9	5/16	10/5	62.5
Cross 2	Progeny 4930LL	85	Soybeans	FSI	160	118	5/7	5/16	10/5	58.9
Desha 1	Armor 46-D08	150	Soybeans	FSI	140	115	5/3	5/8	10/3	83.2
Desha 2	Armor 48-D24	85	Soybeans	FSI	140	118	5/2	5/8	9/27	61.3
Greene	Delta Grow 4967LL	37	Soybeans	FSI	139	85	5/11& 6/6	5/24	10/18	53.5
Jackson	Progeny 4930LL	45	Soybeans	FSI	140	89	5/31	6/8	10/12	34.2
Jefferson	Stine 41LF32	74	Corn	ESI	175	148	3/21	4/1	8/23	76
Lincoln	Asgrow AG43X7	60	Corn	FSI	140	118	5/5	5/12	10/2	64.7
Lonoke	Armor 44L21	40	Rice	ESI	136	110	4/21	4/30	9/20	69.2
Miller	Bayer CZ 4540LL	65	Soybeans	ESNI	140	101	4/30	5/7	10/29	Un-marketable
Randolph	Asgrow AG46X6	35	Rice	FSI	145	116	5/10	5/21	10/24	40.6
St. Francis	Asgrow AG46X6	135	Corn	FSI	160	114	5/1	5/9	10/6	68.8
Washington	Cropland LC5215	43	Soybeans	FSNI	148	125	6/22	6/26	11/16	61.2
Average		61			146.5	114.5	5/7	5/14	10/9	62.8

State Avg. 50 bu./ac. ES = Early-Season; FS = Full-Season.

Table 2. Soil analysis results, applied fertilizer, and soil classification for the 2018 Soybean Research Verification Fields.

County	Soil Analysis Results pH	P	K	Applied Fertilizer N-P-K Pre-plant	Soil Classification
		(lb/acre)		(lb/acre)	
Arkansas	5.7	13	70	0-60-120	Calhoun, Calloway silt loam
Ashley	7.5	26	72	0-50-120	Calhoun, Henry silt loam
Chicot	6.7	28	144	1.5 ton poultry litter	Portland, Perry clay
Clark	5.9	48	288	1.5 ton poultry litter	Sardis silt loam, Marietta fine silt loam
Clay	6.7	47	188	0-75-100	Falaya silt loam
Conway	6.7	86	181	0-0-0	Gallion, Roxana silt loam
Crawford	6.6	55	113	0-0-75	Gallion silt loam
Crittenden	6.1	34	260	0-0-60	Tunica clay, Bowdre silty clay
Cross 1	8.0	20	113	0-50-75	Henry, Calloway silt loam
Cross 2	6	34	225	0-0-0	Alligator, Earle Clay
Desha 1	7.9	31	225	0-30-75	Sharkey and Desha clays, Herbert silt loam
Desha 2	7.5	22	329	0-50-0	Sharkey and Desha clays
Greene	6.7	21	80	0-50-120	Foley-Bonn complex, Calhoun silt loam
Jackson	6.6	14	97	1.5 ton poultry litter	Egam silt loam
Jefferson	7.1	45	160	0-0-50	Coushatta, Roxana silt loam
Lincoln	7.3	26	93	0-50-100	Rilla, Herbert silt loam
Lonoke	5.9	18	92	0-60-90	Calloway silt loam
Miller	7.2	21	308	0-50-0	Latanier, Billyhaw clay
Randolph	7.0	10	150	0-60-50	Jackport silty clay loam
St. Francis	7.3	9	121	0-60-75-.5B	Loring, Calhoun silt loam
Washington	5.6	37	107	0-0-60	Summit silty clay, Samba silt loam

Table 3. Herbicide rates and timings for 2018 Soybean Research Verification Program fields by county.

	Herbicide	
County	**Burndown/Pre-emergence**	**Post-emergence**
Arkansas		1st; 22 oz. RoundUp PowerMax 2nd; 22 oz. RoundUp PowerMax + 1.33 pt. Charger Basic®
Ashley	Burndown; 25.6 oz. RoundUp PowerMax® + 1 pt. 2,4-D	1st; 22 oz. RoundUp PowerMax + 2 oz. Zidua 2nd; 22 oz. RoundUp PowerMax + 1.33 pt. Charger Basic
Chicot	Burndown; 1 qt. Conerstone® + 1 oz. Sharpen® + 1% MSO Pre-emerge; 40 oz. generic paraquat + 5 oz. Verdict® + 1% MSO	1st; 22 oz. RoundUp PowerMax + 1.3 pt. Charger Basic 2nd; 1 qt. Conerstone + 1.2 pt. Charger Basic
Clark	Pre-emerge; 22 oz. Mad Dog® 5.4 + 1 pt. Cinch®	1st; 22 oz. Mad Dog 5.4 + 2 oz. Zidua 2nd; 22 oz. Mad Dog 5.4 + 1.33 pt. Cinch®
Clay	Burndown; 40 oz. Gramoxone® + .25% surfactant Pre-emerge; 6 oz. Zidua Pro®	1st; 1 qt. glyphosate + 1 qt. Prefix® + 6 oz. Flexstar® Pre-harvest; 1 pt. Gramoxone + .25% surfactant
Conway	Burndown; 1 qt. glyphosate + 2 oz. Sharpen Pre-emerge; 1 pt. s-metolachlor + .33 lbs. metribuzin	1st ;1 qt. Liberty + 2 oz. Zidua 2nd; 29 oz. Liberty®
Crawford	Pre-emerge; 1 pt. Charger® + 5 oz. metribuzin + 3 pt. Paraquat + .25% surfactant	1st; 1 qt. Liberty + 3.5 oz. Anthem Max®
Crittenden	Burndown; 1 qt. glyphosate Pre-emerge; 1 pt. s-metolachlor + .5 lbs. metribuzin +40 oz. Gramoxone + .25% surfactant	1st; 1 qt. Liberty + 1 pt. s-metolachlor + 8 oz. Select 2nd; 29 oz. Liberty
Cross 1	Pre-emerge; 1.3 pt. s-metolachlor	1 qt. generic glyphosate +.25 oz. Classic®
Cross 2	Burndown; 40 oz. Gramoxone + .25 % surfactant Pre-emerge; 1 pt. metolachlor +.33 lbs Metribuzin	1st; 1 qt. Liberty + 2 oz. Zidua 2nd; 29 oz. Liberty
Desha 1	Pre-emerge; 40 oz. generic paraquat + 2 oz. Zidua®	1 qt. Prefix + 6 oz. Flexstar + 22 oz. RoundUp PowerMax
Desha 2	Pre-emerge; 1 qt. generic paraquat + 2.5 oz. Enlite®	1st; 1 qt. Prefix + 6 oz. Flexstar + 1.3 oz. Pursuit + 22 oz. RoundUp PowerMax 2nd; 22 oz. Mad Dog 5.4 + 1.33 pt. Charger Basic
Greene	Pre-emerge; 1.3 pt. metolachlor	1st; 36 oz. Liberty + 1.25 pt. metolachlor 2nd; 29 oz. Liberty
Jackson	Incorporated; 2 pt. metolachlor	1st; 1qt. Liberty
Jefferson	Pre-emerge; 1 qt. Cornerstone + 1.2 pt. Me-Too-Lachlor	1st; 1 qt. Total + 2.5 oz. Zidua 2nd; 1 qt. Total + 1.25 pt. Me-Too-Lachlor + 7 oz. Section Three® Pre-harvest; 1 pt. generic paraquat + 1% NIS
Lincoln	Burndown; 1 qt. RoundUp PowerMax + 1 qt. 2,4-D, + .5 oz. Firstshot® + 1% MSO Pre-emerge; 1.5 pt. Boundary® + .5 pt. Me-Too-Lachlor	50 oz. Warrant Ultra + 6 oz. Flexstar + 22 oz. RoundUp PowerMax
Lonoke	Pre-emerge; 2 oz. Zidua	1st; 1 qt. Liberty + 1.3 pt. Charger Basic 2nd; 1qt. Liberty + 1.2 pt. Charger Basic
Miller	Pre-emerge; 40 oz. generic paraquat + 1.5 pt. Boundary	36 oz. Liberty + 1 qt. Prefix + 6 oz. Flexstar
Randolph		1st; 1 qt. glyphosate + 1.3 pt. s-metolachlor 2nd; 1 qt. glyphosate
St. Francis	Pre-emerge; 1.3 pt. Dual Magnum®	1st; 1 qt. glyphosate + 1qt. Prefix
Washington	Burndown; 1 qt. glyphosate Pre-emerge; 3 oz. Fierce® + 4 oz. Dimetric	1st 1 qt. Liberty + 16 oz. Select Max®

Table 4. Fungicide and insecticides applications in 2018 Soybean Research Verification fields by county.

County	Aerial Web Blight	Frogeye	Bollworm/Defoliators	Stink Bug
Arkansas	------	------	1.6 oz. Heligen® + 1% COC	------
Ashley	------	------	------	6.4oz. Tundra® + 1% COC
Chicot	------	------	------	------
Clark	------	------	------	------
Clay	------	------	------	------
Conway	------	------	------	------
Crawford	------	------	------	------
Crittenden	------	------	------	------
Cross 1	------	------	------	------
Cross 2	------	------	------	------
Desha 1	------	------	1.6 oz. Heligen + 1% COC	------
Desha 2	------	------	1.6 oz. Heligen + 1% COC	------
Greene	------	------	------	------
Jackson	------	------	------	------
Jefferson	------	------	------	------
Lincoln	------	------	1.6 oz. Heligen + 1% COC	------
Lonoke	------	------	------	------
Miller	------	------	------	------
Randolph	------	------	------	------
St. Francis	------	------	------	------
Washington	------	------	------	------

----- = no fungicide or insecticide applied.

Assessment of Soybean Varieties in Arkansas for Sensitivity to Chloride Injury

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

Abstract

Various agricultural soils in Arkansas contain elevated levels of chloride salts. Soybean is one of the crops that is adversely affected by high chloride concentration in the plant tissue and this can result in a reduction in yield. With the continued use of salt-affected soil and irrigation water, screening of soybean varieties and breeding lines is extremely important to determine their susceptibility to chloride toxicity. Leaf tissue chloride concentrations were determined from soybean cultivars grown in a hydroponic system with elevated chloride levels. Treated soybean cultivars were compared to a standard, based on leaf tissue chloride concentration. Cultivars having high levels of leaf tissue chloride concentration were categorized as includers, while those having low leaf tissue chloride concentration were categorized as excluders. Cultivars having a segregating population of individual plants with high and low chloride concentrations were designated as mixed. Over the three years 2016 to 2018, only 30% of maturity group 4 (MG 4) soybean and 48% of maturity group 5 (MG 5) soybean showed excluder response. Many of the soybean producers in Arkansas grow MG 4 soybean and are limited in their options when chloride sensitivity is an important factor in their decision.

Introduction

Arkansas has more than 14 million acres of fertile row crop farmland. Crops such as corn, cotton, rice, and soybean are well adapted to the region. Soybean represents the largest cash crop grown in Arkansas with more than 3 million acres of farmland being dedicated to soybean in most years. Factors that limit crop yield must be identified and corrected. Elevated levels of chloride salts have become an identifiable limiting factor to soybean yield in Arkansas.

Elevated concentrations of chloride salts can be found in natural soil horizons, but are more commonly noted with the application of irrigation water from wells with high levels of chloride. Many field crops can be damaged by high chloride levels (Shannon, 1997). Soybean has specifically been noted as being acutely sensitive to chloride salts (Rupe et al., 2000). Some soybean varieties have a genetic trait that excludes harmful chloride levels from the leaves and stems, where excessive chloride accumulation can cause tissue damage and subsequent seed yield loss (Abel, 1969). Sensitive varieties may experience leaf tissue damage ranging from yellowing to necrosis and abscission (Valencia et al., 2008).

A method of determining genetic chloride exclusion in soybean was developed to identify varieties that express this unique genetic characteristic (Rupe et al., 2000). A protocol was established that introduced soybean roots to high levels of chloride salts to initiate a chloride exclusion or inclusion response within each plant. Soybean leaf tissue is then analyzed for chloride concentration and compared to known checks and standards to determine the degree of chloride sensitivity for each soybean variety being evaluated.

Procedures

Soybean varieties were subjected to elevated concentrations of chloride salts while cultivated in a root immersion hydroponic system. A period of chloride salt exposure was followed by laboratory analysis of leaf tissue chloride concentration (Rupe et al., 2000).

This testing procedure utilized a controlled greenhouse to minimize outside environmental variations. Soybean was planted from seed into flats containing Metro Mix soil media (Sun Gro Horticulture, Agawam, Mass.). Throughout the germination process, tap water was added to the flats as needed to maintain adequate soil moisture. Upon reaching the vegetative cotyledon (VC) growth stage, the soybean plants were removed from the flats containing the soil media and the roots of each plant were washed with tap water and trimmed to 1.5 to 2.0 inches in length. The plants were inserted into small holes created in styrofoam insulation boards (Dow Chemical Company, Midland, Mich.) that covered plastic MacCourt Super Tubs (MacCourt Products, Inc., Denver, Colo.).

The plastic tubs were filled with deionized water. The styrofoam boards supported the soybean plants by their cotyledons and allowed them to be suspended in the hydroponic system. A Sweetwater Regenerative Blower (Pentair, Ltd.,

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Schaffhausen, Switzerland) was used to provide aeration to the plant roots through a perforated x-pipe placed in the bottom of each tub. Each x-pipe was constructed of a 0.63-inch PVC pipe.

Upon completion of transplanting soybean plants into the hydroponic system, the plants were allowed to acclimate in the deionized water for two days. After two days, a modified Johnson nutrient solution (Johnson, 1980) was added to each tub of water. This nutrient solution provided the soybean plants with the essential nutrients required for growth (Table 1).

A chloride salt solution (Table 2) was added to the hydroponic tubs after the plants had reached the V3 growth stage and consisted of a blend of calcium chloride and sodium chloride (Sigma-Aldrich, St. Louis, Mo.). This solution mimics natural chloride salt deposits commonly found in groundwater in Arkansas and was added in three parts at 48-hour intervals to slowly bring the total combined nutrient and salt solution to a 50 mmol chloride concentration. After maintaining a 50 mmol chloride concentration in the hydroponic system for 72 hours, the two uppermost, fully developed trifoliate leaves from each plant were collected for analysis.

Leaf tissue samples were dried in a laboratory oven at 140 °F for 24 hours. After drying, each sample was individually ground in a Wiley laboratory mill with a 20 mesh (0.033 inch) sieve (Thomas Scientific, Swedesboro, N.J.).

One hundred mg of ground leaf tissue was added to 250-ml Erlenmeyer flasks containing 50 ml of deionized water used as a solvent. The flasks were placed on an orbital shaker (Labline Instruments, Inc., Melrose Park, Ill.) at 100 rpm for 20 minutes to extract the chloride from each sample. The samples were filtered through a Whatman #1 qualitative filter paper into 125-ml wide-mouth plastic bottles (Thermo Fisher Scientific, Inc., Waltham, Mass.).

Three ml of each leaf tissue sample solution and 1 ml of a weak acid reagent (acetic and nitric acids) were combined into small glass vials. Leaf tissue sample extracts were analyzed for chloride content using a Haake-Buchler digital chloridometer (Buchler Instruments, Inc., Saddlebrook, N.J.) in low power mode, calibrated with a 50-ppm chloride standard solution.

Results and Discussion

After exposure to an elevated concentration of chloride salts, leaf tissue chloride content provided a valuable tool in discerning the genotypic response of each soybean plant and provided a background for determining the inherent degree of sensitivity to chloride (Lee et al., 2004). A dividing line emerged between plants with relatively low levels of chloride in their leaf tissue compared to those having high concentrations.

Soybean sensitivity to chloride is directly correlated to levels of leaf tissue chloride concentration. Plants with low levels of leaf tissue chloride exhibit genetic traits of chloride exclusion, while those with much higher levels express chloride inclusion. These were labeled "excluders' and "includers" respectively (Abel, 1969). The response of each plant within a variety did not necessarily predict the collective response of the variety as a whole. This suggests some degree of genetic diversity within certain varieties.

Therefore, a classification of chloride excluder was made for soybean varieties where, when the roots were exposed to elevated concentrations of chloride salts, every individual plant within the variety contained low levels of leaf tissue chloride. A chloride includer classification was given to varieties where all plants contained relatively high concentrations of leaf tissue chloride when their roots were exposed to elevated chloride salts. Some varieties of soybean had a mixed genotypic response when their roots were exposed to chloride, where some plants had low levels of leaf tissue chloride while others had high levels. This suggested some genetic variation within mixed reaction varieties.

Soybean chloride tolerance has been noted to derive from pedigrees found more commonly in maturity group five (MG 5) varieties than among those of MG 4 (Lee et al., 2004), with a higher percentage of chloride excluders among MG 5 (48%) varieties than among MG 4 (30%) varieties (Table 3). By identifying the chloride response of each variety, a breeding plan of action can be established that considers these traits for further advancement.

Practical Applications

Arkansas soybean producers have excellent potential for profitable yields, but still need to be aware of the potential limiting factor chloride toxicity may cause with select varieties. By testing soybean varieties grown within the state of Arkansas for sensitivity to chloride salts, growers can choose the best varieties for their particular fields. The knowledge accrued will help to ensure the profitability and security of Arkansas soybean production by reducing chloride-induced yield limitations through genetic selection.

Acknowledgments

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Table 1. Modified Johnson nutrient solution.

Nutrient/Element	Final Nutrient Concentration	Final Nutrient Concentration	Source of Nutrient
	Macronutrient Solution		
	(mmol)	**(ppm)**	
N	7.0	98.0	KNO_3, $Ca(NO_3)_2$
P	1.0	31.0	KH_2PO_4
K	4.0	156.4	KH_2PO_4, KNO_3
Ca	2.0	80.2	$Ca(NO_3)_2$
Mg	1.0	24.3	$MgSO_4$
S	1.0	321.0	$MgSO_4$
	Micronutrient Solution A		
	(umol)	(ppm)	
B	50.0	0.54	H_3BO_3
S	12.5	0.40	$MnSO_4$, $ZnSO_4$, $CuSO_4$
Mn	10.0	0.55	$ZnSO_4$
Zn	2.0	0.13	$MnSO_4$
Na	1.0	0.02	Na_2MoO_4
Cu	0.5	0.03	$CuSO_4$
Mo	0.5	0.05	Na_2MoO_4
	Micronutrient Solution B		
	(µmol)	(ppm)	
N	100.0	1.40	$C_{10}H_{12}N_2O_8FeNa$
Fe	50.0	2.79	$C_{10}H_{12}N_2O_8FeNa$
Na	50.0	1.15	$C_{10}H_{12}N_2O_8FeNa$

Table 2. Chloride salt solution.

Element	Final Element Concentration	Final Element Concentration	Source of Element
	(mmol)	(ppm)	
Cl	50.0	1773	$CaCl_2$, NaCl
Ca	20.0	802	$CaCl_2$
Na	10.0	230	NaCl

Table 3. Percent chloride response by maturity group (MG).

Maturity Group	Excluder	Includer	Mixed
	----------------------------------	%	----------------------------------
		2016	
MG IV	26	60	14
MG V	49	39	12
		2017	
MG IV	35	51	14
MG V	50	38	12
		2018	
MG IV	30	63	7
MG V	45	45	10
		3-year average (2016–2018)	
MG IV	30	58	12
MG V	48	41	11

Breeding Soybean Cultivars in Arkansas with High Yield and Disease Resistance

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Abstract

The University of Arkansas System Division of Agriculture's Soybean Breeding Program's main objective is developing high yielding and disease-resistant maturity groups (MG) 4 and 5 soybean varieties locally adapted to Arkansas' environments. Important specialty traits have also been introduced in the breeding program, including herbicide tolerance (glyphosate) and modified seed composition. The breeding process consists of identifying parents from multiple sources, including elite Arkansas lines, germplasm lines from the Arkansas Soybean breeding program, elite public genetics, and exotic germplasm, and recombining them through crossing. Then, populations are advanced until a desired level of homozygosity is reached and single plants are selected and subsequently grown as progeny rows. Thereafter, we evaluate the best lines in preliminary and advanced yield trials in Arkansas, followed by the Arkansas State Variety Testing, the United States Department of Agriculture Uniform Preliminary and Final Tests, and other southern states' variety testing programs. Through these breeding efforts, the Division of Agriculture's Soybean Breeding program has publicly released 10 soybean varieties in the last 2 decades.

Introduction

The University of Arkansas System Division of Agriculture's Soybean Breeding Program strives yearly to develop soybean varieties with high yield, pest resistance, high adaptability, and improved seed quality traits. Our breeding program targets have historically been maturity group (MG) 5 soybean development; however, in the last few years, the program has been putting more effort toward shifting the maturity balance, thus significantly increasing the proportion of MG 4 materials in variety development.

This breeding program has a successful history, with 10 publicly released soybean varieties in the last 2 decades. Most of our previously released cultivars, including Osage (Chen et al., 2007), Ozark (Chen et al., 2004), UA 5612 (Chen et al., 2014a), UA 5213C (Chen et al., 2014b), UA 5014C (Chen et al., 2016), UA 5814HP (Chen et al., 2017), and UA 5615C have been used in commercial grain production and have been used as parents by other breeding programs. Also, Osage and UA 5612 have been used as yield checks in the United States Department of Agriculture (USDA) Uniform tests. The work herein reported highlights the processes in place for the development of new MG 4 and MG 5 commercial soybean varieties.

Procedures

Our breeding objective is to combine the best traits from different cultivars and/or lines to release the best soybean varieties to the Arkansas farmers. Integration of conventional breeding and marker-assisted selection (MAS) is used to identify traits of interest and improve breeding efficiency in our program. Our breeding scheme encompasses three main steps: 1) identification and selection of high-yielding parents with desired complementary traits for cross and development, 2) advancement of breeding populations for three to four generations to allow genetic segregation/recombination, and 3) selection of superior performing lines with desired traits, followed by evaluation in multi-location tests for multiple years. In 2018, a total of 245 different cross combinations were produced. A bulk-pod descent method was used to advance plant populations at early generations, and 20,000 $F_{4:5}$ progeny rows were evaluated for adaptation and agronomic performance. Off-season nurseries are used to speed up the breeding process. The first year of yield trials was tested in four Arkansas locations in non-replicated tests. Advanced yield trials were tested in five Arkansas locations with two replications. The most promising lines from Arkansas' testing are entered into USDA Southern Uniform Tests and the

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Arkansas Soybean Variety Performance Tests; simultaneously, the lines are increased for foundation seed production in preparation for cultivar release. All pre-commercial lines are screened in the greenhouse and/or under field conditions for disease resistance (Soybean Cyst Nematode, Root-knot Nematode, Sudden Death Syndrome, Stem Canker, and Frogeye Leaf Spot, among others).

Results and Discussion

A total of 15 high-yielding and 4 advanced high-yielding lines were evaluated in the 2018 USDA Southern Regional Uniform and Uniform Preliminary Tests, respectively (Table 1). Those 15 lines in the Uniform Preliminary test yielded between 56.1 and 66.8 bu./ac. The line R15-1587 in MG 4 was ranked 2nd with 66.8 bu./ac yield, and the line R14-898 in MG 5 was ranked 3rd with 66.2 bu./ac yield. The four lines in the Uniform test yielded between 49.5 and 59.1 bu./ac. In the MG 5 test, R14-14797 was ranked 5th with 59.1 bu./ac yield.

In addition, we evaluated a total of 1572 lines in advanced and preliminary yield trials in Arkansas in 2018 (Table 1). In all, 30% of commodity lines in yield testing were of MG 4, and 70% were of MG 5. Approximately 70% of the variety development program in 2018 was conventional (698 entries) and 30% was glyphosate-tolerant (319 entries). The breakdown by testing stage is as follows: In 2018, there were 53 pre-commercial, 49 advanced, 192 intermediate, and 404 preliminary conventional lines. Also, in 2018 there were 9 pre-commercial, 20 advanced, 28 intermediate, and 262 preliminary glyphosate-tolerant lines. Additionally, a total of 8807 single plants were selected and harvested from F_3 and F_4 breeding populations and will be evaluated as progeny rows.

Practical Applications

We strive to provide Arkansas farmers with high-yielding locally adapted cultivars with low cost. The continued release of conventional and glyphosate-tolerant public cultivars such as Ozark, UA 4805, Osage, UA 5612, UA 5213C, UA 5014C, UA 5414RR, and UA 5715GT provides low-cost seed for Arkansas growers and also serves as a great source of germplasm for breeding programs in the United States.

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Table 1. Overview of the University of Arkansas System Division of Agriculture's Soybean Breeding and Genetics Program tests in 2018.

Test	No. of entries
USDA Uniform/Preliminary Tests	19
AR Variety Testing Program	22
Arkansas advanced lines	214
Arkansas preliminary lines	1317
Progeny rows	20,000
Breeding populations (F_1 – F_4)	8807
New crosses	245

Screening Soybean Germplasm and Breeding Soybeans for Flood Tolerance

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Abstract

Flooding is an abiotic stress that can be detrimental to soybean growth and development. Soybean responses to flooding and its effects are dependent on the growth stage of the plant during flood initiation. Most of the soybean commercial cultivars in the United States are generally flood-sensitive; therefore, it is important to develop flood-tolerant soybean cultivars for grain production in regions of heavy rainfalls. The Soybean Breeding Program at the University of Arkansas System Division of Agriculture is committed to developing high-yielding, flood-tolerant varieties and germplasm for the southern soybean-producing regions. The breeding effort includes germplasm characterization and identification of flood-tolerant sources to develop the desired varieties; evaluation of the effects of flooding stress on yield and seed; identification of flood Quantitative Trait Loci (QTLs) for marker-assisted selection (MAS); and assessment of the effectiveness of different selection methodologies for flood tolerance. This report highlights the breeding efforts made by the Soybean Breeding Program for the flood tolerance project in 2018.

Introduction

Flooding is one of the most hazardous natural occurrences caused by heavy rains, excessive irrigation, and low infiltration rate of soils, and its prolonged occurrence severely reduces the productivity of crops in major growing regions in the world. Fields under flood conditions cause billions of dollars in losses for farmers (Boyer, 1982; Rosenzweig et al., 2002). Most of the soybeans grown in the U.S. are produced in the upper Midwest; however, the southern part of the Mississippi Delta is also considered an important region for soybean production. In the Mississippi Delta region, flooding has the potential to reduce up to 25% of soybean grain yield in soybean-paddy rice rotations (VanToai et al., 2010). This is because most of the soybean cultivars are intolerant to flooding (Russell et al., 1990). Oosterhuis et al. (1990) observed that soybean yield can be reduced from 17% to 43% when waterlogging occurs at the vegetative growth stage, and 50% to 56% at the reproductive stage. Also, a three-year field study reported a 40% yield reduction in flood-tolerant soybean germplasm versus an 80% reduction in flood-susceptible germplasm (Shannon et al., 2005). Thus, developing soybean varieties that can endure flooding without significantly reducing yield is critical. Screening and identification of germplasm for flood tolerance and using that germplasm in breeding efforts has become an ongoing goal of the Soybean Breeding Program at the University of Arkansas System Division of Agriculture.

Procedures

Germplasm. Fifty-nine lines from the Arkansas Soybean Breeding Program were screened at V2 or R1 soybean growth stages, in which foliar damage scores (FDS) were recorded and data analyzed. Additionally, 87 Arkansas and Missouri high-yielding lines, 147 MG 4 cultivars/lines from 23 companies and universities, and 51 MG 5 cultivars/lines from 17 companies and universities were screened for flood tolerance at the V2 growth stage. Also, 13 advanced lines were evaluated as yield trials in four Arkansas locations with two replications, and 12 preliminary lines with 1 replication trial were screened for flood tolerance at V2 and R1 stages at the Rice Research and Extension Center (RREC).

Experimental Design. Experiments for flood tolerance were planted in June 2018, in single-row 10-feet long plots planted with 100 seeds of each variety/line. Once plants reached V2 or R1 growth stage, flooding was imposed for 8 days with irrigating water creating a layer of 4–6 inches of water above the soil surface. Foliar damage scores (FDS) were collected three days after water drainage using a 1 to 9 scale, where 1 and 9 indicated less than 10% and over 85% of the plants showing foliar damage or death, respectively (1 = 0–10%; 2 = 11–20%; 3 = 21–30%; 4 = 31–40%; 5 = 41–50%; 6 = 51–60%; 7 = 61–70%; 8 = 71–85%; 9 = 86–100%). Varieties/lines are considered highly flood-tolerant if average FDS = 1.0 to 3.9, moderately tolerant if average FDS = 4.0 to 5.9, sensitive if average FDS = 6.0 to 7.9, and highly sensitive if average FDS = 8.0 to 9.0.

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Results and Discussion

For the experiment with 59 lines screened for flood tolerance at V2 or R1 growth stages, we observed good symptom severity, with an average FDS_V2 score of 6.0; but the least significant difference (LSD) for the experiments was high, with an average of 2.7 and a range of 2.5 to 3.3 scale points. Also, we observed an average FDS_R1 of 7.0 and an average LSD of 2.3 scale points. Similarly, in the 87 Arkansas and Missouri high-yielding lines screened for flood tolerance at the V2 growth stage, the grand mean FDS_V2 was 5.0, with a 38.4% coefficient of variance (CV) and 3.1 LSD. The result also exhibited that most high-yielding lines from Arkansas and Missouri are not tolerant of flooding. In the screening of 147 MG4 cultivars/lines from 23 companies and universities, the grand mean of FDS_V2 was 5.2, with 33.9% CV and 2.9 LSD. While for the 51 MG 5 cultivars/lines, the grand mean of FDS_V2 was 5.5 with 35.6% CV and 3.2 LSD. The results showed that most soybean cultivars/lines from companies and universities are sensitive to flood, and there was a high level of variation within the experiment. Results from the 13 advanced lines screened for flood tolerance at V2 and R1 stages made it possible to select R16-45 as a pre-commercial line presenting high-yielding (95.6% check mean, and 70.9 bu./ac) and flood tolerance at R1 stage (FDS_R1= 2.4). This line will be planted in the regional yield test in 2019. For the preliminary flood test, none of the 12 lines evaluated was selected for flood advanced trial.

The high coefficient of variation and high LSD observed across all trials could be a result of dry planting conditions that translated into poor stands, or due to insufficient replications of the trial. As an improvement for the management of the flood trials, the Arkansas Soybean Breeding Program is planning to modify planting dates (plant earlier to simulate V2 flooding under cooler weather) and increase the number of replications in future experiments.

Practical Applications

The Soybean Breeding Program at the University of Arkansas System Division of Agriculture continuously works on efficiently identifying new sources of flood tolerance from diverse germplasm. Incorporation of this trait into high-yielding adapted cultivars will offer the growers waterlogging-tolerant varieties that will maintain their yield under flood stress.

Acknowledgments

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Genomic Selection for Seed Yield and Drought Traits Under Various Water Regimes

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Abstract

Drought is an important constraint in soybean production, and it has a severe effect on dryland soybean production. However, water accessibility, availability and, quality could even be problematic under irrigated soybean production in cases where well or irrigation water becomes scarce or salty. This study evaluates the response of four different soybean populations planted under dryland conditions during summer 2018. Two populations were selected based on phenotypic variation and the mean difference of the population wilting scores and were used to run a genome-wide association study (GWAS) to detect single-nucleotide polymorphisms (SNPs) associated with canopy wilting. The two selected populations will be planted under various irrigation levels in further genomic selection experiments to assess the response to selection for yield and other related traits.

Introduction

Crops are subject to different abiotic and biotic stresses during their growing season. Among abiotic stress, drought causes a drastic effect on productivity in rain-fed areas as it reduces plant growth (Toker et al., 2007) and seed yield. According to Clement et al. (2008), soybean as part of the Fabaceae family is a highly drought-sensitive legume. Soybean has drought tolerance mechanisms that include increased rooting depth, reduced stomatal conductance, leaf rolling/folding, reduced evaporation surface, increased leaf-surface wax accumulation, and enhanced water-storage abilities in specific organs (Carrow, 1996; Fang and Xiong, 2015; Ludlow and Muchow, 1990; O'toole and Bland, 1987). Additionally, slow canopy wilting is a mechanism to minimize transpiration under water deficit by keeping a greater leaf turgor pressure (Devi and Sinclair, 2013). The University of Arkansas System Division of Agriculture's Soybean Breeding Program had released germplasm with slow wilting (Manjarrez-Sandoval et al., 2019 in press) and other drought tolerance traits (Chen et al., 2007). Nevertheless, it is vital to understand how these different drought-tolerance traits will perform under various levels of water restrictions.

Procedures

Four cross-combinations were made in 2014 in Fayetteville. Two represented crosses between high-yielding commodity parents (N07-14753 × R11-1057, and R10-197 × N07-14221), one was the cross between a parent with improved yield stability under non-irrigated conditions and a high-yielding commodity parent (R11-2577 × N07-14221), and the last cross was between a high-yielding commodity parent and drought parent with slow wilting (R11-2933 × R11-1057). The F_1 seeds were sent to Argentina for a winter nursery in 2015. The F_2 seeds were bulk harvested, and lines were grown in Kibler in 2016; then, F_3 seeds were bulk harvested and planted in Fayetteville. The F_4 lines were developed in Fayetteville in 2017 by single-plant selection and were bulk harvested. A total of 328 $F_{4:5}$ breeding lines were planted in Stuttgart under dryland condition in 4.6 m-long plots to screen for canopy witling. Wilting scores were visually rated per King et al. (2009). Each plot was graded on a scale (%) of 0 (no wilting), 40 (moderate wilting), 60 (severe wilting), and 100 (plant death). A t-test was performed in SAS® v. 9.4 (SAS Institute Inc., Cary, N.C.) to evaluate the variation on the wilting of the four populations. Fresh young soybean leaves were collected for DNA extraction for the two populations that represented the greatest variation. The extraction was done via the CTAB protocol (Doyle, 1990). Single-nucleotide polymorphisms (SNPs) were identified using the Soy6K SNPs Infinium Chips in the Soybean Improvement Laboratory USDA-ARS Beltsville. After obtaining the 6000 SNPs for all 165 genotypes, markers with minor allele frequency (MAF) < 2.5 % and markers with a missing rate >30% were removed, leaving 2732 polymorphic SNPs after filtering. A threshold value

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($-Log_{10}$ (P-value) $\geq$ 3.5), which is equivalent to P-value $\leq$ 0.0003, was used to declare a significant association of SNPs with witling. Association analysis was conducted using the FarmCPU model in the R package (Liu et al., 2016). The two populations having the greatest variation were sent to a winter nursery in Costa Rica to increase the seeds and to advance the population.

Results and Discussion

There was a highly significant difference between (N07-14753 × R11-1057) and (R11-2933 × R11-1057) progenies (P-value <0.0001) (Table 1) and (R10-197 × N07-14221) and (R11-2933 × R11-1057) progenies (P-value <0.0001) (Table 1). Significant difference in wilting score was also shown between (R11-2577 × N07-14221) and (R11-2933 × R11-1057) off-springs (P-value <0.01) (Table 1). Results showed that (N07-14753 × R11-1057) and (R11-2933 × R11-1057) progenies have the greatest variation and segregation in wilting. (N07-14753 × R11-1057) progenies have the highest wilting score (31.30 ± 5.39 %); while (R11-2933 × R11-1057) has the lowest wilting score (26.30 ± 3.54%) on average (Table 2 and Fig. 1).

Association analysis using 2732 SNPs and FarmCPU model identified eight SNPs associated with wilting score ($-Log_{10}$ (P-value) $\geq$ 3.5; P-value $\leq$ 0.0003) (Fig. 2). The SNPs were in Chromosome 2, 10, 16, 12, and 14. The Q-Q plot of the FarmCPU model (Fig. 3) resulted in a sharp deviation from the expected P-value distribution in the tail area, indicating that false positives were adequately controlled.

Practical Applications

This experiment, in which we confirmed the segregation for drought tolerance traits (wilting), was necessary to select the two populations that will be subjected to various irrigation restrictions in the subsequent analysis of genomic selection. Having a good understanding of the benefits of drought tolerance traits is critical for the proper definition of breeding objectives and corresponding deployment of breeding lines under various reduced irrigation conditions.

Acknowledgments

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Table 1. A t-test comparison of wilting scores among four populations.

Traits	Pedigree	N07-14753 × R11-1057	R10-197× N07-14221	R11-2577 × N07-14221	R11-2933 × R11-1057
Yield × Yield	N07-14753 × R11-1057	-	0.6459[a]	0.1743	0.0003 ***
Yield × Yield	R10-197 × N07-14221		-	0.3423	0.0007 ***
Drought × Yield	R11-2577 × N07-14221			-	0.0188 *
Drought × Yield	R11-2933 × R11-1057				-

[a] *P*-value for t-test on the mean of wilting scores between population 1, 2, 3, and 4.
* Significant at $P < 0.05$ level.
*** Significant at $P < 0.001$ level.

Table 2. Descriptive statistics for wilting scores of four populations.

Traits	Pedigree	Cross type[a]	# Individuals	Mean	Std dev[b]	C.V.[c]	Minimum	Maximum	Range[d]
Yield × Yield	N07-14753 × R11-1057	Yield × Yield	73	31.30	5.39	20.49	10.00	35.00	25.00
Yield × Yield	R10-197 × N07-14221	Yield × Yield	85	26.65	4.15	15.59	15.00	35.00	20.00
Drought × Yield	R11-2577 × N07-14221	Drought × Yield	78	26.60	3.73	14.00	15.00	35.00	20.00
Drought × Yield	R11-2933 × R11-1057	Drought × Yield	92	26.30	3.54	11.30	20.00	35.00	15.00

[a] Crosses: high-yielding commodity parent x high-yielding commodity parent; high-yielding commodity parent x high-yielding commodity parent; drought parent smaller beta x high-yielding commodity parent; drought parent slow wilting x high-yielding commodity parent.
[b] Standard deviation.
[c] Coefficient of variation.
[d] Range defined the difference between maximum and minimum.

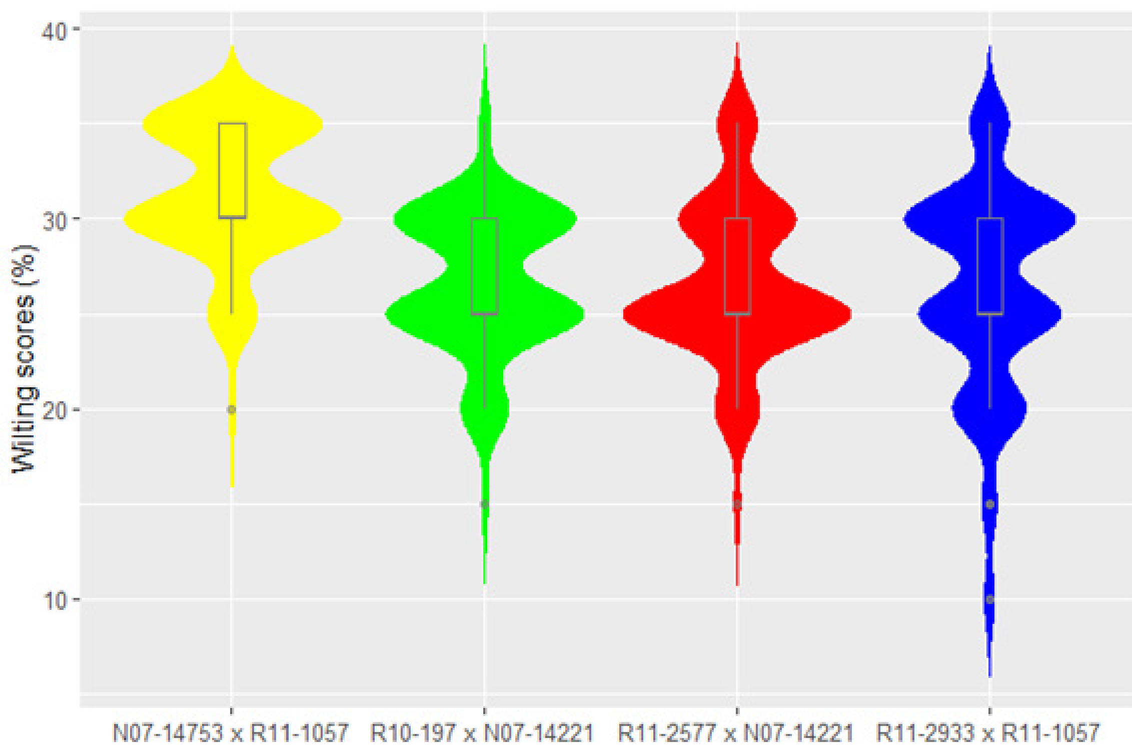

Fig. 1. Violin boxplot representing the wilting score (%) of four populations.

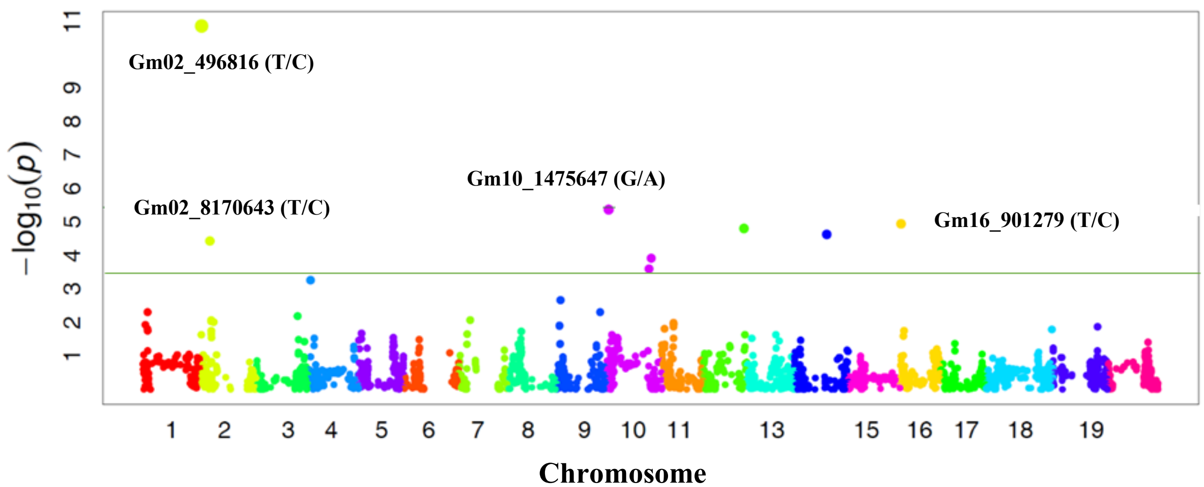

Fig. 2. Manhattan plot of -Log$_{10}$ (*P*-value) vs. chromosomal position of single-nucleotide polymorphisms (SNPs) markers associated with wilting from FarmCPU model. The green line represents the threshold (-Log$_{10}$ (*P*-value) ≥ 3.5; *P*-value ≤ 0.0003). The dots above the lines represent the most significant SNPs with threshold (-Log$_{10}$ (*P*-value) ≥ 3.5; *P*-value ≤ 0.0003).

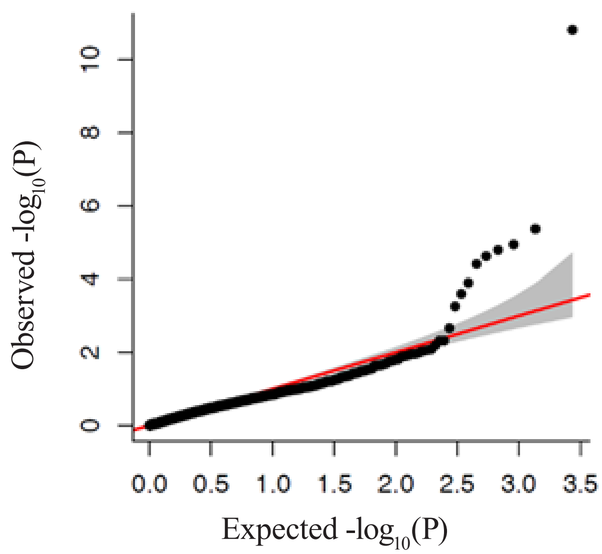

Fig. 3. Q-Q plot from FarmCPU model.

Soybean Germplasm Enhancement Using Genetic Diversity

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Abstract

One of the main goals of the Soybean Breeding Program of the University of Arkansas System Division of Agriculture is the incorporation of diverse or exotic germplasm into elite Arkansas lines, to enhance seed yield, pest and disease resistance, and abiotic stress tolerance. Under such breeding efforts, in 2018 the program advanced four breeding lines (R13-11034, R15-7063, R15-7171, and R16-7045) derived from exotic germplasm into a regional protein test. Also, R16-4053 and R13-12468 were advanced into the 2019 USDA Uniform trials, and R16-4235 was entered into the 2019 United States Department of Agriculture Preliminary trials. Additionally, R10-5086 and R11-6870, two lines with 25% exotic germplasm in the pedigree, and R10-2436 and R10-2710, germplasm lines with drought tolerance, were made available for public and private breeders to be used as parents for crossing. These breeding efforts are key to the sustained relevance of the soybean breeding program in Arkansas.

Introduction

Exotic germplasm plays a key role in soybean breeding programs for cultivar development (Carter et al., 1993; Gizlice et al., 1994). Recently, the University of Arkansas System Division of Agriculture's Soybean Breeding Program released five germplasm lines with exotic parentage, namely R99-1613F, R01-2731F, R01-3474F (Chen et al., 2011), R10-5086, and R11-6870 (Manjarrez-Sandoval et al., 2018). The Soybean Breeding Program uses exotic germplasm to increase not only genetic diversity for seed yield but also pest and disease resistance and abiotic stress tolerance. Two germplasm lines, R01-416F and R01-581F, with improved yield and nitrogen fixation under drought stress were released in 2006 (Chen et al., 2007). Moreover, two drought-tolerant germplasm (R10-2436 and R10-2710) with high yield under irrigation and low yield reduction under drought were released in 2017 (Manjarrez-Sandoval et al. 2019, in press). Continuous introduction of new genes for maturity, yield, and biotic and abiotic stress tolerance, available either from other world regions or from elite public materials developed in the United States, is critical for the enhancement of the Arkansas Soybean Breeding Program's soybean germplasm pool and for the success of the products developed by this breeding program.

Procedures

In 2018, a total of 27 crosses were made for germplasm enhancement using diverse genetic sources. The F_1 breeding populations were grown and were checked for the presence of morphological markers. The breeding populations were advanced using the modified single-pod descent method (Fehr, 1987) from F_2 to F_4 generations. Single plants were selected in F_3 or F_4 breeding populations and subsequently, single rows were grown and lines were selected visually based on overall field appearance. The preliminary and advanced breeding lines with the best agronomic performance were extensively evaluated in Arkansas and other southern states for yield, maturity, plant height, lodging, shattering, and target traits according to the breeding objective, such as drought tolerance, pest, and disease resistance.

Results and Discussion

Genetic Diversity for Yield Improvement. In 2018, four lines (R13-11034, R15-7063, R15-7171, and R16-7045) derived from exotic germplasm were selected from the "pre-commercial" yield trial and entered into a 2019 USBPRODIV-5 "regional" test. Twelve of the 15 "advanced"-stage and 49 "preliminary"-stage lines with a diverse exotic pedigree that were evaluated in five and four Arkansas locations, were selected to be planted into a 2019 "advanced" diversity test (Table 1). One-hundred sixty lines derived from diverse pedigrees were selected from progeny rows into 2019 "preliminary" tests. Also, a total of 2550 single plants were selected from F_3 and F_4 breeding populations and will be evaluated in the 2019 progeny row test. In 2018, we advanced 11 F_4, 13 F_3, 10 F_2, and 1 F_1 breeding populations in the genetic diversity project, using a modified single-pod descent method (Fehr,

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1987). We also made 15 new cross combinations as part of this project. Seven high-yielding breeding lines with exotic parentage (R15-7090, R15-7025, R13-11034, R14-13157, R15-7016, R15-7063, and R15-7171), together with two released germplasm lines, R10-5086 and R11-6870, were grown as breeder seed in 2018 and made available to other breeders via material transfer agreements for use in crossing.

Drought Tolerance. Exotic germplasm had been successfully used to develop and release germplasm lines R10-2436 and R10-2710 with drought tolerance. In 2018, both lines were increased in Arkansas and Costa Rica for germ- plasm-collection deposit and material transfer with other public and private breeders.

Two lines were advanced into the 2019 United States Department of Agriculture (USDA) "Uniform" trials; the lines were R13-12468, derived from drought-tolerant pedigree R01-581F, and R16-4053, the latter averaging 90.4% of the check mean (73.1 bu./ac) and low wilting score (12.5%) in 2018 "advanced" trials. The yield of 32 preliminary breeding lines was evaluated in one-replication trials at three Arkansas locations under full irrigation. Nine high-yielding lines (99.2% to 111.6% of check mean 50.4 bu./ac) were selected to enter the 2019 drought "advanced" tests (Table 1). Also, 54 lines were selected from progeny row trials into the 2019 "preliminary" tests. In addition, 1000 single plants were selected from F_3 and F_4 breeding populations and will be evaluated in 2019 progeny rows. Finally, 9 F_4, 11 F_3, 6 F_2, and 6 F_1 breeding populations were advanced and 11 new breeding populations for the drought tolerance project were initiated.

Disease Resistance. The introduction continues of germplasm with resistance to the main diseases in Arkansas such as sudden death syndrome (SDS), soybean cyst nematode (SCN), frogeye leaf spot (FLS), soybean mosaic virus (SMV), phomopsis seed decay (PSD), stink bug (SB), and soybean rust (SR). In 2018, 15 advanced lines with pest and disease resistance were tested in two-replication yield trials at four Arkansas locations. Line R16-4235 with high-yielding (100.2% of check mean 75.9 bu./ac) and potential for SCN resistance was selected for the 2019 USDA Uniform test. A total of 16 high-yielding lines with exotic pedigree were also selected from 50 "intermediate" and "preliminary" stage lines for the 2019 "advanced" tests (Table 1). A total of 110 lines with diverse pest and disease resistant traits in their pedigree were selected from progeny row tests for the 2019 "preliminary" trials. Meanwhile, a total of 3500 single plants were selected from F_3 and F_4 breeding populations and will be evaluated in the 2019 progeny row test. In 2018, 6 F_4, 7 F_3, 5 F_2, and 6 F_1 breeding populations were advanced in the pest and disease resistant project.

Practical Applications

The Arkansas Soybean Breeding Program has made progress in the development of commodity and value-added varieties through genetic diversity. Thanks to the active exchange of soybean germplasm among the U.S. public breeding community, the Arkansas Soybean Breeding Program has been able to integrate the necessary maturity, yield and stress resistance/tolerance traits into the parental stock. Germplasm exchange has enabled us to develop varieties and germplasm with improved yield, resistance to pest and disease, and/or tolerance to drought conditions.

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Table 1. Germplasm enhancement project overview in 2018.

Test	"Advanced" stage entries	"Preliminary" stage entries
High yielding genetic diversity	15	49
Drought tolerance	10	32
Pest and disease resistance	15	50

Purification and Production of Breeder Seed and Foundation Seed of University of Arkansas System Division of Agriculture Soybean Lines

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Abstract

The University of Arkansas System Division of Agriculture's Soybean Breeding program is committed to developing high yielding varieties with high levels of genetic purity. Such purity is achieved with significant efforts in line grow-outs, re-selections, and rouging for off-types. Our Purity and Foundation seed programs guarantee breeder- and foundation-level seed resources of current and future variety releases for regional soybean dealers and farmers. This report summarizes the purification efforts during the 2018 growing season. The pure-seed lines and varieties herein reported are the cornerstone of the Arkansas Foundation Seed Program.

Introduction

The University of Arkansas System Division of Agriculture's Soybean Breeding and Foundation Seed Programs provide a unique niche for the development of soybean varieties locally adapted and tolerant/resistant to major biotic and abiotic stresses. Production of high-quality seed with a high level of genetic purity is critical for breeding operations. The Official Standards for Seed Certification in Arkansas (Arkansas State Plant Board, 2013) list the various requirements on genetic purity, contamination, and germination for the certification of breeder-, foundation-, registered-, and certified-seed classes. The Soybean Breeding and the Foundation Seed programs utilize line grow-outs, seed increases, isolation, and rouging for off-types to ensure the seed produced meets the desired seed class requirements. This project lists the purification efforts sponsored by the Arkansas Soybean Promotion Board.

Procedures

The Soybean Breeding and Genetics Program grows breeder seed row and foundation increases at the Rice Research and Extension Center near Stuttgart, Ark. Lines grown for the foundation-seed class were planted in 15-ft. isolation. All seed classes were rogued in-season for flower, maturity, plant height, and pod and pubescence color.

Results and Discussion

In 2018, five publicly released varieties were grown for foundation-seed class production, namely UA5014C, Osage, UA5612, UA5414RR, and UA5715GT (Table 1). In addition, 44 pre-commercial lines were grown for breeder seed production, with a breakdown as follows: 19 lines were conventional, 2 were flood-tolerant, 1 was high oleic, 2 were high-oleic and low-linolenic, 2 high protein, 4 glyphosate-tolerant, 6 had various disease tolerance traits, 7 had exotic genetic diversity, and 2 were drought-tolerant lines (Table 1).

Practical Applications

The production of breeder and foundation seed of pre-commercial lines and commercial varieties generates high-quality seed to local seed producers, enhancing the competitiveness of Arkansas soybean in both the national and international markets.

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

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Table 1. 2018 Foundation and pre-foundation seed overview at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart.

Test	Name	Project	Acres Planted	Purification lbs. produced
Foundation	UA5014C	Conventional	2.15	
Foundation	Osage	Conventional	2.15	
Foundation	UA5612	Conventional	2.15	
Foundation	UA5414RR	Roundup Ready	2.39	
Foundation	UA5715GT	Roundup Ready	2.15	
Breeder Seed	R15-818	Conventional	0.19	66
Breeder Seed	R15-1150	Conventional	0.19	71
Breeder Seed	R15-2422	Conventional	0.19	55
Breeder Seed	R15-1587	Conventional	0.19	69
Breeder Seed	R15-1194	Conventional	0.19	79
Breeder Seed	R14-356	Conventional	0.19	76
Breeder Seed	R13-1409	Conventional	0.19	78
Breeder Seed	R13-818	Conventional	0.19	74
Breeder Seed	R14-898	Conventional	0.19	56
Breeder Seed	R15-1687	Conventional	0.19	46
Breeder Seed	R15-489	Conventional	0.19	46
Breeder Seed	R14-1422	Conventional	0.19	72
Breeder Seed	R14-14648	Conventional	0.19	81
Breeder Seed	R13-9687	Conventional	0.09	239
Breeder Seed	R10-298	Conventional	0.09	218
Breeder Seed	R13-13997	Conventional	0.35	131
Breeder Seed	R11-171	Conventional	0.19	38
Breeder Seed	R15-4655	Conventional	0.19	57
Breeder Seed	R14-15079	Conventional	0.09	78
Breeder Seed	R04-342	Flood	0.19	36
Breeder Seed	R07-6669	Flood	0.38	139
Breeder Seed	R15-5695	High Oleic	0.19	78.5
Breeder Seed	R14-10150	High -Oleic Low-Linolenic	0.19	58
Breeder Seed	16UARK-52	High -Oleic Low-Linolenic	0.19	60
Breeder Seed	UA 5814HP	High Protein	0.09	18.5
Breeder Seed	R11-7999	High Protein	0.09	76
Breeder Seed	R15-2465RR	Roundup Ready	0.19	54
Breeder Seed	R12-6751RR	Roundup Ready	0.19	50
Breeder Seed	R14-14797RR	Roundup Ready	0.19	58
Breeder Seed	R13-4638RY	Roundup Ready	0.19	126
Breeder Seed	R11-982G	Disease	0.19	228
Breeder Seed	R11-1294	Disease	0.19	216
Breeder Seed	R15-8098	Disease	0.19	13
Breeder Seed	R14-14314	Disease	0.19	77
Breeder Seed	R15-8014	Disease	0.19	68
Breeder Seed	R15-7090	Diversity	0.19	69
Breeder Seed	R15-7025	Diversity	0.19	82
Breeder Seed	R13-11034	Diversity	0.19	82
Breeder Seed	R14-13157	Diversity	0.19	73
Breeder Seed	R15-7016	Diversity	0.19	77
Breeder Seed	R15-7063	Diversity	0.19	88
Breeder Seed	R15-7171	Diversity	0.19	76
Breeder Seed	R13-12468	Drought Tolerant	0.19	85
Breeder Seed	R11-2755	Drought Tolerant	0.19	79

Soybean Variety Advancement Using a Winter Nursery

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Abstract

The Soybean Breeding Program of the University of Arkansas System Division of Agriculture is responsible for developing Maturity Group (MG) 4 soybean varieties with desirable agronomic traits and adapted to Arkansas' growing regions. To increase the efficiency of the breeding process, the program utilizes nurseries in South America to take advantage of their climates during winter months in the United States. Using these off-season nurseries provides the program with the opportunity to expedite the advancement of our materials. In October 2017, 2000 single plants were selected in Kibler, Ark., and subsequently processed and shipped to Quillota, Chile to grow as progeny rows. In April 2018, 260 MG 4 rows were selected in Chile to be bulk-harvested and shipped back to Arkansas where they were planted into preliminary yield trials in May 2018. This new workflow shortened the breeding cycle by one year and increased the proportion of MG 4 entries in the first year of yield trials from 13% to 32%, which is a step in the direction towards our goal of a 70% MG 4 mix by 2021.

Introduction

The University of Arkansas System Division of Agriculture's Soybean Breeding Program aims to meet the demands of farmers in the state of Arkansas. To do so more efficiently, it is imperative to employ various breeding tools and methods. One such method is the utilization of winter nurseries to expedite the development of new germplasm (O'Connor et al., 2013). In plant breeding, the rate of genetic gain is indirectly proportional to the number of years per breeding cycle, and processes that shorten the time from crossing to product development have a very strong impact on product performance (Cobb et al., 2019). As applied in this project, progeny rows are grown counter-season in South America (Chile) in a favorable environment for phenotypic selection, and individuals with the best agronomic profile are selected for yield testing in the United States mainland. This workflow saves the breeding program one year in the product development cycle, thus significantly impacting the rate of genetic gain.

Procedures

Two-thousand single plant selections (SPS) were made based on early maturity (MG 4) from nine genetic populations in Kibler, Ark. Six of those populations were developed from crossing high-yielding conventional and MG 4 parents (TN12-4061 × R09-1589, R11-1578 × V11-2149, LD11-7311 × UA 5014C, K11-1868 × R12-2142, R11-5495 × UA 5014C, and R12-3616 × R11-5131). While three populations were developed from crossing glyphosate-tolerant and MG 4 soybeans (LEO 2939-04S809 × R04-572, LEO 4415-08 × JTN-4307, and SRM 5500 × R11-7141). The single plants were threshed, cleaned for purity, treated with fungicide, and shipped to a winter nursery in Quillota, Chile to be grown as progeny rows during winter 2017-2018. In April 2018, 260 selections were made based on maturity and uniformity. Selections were bulk harvested and shipped back to Fayetteville, Ark. in May 2018 for yield testing at four locations with one replication each.

Results and Discussion

Because of this project, in 2018 we were able to yield test 260 lines one year earlier than under the standard work-flow, but keeping inbreeding stage consistent. Also, this work-flow allowed the proportion of MG 4 entries in the first year of yield trials to increase from 13% to 32%, in line with the goal of reaching 70% MG 4 entries by 2021.

Practical Applications

The reduction of development time for product development is critical for the Arkansas Soybean Breeding program to meet customer's demand for MG 4 soybean varieties. This improved breeding workflow, saving one year of breeding

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time, provides a competitive edge for the development of locally adapted soybean varieties.

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Evaluation of Soybean Androgenesis by Isolated Microspore Culture

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Abstract

Doubled haploid technology provides an advanced breeding platform capable of yielding elite cultivars in a timeframe unmatched by traditional breeding. However, such a platform has yet to be reported for soybean. We have developed a pipeline capable of producing embryos efficiently by culturing microspores, the immature male gametophyte of plants. Following a series of cold shocks to the donor plants and initial cold incubation, isolated microspores of soybean were cultured with 10 ppm 2, 4-dichlorophenoxyacetic acid as auxin and 0.1 ppm 6-benzylaminopurine as cytokinin. All culture replicates exhibited sustained cell divisions leading to the formation of complex structures including embryos. Preliminary flow cytometry results indicated the haploid status of the isolated microspores placed into culture and the occurrence of spontaneous chromosome doubling. Embryo development has been documented and compared to the androgenesis model system, *Brassica napus,* with many similarities. Ongoing work will focus on the conversion of these embryos into plants.

Introduction

The goal of this research project is to develop a system for recovering doubled haploids of soybean as an enabling technology for advanced breeding and genetics applications. Doubled haploid breeding systems reduce the time and cost of developing new cultivars (Ferrie and Caswell, 2011). To our knowledge, doubled haploids of soybean have not been available yet for breeders to use (Lulsdorf et al., 2011). Doubled haploid breeding methods have been used to develop new cultivars in several crops, including self-pollinating (e.g., peppers, wheat) as well as out-crossing crops (e.g., barley, rye) (Ferrie and Caswell, 2011). This soybean system will be based on the isolation and culture of microspores (immature pollen grains, male gametes, haploid) to obtain haploid plants and/or doubled haploid plants from the microspores. Doubled haploid plants are true-breeding lines in one step, with all traits fixed, as opposed to 6 to 7 generations of inbreeding to fix traits conventionally (Ferrie and Caswell, 2011). Previous efforts in soybean microspore culture resulted in limited cell divisions and early embryo arrest at the 8-cell stage (Rodrigues et al., 2006).

Preliminary results (Garda, 2018) encourage evaluating this approach. By scoring for a putative gametic response as opposed to somatic tissue response from anther cultures (microspores are contained within the anthers), several factors that stimulate putative gametic/microspore response in soybean were identified (Garda, 2018). Sustained cell divisions from soybean isolated microspore cultures have been documented in this system, including the formation of heart-stage embryos (Garda, 2018), which had not been reported in the literature previously. In this project, first the isolated microspore culture system for sustained cell division is optimized. The next step is optimization for chromosome doubling. Third, the culture system for embryo formation is optimized. The final step will be an attempt to produce haploid or doubled haploid plants from these embryos. Progress on the first three objectives is presented here.

Procedures

Genotypes IAS-5, known to respond in anther and microspore cultures (Rodrigues et al. 2004; 2006), and Embrapa-1 (IAS-5 x Paranaiba derivative) were used as donor material; seeds were obtained from USDA Germplasm Resources Information Network. Plants were grown in growth chambers set to 82 °F continuous, 16 hours light/day at 10,000–15,000 lux, and 90% relative humidity (Garda, 2018). When the majority of floral buds were at 0.12 inch in length, donor plants were subjected to a 50 °F day/46 °F night for 3 days plus 39 °F overnight. Floral buds 0.12–0.14 in. in length were collected and surface sterilized (7.5 minutes in H_2O + 20% bleach + 1 drop of Ivory liquid soap, rinse in sterile H_2O 5 minutes each for 3 times). Under sterile conditions, anthers were dissected

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and placed into a tube with 0.017 oz. of 2% sucrose, 2% sorbitol and 0.3 M mannitol. Anthers were gently macerated with a glass rod to release microspores (Rodrigues et al., 2006), then transferred into a 0.17-oz tube with 0.12 oz of 2% sucrose + 2% sorbitol + 0.3M mannitol. The tube was vortexed at half-strength for 2 minutes, filtered through a 0.0024-in. sterile strainer filter unit and again through a 0.0016-in. sterile strainer filter unit. Filtered microspores were aliquoted into 0.034-oz microcentrifuge tubes using a 0.0016-in. pipette tip strainer. Tubes were centrifuged for 6 minutes at 2000 RPM; a small pellet of microspores was formed. The supernatant was discarded; microspores were re-suspended into 0.17–0.34 oz of the culture medium placed into a sterile 4-welled culture plate. Plates were incubated in the dark at 52 °F for 4 days to 2 weeks under gentle shaking conditions, then transferred to 64 °F for 3 days to 2 weeks in low light, and finally transferred to 77 °F in high light. Initial culture medium (designated BNN) contained the macronutrient salts and vitamins of Nitsch and Nitsch (1969), the micronutrient salts of Gamborg et al. (1968), 2% sucrose, 2% sorbitol, pH 5.8, with varying concentrations of 2,4-dichlorophenoxyacetic acid (2,4-D), α-naphthaleneacetic acid (NAA) or picloram (PIC) as auxin, 6-benzylaminopurine (BA) as cytokinin, and/or abscisic acid (ABA). We also explored a sorbitol osmoticum gradient, as well as a pH gradient in various experiments.

Cell densities and viabilities were recorded using an Invitrogen Countess™ cell counting chamber and Tryptan Blue exclusion (adding 0.4 ppm Trypan Blue to suspension culture at a 1:1 ratio). Images for each culture were acquired every few days and weekly with a Zeiss Axiocam inverted microscope (Oberkochen, Germany) equipped with ZEN software at 200x magnification. A BD FACSCalibur (Franklin Lakes, N.J.) flow cytometer was used to assess ploidy, cell size, cell complexity, and autofluorescence of chlorophyll and remaining cell wall fragments of microspore protoplasts. Protoplasts were generated by incubating pelleted cultures in an enzyme solution (1% [w/v] Macerozyme R-10 and 1% Cellulase R-10 in 0.4 M mannitol, pH 5.8) for 16 hours at 82 °F to remove the cell wall. Protoplasts were rinsed with 1X PBS (phosphate-buffered saline) and fixed in ice-cold 70% ethanol for 12–14 hours. Fixation was followed by nuclei staining with a Sysmex Partec ploidy analysis kit (Product #05-5002). Unstained protoplasts were used as a negative control, microspore protoplasts fixed at the time of isolation as a haploid control, and protoplasts from soybean mesophyll cells (obtained from leaves of the donor plants) as a diploid control.

Results and Discussion

The microspore culture system described by Garda (2018) was optimized for sustained cell divisions by assessing osmoticum, pH, cell density, and phytohormone treatments. High osmoticum interacted with pH (pH 9.0 + 12% sucrose, or pH 5.8 + 2% sucrose were the best treatments; data not shown), but sustained cell divisions occurred across all pH and all osmoticum treatments. The minimum successful cell density required for sustained cell divisions was 338/oz and the maximum tested was 3,380,000/oz. Initial cell divisions occurred but were not sustained in media containing no phytohormones (negative control). Auxin was required to promote sustained cell divisions; 2,4-D, NAA and PIC as auxin each supported sustained cell divisions, with 10 ppm 2,4-D being the best treatment (data not shown). Addition of 0.1 ppm BA as cytokinin stimulated sustained cell divisions. Abscisic acid did not affect cell division. Currently, 100% of cultures exhibit sustained cell divisions using 10 ppm 2,4-D + 0.1 ppm BA.

Flow cytometry demonstrated the haploid state of freshly isolated microspores as placed into culture (Fig. 1), confirming that microspores are being cultured with few or no somatic cells. After 1–2 weeks, some cultures exhibited spontaneous doubling of the chromosomes (Fig. 1). Cultures exhibiting sustained cell divisions also showed higher levels of complexity (Fig. 1). Spontaneous doubling is known to occur in microspore cultures of other species (Lulsdorf et al., 2011; Ferrie and Caswell, 2011). Additional experiments are underway to determine which treatments promote chromosome doubling reliably. The doubled haploid system would be more efficient if chromosome doubling were achieved in cultured cells prior to plant regeneration, eliminating the need to double the chromosomes of the plants.

Optimization for embryo formation involved the manipulation of phytohormones. As shown in Table 1, all three auxins (2,4-D, NAA, PIC) supported embryo formation, but 2,4-D appeared most supportive. The addition of ABA did not promote embryo formation (Table 1). Media including 0.5 – 40 ppm 2,4-D demonstrated the high frequency of embryo development (Table 1). Treatment BNN-1, including 10 ppm 2,4-D + 0.1 ppm BA, yielded the highest number of embryos per individual culture, as well as the most developmentally advanced embryos (data not shown). About 70% of the embryos were observed during the first 2 weeks of culture, and 95% were observed during the initial 4 weeks in culture (Fig. 2). Viability stabilized after 4 weeks in culture (Fig. 3). Embryo development was compared to the *Brassica* model system (Tang et al., 2012), and based on that model a proposed sequence of soybean developmental stages is shown in Fig. 4. Ongoing experiments are focused on generating larger numbers of embryos, especially of the heart-stage embryos (Fig. 4), and on the conversion of these embryos into plants.

Practical Applications

Despite its value, soybean is still subjected to a myriad of biotic and abiotic yield-limiting factors. For example, insects and other biotic pests cause an annual yield loss of 9% in Arkansas and surrounding states (Rupe and Luttrell, 2008). Yield loss estimates due to Frogeye Leaf Spot (*Cercospora sojina*) have been reported as high as 30% across the U.S. (Cropwatch, 2019). Excessive soil salinity, a prevalent abiotic condition in irrigated fields, is capable of negatively impacting plant health and reducing soybean yield by up to 40% (Miransari, 2015; Deshmukh et al., 2014). By application of a soybean doubled haploid platform, breeders can overcome these production challenges by dramatically reducing the time required to develop new cultivars, resulting in increased economic yield for growers. Figure 5 illustrates how these traits can be combined from two parents into one true-breeding elite line in one step using doubled haploid breeding. Accomplishing the same combination of traits by conventional breeding requires 6 to7 backcross generations and multiple years of selection.

Acknowledgments

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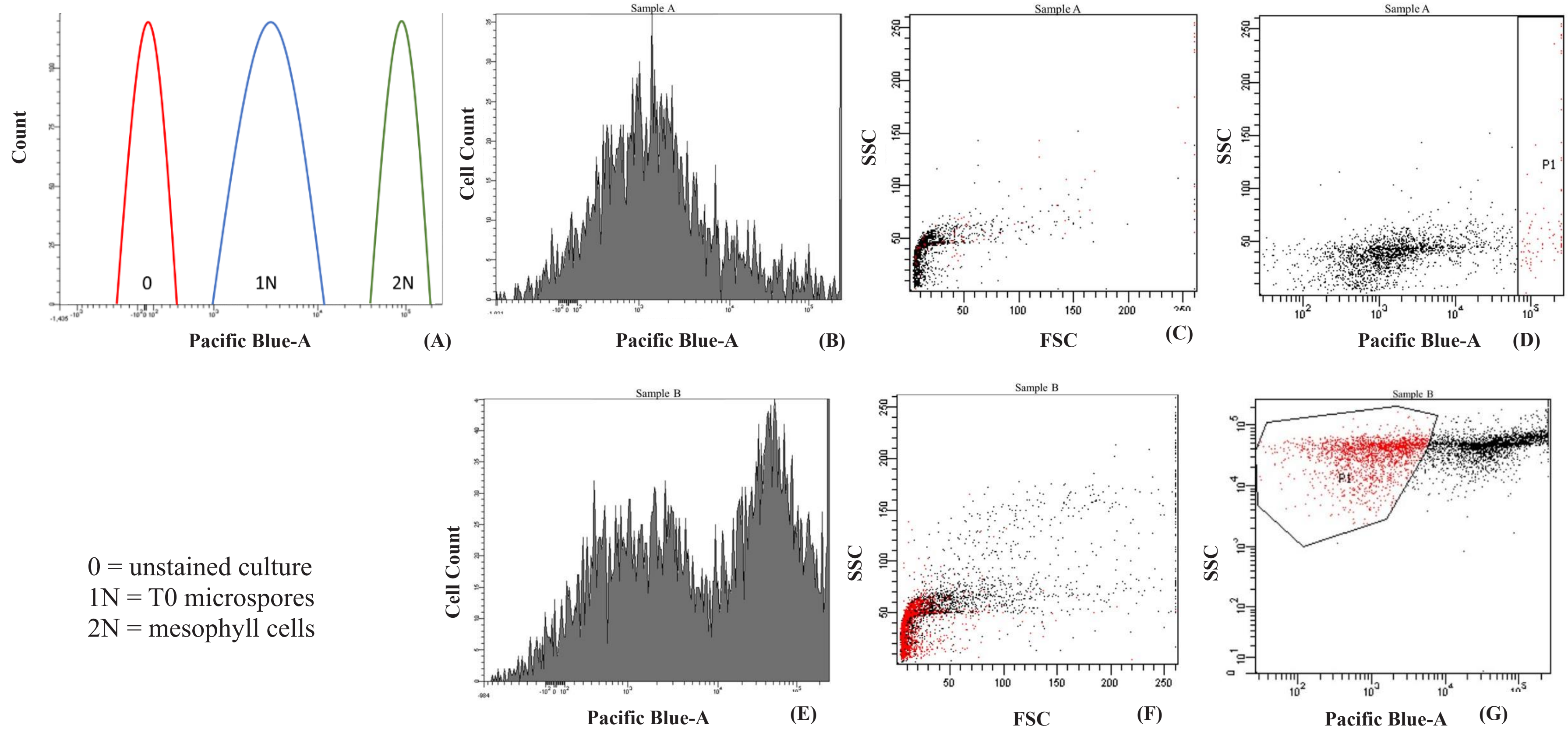

Fig. 1. Flow cytometric analyses of soybean microspores and cultures. (A): Approximate peaks for controls used during flow analysis. 1N are haploid, 2N are diploid. (B)–(D): Flow analysis of a culture in which most microspores are in a haploid state (B). (C) shows the relationship of cell size (*x*-axis) to cell complexity (*y*-axis). (D) is the relationship between ploidy (*x*-axis) and cell complexity (*y*-axis). (E)–(G): Flow analysis of a culture with a population of microspores that have undergone chromosome doubling. Variation of both cell size and complexity is greater when compared to that of the predominantly haploid culture.

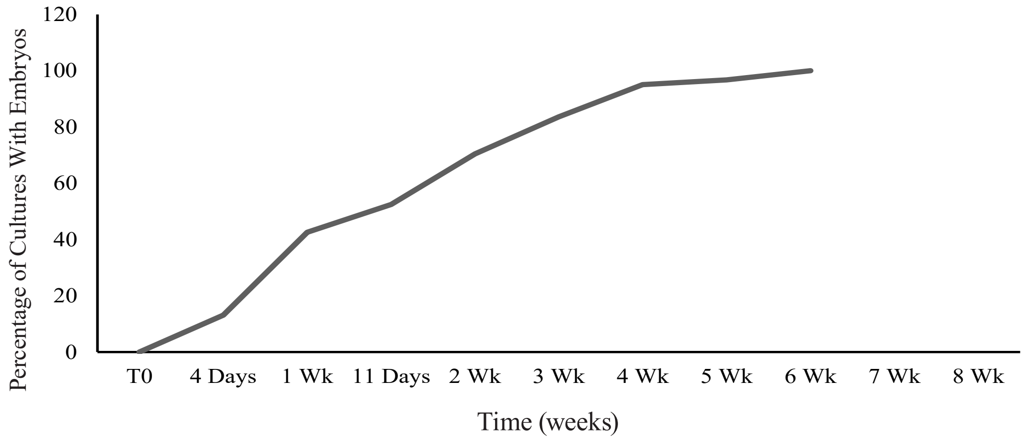

Fig. 2. Time course of embryo observation in the isolated microspore culture system. Approximately 70% of documented embryos are observed within 2 weeks of culture, with 100% being observed within 6 weeks.

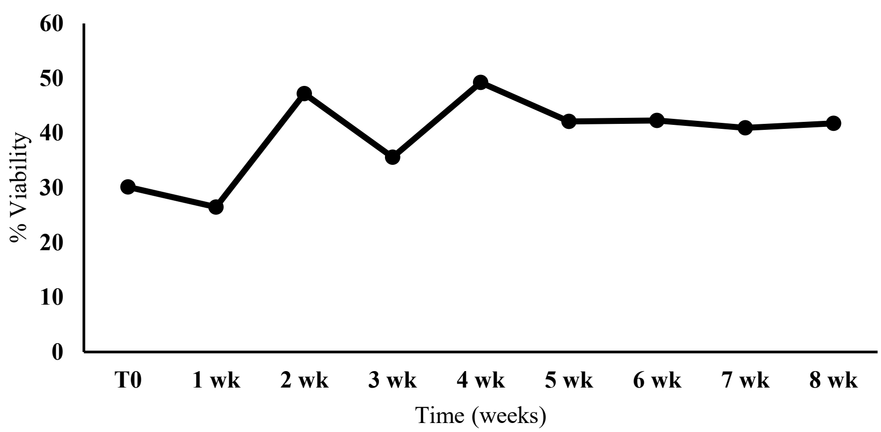

Fig. 3. Viability of isolated microspores over time. Fluctuation is observed for the first 4 weeks, with viability stabilizing between weeks 5 and 6. This correlates with the time in which embryo formation is observed (Fig. 2).

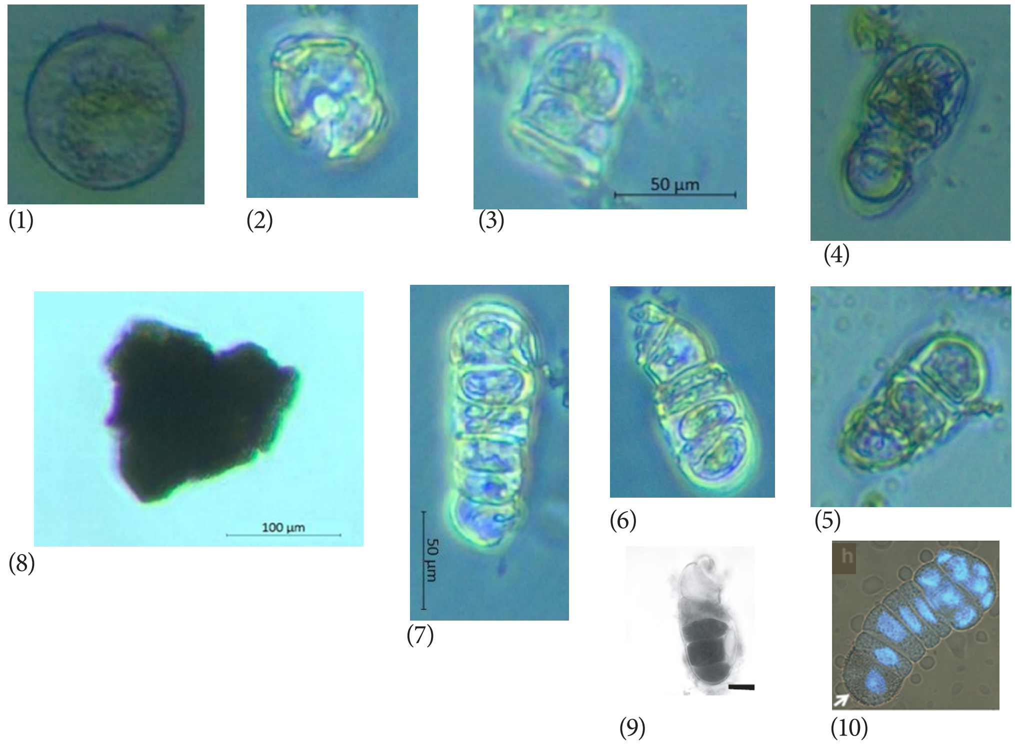

Fig. 4. Proposed stages for microspore embryo development in soybean. Image 1 (top left) is a T0 microspore (0.0014-0.0016 in.). Development progresses from left to right in the upper panes, then from right to left in the second row of panes with image 8 (bottom left) being a heart-shaped embryo (>0.004 in.). Image 9 represents the most advanced microspore-derived structure previously documented from soybean androgenesis (Cardoso et al., 2007), similar to image 6. Image 10 is a well-formed embryo from the model species *Brassica napus* (Soriano et al., 2013), similar to image 7.

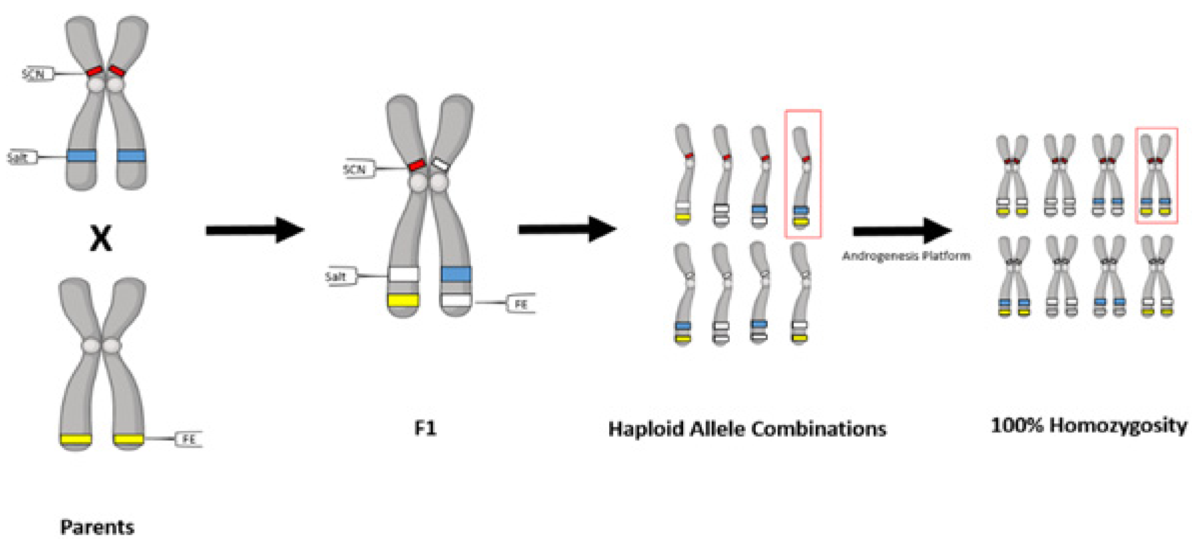

Fig. 5. Soybean doubled haploids have practical applications to plant breeders. Parent 1 has a trait package conferring Soybean Cyst Nematode (SCN) resistance (red) and salinity tolerance (blue). Parent 2 is resistant to Frog Eye Leaf Spot (FE) (yellow). A resulting F_1 population can yield gametes (i.e., microspores) with any of the shown allele combinations (white traits are susceptible). By doubling the chromosome numbers for each gamete, homozygous plants can be generated in one step that combines resistance to SCN and FE and tolerance to salinity. Note that this a conceptual diagram in which all traits are represented on one chromosome for simplicity.

Table 1. Developmental response of soybean microspore cultures using different phytohormone treatment medium.

Treatment	2,4-D	BA	NAA	ABA	Picloram†	Cultures with Embryos	Total Cultures	%
	----------------------ppm---------------------------							
BNN-1	10	0.1	0	0	0	15	20	75.0
BNN-2	0	0.1	0	0	0.06	3	6	50.0
BNN-3	0.25	0.1	2	0	0	3	5	60.0
BNN-4	0	0.1	0	0	0.6	2	5	40.0
BNN-5	5	0.1	0	0	0	13	15	86.7
BNN-6	20	0.1	0	0	0	8	8	100.0
BNN-7	40	0.1	0	0	0	4	5	80.0
BNN-8	0.5	0.1	0	0	0	6	7	85.7
BNN-9	0.05	0.1	0	0	0	3	7	42.9
BNN-10	5	0.1	0	0.1	0	4	6	66.7
					total	61	84	72.6

BA = 6-benzylaminopurine; ABA = abscisic acid; NAA = naphthaleneacetic acid.

Field Efficacy of NemaStrike™ ST to Manage Southern Root-knot Nematode in Arkansas.

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Abstract

Tioxazafen (NemaStrike™ ST) is being marketed as a seed-applied nematicide in soybean. Currently, there is little information on the field efficacy of tioxazafen to control plant-parasitic nematodes in soybean. During the 2018 cropping season, tioxazafen and four other seed-applied nematicides were evaluated in a field with a history of southern root-knot nematode (*Meloidogyne incognita*). In a replicated, small plot trial, there was no reduction of nematode infection by any seed-applied nematicide with an average infection of 28.6% of the root system galled. Similarly, there was no significant yield protection by any seed-applied nematicide with a range of -1.2 to 4.8 bu./ac over the non-treated control (19.9 bu./ac). In the non-replicated strip trial, seed-applied tioxazafen was variable in protecting yield potential on a susceptible soybean cultivar, Asgrow AG 46X7. The benefits of seed-applied nematicides were inconsistent in suppressing root-knot nematode infection (galling) and yield protection at a severe damage threshold. Additional studies are needed to determine the nematode population density at which these nematicides provide consistent root and yield protection.

Introduction

The southern root-knot nematode (*Meloidogyne incognita*) is among the most important plant-parasitic nematodes that affect soybean production in the Southern United States. It has been reported in nearly every soybean-producing county in Arkansas and yield losses greater than 60% have been observed on susceptible soybean cultivars in field trials where nematode population densities were severe (Emerson et al., 2018; Faske et al., 2018). According to the Southern Soybean Disease Workers, the average yield loss estimates due to the southern root-knot nematode in 2018 was reported to be 4.5% or 8.6 million bushels of grain in Arkansas and 1.1% or 13 million bushels of grain across the South (Allen et al., 2019).

Management strategies consist of resistant cultivars, crop rotation with non-host crops and nematicides. Non-fumigant nematicides are commonly applied as a seed treatment in soybean. Since 2011, several seed-applied nematicides have become commercially available, which can be divided into two groups: chemical and biological nematicides. Abamectin (Avicta® 500 FS, Syngenta Crop Protection, Greensboro, N.C.) was registered in 2011 as the first chemical seed-applied nematicide in soybean. Fluopyram (ILeVO®, Bayer CropScience, Research Triangle Park, N.C.) is a succinate dehydrogenase inhibitor (SDHI) fungicide that was registered in 2014 as a seed-applied fungicide and nematicide in soybean. Tioxazafen (NemaStrike™ ST, Monsanto ST, Monsanto Company, St. Louis, Mo.) was registered in 2017 as a seed-applied nematicide in soybean, cotton, and corn. *Bacillus firmus* I-1582 (VOTiVO®, Bayer CropScience, Research Triangle Park, N.C.) was the first commercially available seed-applied bionematicide registered in 2010 in soybean. Other seed-applied bionematicides include heat-killed *Burkholderia rinojensis* A396 (BioST® Nematicide 100, Albaugh LLC, Ankeny, Iowa) that was registered in 2017 for use in cotton, corn, and soybean and *Bacillus amyloliquefaciens* PTA-4838 (Aveo™ EZ Nematicide, Valent USA Corporation, Walnut Creek, Calif.) that was registered in 2017 for use in soybean. Since 2010, there have been six seed-applied nematicides registered for use to manage root-knot nematode in soybean. Thus, there is little information on these seed-applied nematicides including tioxazafen, NemaStrike™ ST. Thus, the objectives of this study were to evaluate the field efficacy of NemaStrike™ ST in a replicated, small plot and non-replicated, strip trials.

Procedures

The field efficacy of NemaStrike™ ST was evaluated in a soybean production field with a history of southern root-knot nematode near Kerr, Ark. This site had a low population density of root-knot nematode (26/100 cm^3 soil) at planting that was previously cropped in corn. Based on the web soil sur-

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vey, the soil series was a Keo silt loam; however, lab analysis classified the soil texture as a sandy loam (58% sand, 40% silt, and 2% clay, and < 1% OM).

Replicated Small Plot Experiment. The root-knot nematode susceptible cultivars, Asgrow 'AG 42X6'and "AG 51X8' were used. A base fungicide treatment of Allegiance® FL (metalaxyl) + Proline® 480 SC (prothioconazole) + Fluoxastrobin ST (fluoxastrobin) (Bayer CropScience, Research Triangle Park, N.C.) was applied at a rate of 0.12 + 0.12 + 0.2 mg ai/seed, respectively. Further, a base insecticide treatment of Gaucho® 600 FS (Bayer CropScience) was applied at a rate of 0.12 mg ai/seed for all treatments, except those treated with a bionematicide, Aveo™ EZ Nematicide (living *B. amyloliquefaciens* PTA-4838; Valent USA Corporation, Walnut Creek, Calif.) and BioST® Nematicide 100 (*B. rinojensis* A396; Albaugh LLC, Ankeny, Iowa). Rates of other products are listed in Table 1 and all seed treatments were applied commercially.

Both cultivars were planted on 29 May at a seeding rate of 150,000 seed/ac. Weeds were controlled in plots based on recommendations by the University of Arkansas System Division of Agriculture's Cooperative Extension Service. This study was furrow irrigated. The experimental design consisted of four, 30-ft-long plots spaced 30-in. apart, separated by a 5-ft fallow alley. Treatments were arranged in a split-plot design with nematicide treatment as the main plot and soybean cultivar as a subplot. Each cultivar by treatment combination was replicated four times. Seedling vigor, phytotoxicity, and stand counts were evaluated on 5 June, 27 days after planting (DAP). Vigor was based on a 1–5 scale with 5 being the best and stand count was seedling per 10 feet of row. Soil samples were collected within each block at planting and harvest. Soil samples were a composite of a minimum of 10 soil cores taken 8 to 10 in. deep with a 0.75-in.-diameter Oakfield soil probe. Vermiform nematodes were collected with a Baermann ring system and enumerated using a stereoscope. To determine nematode infection, ten roots were arbitrarily sampled from rows one and four on 19 July (51 DAP) from each plot. Gall rating was based on the percentage of root system galled. The center two rows of each plot were harvest on 2 October with a K Gleaner combine equipped with a HarvestMaster™ Single BDS HiCap HM800 Weigh System.

Non-replicated Large Plot Experiments. All seed treatments were applied commercially on Asgrow AG 46X7, a root-knot susceptible cultivar. A base fungicide and insecticide treatment of Acceleron® DX-109 (pyraclostrobin) + DX-309 (metalaxyl) + DX-612 (fluxapyroxad) + IX-409 (imidacloprid) (Monsanto Company, St Louis, Mo.) was applied at a rate of 0.0084, 0.0030, 0.0082, and 0.0747 mg ai/seed, respectively. The soybean cultivar was planted on 9 May at the same seeding rate as described previously. The non-replicated strip trials consisted of 8, 450-ft-long plots spaced 30-in. apart, separated by a 5-ft fallow alley Treatments were randomized within each strip, but not replicated. Plots were evaluated visually for vigor and treatment response during the cropping season. A few plants from non-nematicide treated plots were sampled at the R5 growth stage to confirm root-knot nematode susceptibility. Each plot was harvest on 23 October with a K Gleaner combine equipped with a HarvestMaster™ Single BDS HiCap HM800 Weigh System.

Data were subject to analysis of variance (ANOVA) using SPSS 25.0 (SPSS Inc. Chicago, Ill.). Percent root system galled data were arsine transformed [arcsine(square root(x)] to normalize for analysis and non-transformed data are reported. Means when appropriate were separated according to Tukey's honest significant difference (HSD) test at $\alpha = 0.05$.

Results and Discussion

There was no ($P > 0.05$) cultivar by seed-applied nematicide interaction for stand, nematode infection, or yield, thus only the main effects are reported. Stand counts were similar among seed-applied nematicides, so none had a negative effect on seedling emergence. Similarly, the percentage of root system galled at 51 DAP was similar among seed-applied nematicides with the lowest numeric rating of 18.7% observed with NemaStrike™ ST. Galling was similar between cultivars with an average of 30.0%. Grain yield was similar among seed-applied nematicides with the greatest numeric yield observed with ILeVO® + NemaStrike™ ST at 24.7 bu./ac. In comparison to the non-nematicide control, NemaStrike™ ST contributed to 3.2 bu./ac, ILeVO® contributed to 3.3 bu./ac and the combination to 4.8 bu./ac in yield protection. Nematode population densities at harvest averaged 368 J2/100 cm^3 soil in this experiment, which is considered severe for soybean in Arkansas. Water stress caused by root-knot nematodes and drought-like conditions in June and July contributed to significant yield losses in these cultivars.

Field efficacy of NemaStrike™ ST was similar in large non-replicated, strip plots compared to that in the replicated, small plot experiment. Yield protection was either 1 bu./ac greater or 3 bu./ac less than the non-nematicide treated control. Galling at harvest confirmed the susceptibility of AG 46X7 as highly susceptible with >90% of the root system galled. Nematode population densities at harvest averaged 548 and 184 J2/100 cm^3 soil per east and west strip trial, respectively.

These data support the value of small plot research regarding field efficacy of seed-applied nematicide experiments. Further, these experiments provide some insight as to the field performance of NemaStrike™ ST and other seed-applied nematicides in a field with a severe population of southern root-knot nematode.

Practical Applications

Seed-applied nematicides are among the most commonly applied nematicides used in soybean in Arkansas and the mid-South. In this study, the benefit of seed-applied nematicide, specifically NemaStrike™ ST, was variable in protecting soybean yield potential when southern root-knot nematode population density was severe.

Acknowledgments

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Table 1. Field performance of NemaStrike™ ST nematicide and other seed-applied nematicides on two soybean cultivars in a southern root-knot nematode infested field.

	Stand † (27 DAP)	Percent root galling‡ (51 DAP)	Yield§
Cultivar			**(bu./ac)**
Asgrow AG42X6	77.3	30.8	21.1
Asgrow AG51X8	79.5	29.3	22.0
Nematicide treatment and rate			
Non-nematicide treated control	77.1	27.3	19.9
Aveo™ EZ Nematicide (0.2 fl oz/cwt)	80.1	30.5	18.7
BioST® Nematicide 100 (3.0 fl oz/cwt)	79.3	26.9	19.9
ILeVO® (0.075 mg ai/seed)	79.6	35.7	21.2
ILeVO® (0.15 mg ai/seed)	77.1	30.1	23.2
NemaStrike™ ST (0.25 mg ai/seed)	78.5	18.7	23.1
ILeVO® (0.15 mg ai/seed) + NemaStrike™ ST (0.25 mg ai/seed)	78.5	31.0	24.7
Statistics: *P* > F			
Cultivar	0.26	0.93	0.53
Treatment	0.42	0.85	0.23
Cultivar x Treatment	0.13	0.39	0.10

DAP = days after planting.
† Population of plants per 10 ft. of row.
‡ Percent of root system galled by root-knot nematode.
§ Adjusted to 13% moisture.

Table 2. Field performance of NemaSTrike™ ST nematicide in two non-replicated strip trials (East and West) in a southern root-knot infested field.

Nematicide Treatment and Rate	Yield†	
	(bu./ac)	
	East	West
Non-nematicide treated control	27	31 b‡
NemaStrike™ ST (0.25 mg ai/seed)	28	28 ab
Poncho®/VOTiVO® (0.13 mg ai/seed)	28	25 a
P > F	0.20	0.05

† Adjusted to 13% moisture.
‡ Numbers within columns followed by the same letter are not significantly different at $\alpha = 0.05$ according to Tukey's honest significant difference test.

Effect of Seed Treatments and Cover Crops on Soybean Stands and Yields, 2018

J. Rupe[1] *and R. Holland*[1]

The effect of seed treatment and cover crop on soybean stands and yields and on nematode and soil microbial densities was determined at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station in 2018. The cover crops were canola, tillage radish, Indian mustard, vetch, and wheat incorporated into the soil and two cereal rye treatments (one incorporated and one not). Soybean seed (cv. UA 5715GT) was treated with either ApronMaxx® + Vibrance®, ApronMaxx® + Vibrance® + Cruiser®, ApronMaxx® + Vibrance® + Cruiser® + Avicta®, or untreated and planted into each cover crop three weeks after incorporation. The greatest biomass was with the cereal rye treatments and wheat. Poor stands of the other crops limited biomass in 2018. Incorporation of the cover crops increased soil bacterial densities, but reduced densities of fungi and oomycetes. Soybean cyst nematode eggs were significantly lower with all cover crops compared to the fallow pre-incorporation and lowest with canola, wheat, and vetch post-incorporation. All seed treatments resulted in greater stands than the untreated control across cover crops. Yields were not affected by cover crop or seed treatment. The effects of cover crops appear to be cumulative over years.

Introduction

Winter cover crops are increasingly used by growers to control erosion and nutrient runoff from fields. They are also an important management tool to improve soil health by changing the physical, chemical and biological characteristics of the soil. Some cover crops have also been reported to reduce soilborne diseases and plant-parasitic nematodes. Disking-in brassica residues have reduced disease in several crops including soybean (Lodha, et al., 2003, Wen, et al., 2017) and cotton (Bates and Rothrock, 2005). Previous work by Craig Rothrock has found that the Indian mustard (*Brassica juncea*) cv. 'Fumus' suppressed root-knot and reniform nematodes and seedling disease and increased soybean yields. This cultivar of mustard was bred for high levels of glucosinolates which break down to form isothiocyanates that act as biofumigants. In some cases, cover crops can lead to stand failure or damaged seedlings due to increased microbial activity or to phytotoxic chemicals from the decomposition of the cover crops (Acharya, et al.; 2018, Dabney et al., 1996). Some cover crops have increased seedling pathogens, particularly *Fusarium* spp., *Rhizoctonia solani*, and *Pythium* spp., requiring seed treatments to control these diseases (Acharya et al., 2018). There is little information on the role of seed treatments on soybean planted into cover crops. The objective of this study was to determine the effects of cover crops and seed treatments on soybean stands and yields.

Procedures

Four seed treatments were imposed on an established cover crop study at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station. This was the fourth year of the cover crop treatments. The cover crop treatments were canola, tillage radish, Indian mustard, vetch, wheat, and two cereal rye treatments (one soil incorporated and one non-incorporated with soybeans planted no-till). This was the first year for the cereal rye treatments. Before planting, cover crop biomass was taken. Soil samples were taken at biomass termination, five weeks later and at planting. Soil was assayed for general microbial activity. Within each cover crop plot, soybeans with four seed treatments were planted. The seed treatments were ApronMaxx® + Vibrance®, ApronMaxx® + Vibrance® + Cruiser®, ApronMaxx® + Vibrance® + Cruiser® + Avicta®, and untreated. The fungicides ApronMaxx (mefenoxam + fludioxonil) and Vibrance (sedaxane) were applied to the seed at 5 and 1 oz/cwt, respectively. The insecticide Cruiser (thiamethoxam) was applied to seed at 1.3 oz/cwt. The nematicide Avicta (abamectin) was applied to seed at 3.0 oz/cwt. Stand counts were taken two and four weeks after planting and yield was recorded. Soybean cyst nematode densities were determined throughout the season.

Results and Discussion

Biomass varied significantly between cover crops (Table 1). The two cereal rye treatments had the greatest biomass

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followed by wheat. Poor stands of the other cover crops resulted in low biomass accumulation. Across the sampling periods, cover crop had a significant effect on total fungi and total oomycete densities with the greatest densities of both groups found in the vetch treatment. Since the same cover crops had been planted in these plots for four years, changes in the soil microbial community appear to be due to long term cover crop use, not just one season. There was no significant effect of cover crop on the density of total bacteria; however, there was a significant effect of sampling time for all three categories of soil microorganisms. Total fungus and total oomycete densities were highest before cover crops were incorporated (12 April) (Table 2). Total fungus densities remained low for the post-incorporation (17 May) and at planting (8 June); oomycete densities dropped after incorporation, but then rebounded to levels similar to those pre-incorporation at planting. Total bacterial densities were their greatest post-incorporation, but lowest at pre-incorporation and planting. Other studies have reported cover crop termination and incorporation can reduce stands and plant vigor due to increases in pathogen densities and to phytotoxic chemicals produced by the decaying cover crop (Acharya, et al., 2018; Dabney et al., 1996).

Cover crop affected soybean cyst nematode (SCN) egg densities at both pre-incorporation (April) and post-incorporation (May), but not at other sampling times (Table 1). Pre-incorporation, SCN egg densities were highest in the fallow treatment and lower with all cover crop treatments. Post-incorporation, SCN egg densities were highest with cereal rye-non-incorporated and lowest for canola, wheat, and vetch. Other studies have found that cereal rye (Eastburn, 2014) and mustards (Bates and Rothrock, 2005) reduce plant-parasitic nematodes.

Cover crop did not significantly affect stand, but seed treatment did. All seed treatments resulted in significantly greater stands than the untreated seed at four weeks (Table 3). Seedling vigor was greater in the cereal rye non-incorporated treatments than all other cover crop treatments. Since stands from all seed treatments were similar and significantly greater than the untreated, fungi and oomycetes (primarily *Pythium* spp.) appeared to be the primary seedling pathogens. Last year, because of damage due to grape colaspis, seed treatments with Cruiser had significantly greater stands than the untreated or seed treated only with ApronMaxx + Viabrance.

Practical Applications

Cover crops significantly impacted the biotic and abiotic soil environment. These effects appear to be cumulative over the years of cover crop use. Small seeded cover crop species, particularly the mustard and brassica species produced inconsistent stands between years. Cereal rye produced the most biomass this year and has been reported to suppress many pathogens as well as weeds (Eastburn, 2014, Wen et al., 2017). The non-incorporated (no-till) cereal rye treatment also produced more vigorous soybean seedlings due to retained soil moisture that was lost in the other treatments after tillage. Because of the advantages of cereal rye and no-till in retaining soil moisture, future research will focus on the use of a cereal rye cover crop, no-till, and seed treatments on effective soybean production.

Acknowledgments

This research was funded by the Arkansas Soybean Promotion Board and supported in part by the United States Department of Agriculture. We want to thank Station Director Claude Kennedy and Farm Manager Clayton Treat for managing our plots and the Arkansas Nematode Diagnostic Laboratory for processing the nematode samples. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. Effect of cover crop across sampling dates on soil densities† of fungi (cfu/g), oomycetes (cfu/g), soybean cyst nematode (SCN) (eggs/200cc soil), and cover crop biomass (lb/ac) collected at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Ark. 2018.

			SCN eggs		
Cover Crop	**Fungi**	**Oomycetes**	**April**	**May**	**Biomass**
Canola	18,920 b§	406 ab	301 b	186 b	4314 d
Fallow	17,874 b	385 ab	1,173 a	366 ab	499 g
Mustard	20,753 b	362 b	440 b	232 ab	2496 ef
Radish	19,596 b	386 ab	455 b	355 ab	1480 fg
Cereal Rye-Incorp‡	19,111 b	464 ab	539 b	241 ab	13,478 b
Cereal Rye-Noninc	22,140 ab	334 b	492 b	672 a	15,439 a
Vetch	27,593 a	531 a	243 b	184 b	3245 de
Wheat	21,329 b	417 ab	311 b	54 b	8807 c

† Soil microorganisms and nematodes sampled from the upper 15cm of soil from each cover crop plot on April 12, May 17, and June 8, 2018.

‡ Cereal rye was either incorporated into the soil by disking (Incrop) or not incorporated (Noninc) and planted no-till.

§ Means followed by the same letter do not significantly differ.

Table 2. Effect of sample date on soil densities of fungi, oomycetes, and bacteria (cfu/g soil) collected across cover crop treatments at cover crop incorporation (15 April), five weeks after incorporation (17 May), and at planting (8 June) at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Ark., 2018.

Sample Date	Fungi	Oomycetes	Bacteria
12 Apr	25,874 a†	484 a	407,084 b
17 May	17,552 b	291 b	1,143,353 a
8 Jun	19,647 b	477 a	507,491 b

† Means followed by the same letter do not significantly differ.

Table 3. Effect of seed treatment on two week (2 week) and four week (4 week) soybean stands (plants/acre) across cover crop treatments at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Ark. 2018.

	2 week	**4 week**
Seed Treatment†	**Plants/acre**	
Untreated	47,135 b‡	48,785 b
ApronMaxx® + Vibrance®	51,071 a	55,180 a
AppornMaxx + Vibrance + Cruiser®	50,721 a	54,829 a
ApronMaxx + Vibrance + Cruiser + Avicta®	49,662 ab	53,822 a

† Untreated seed were treated with water only, in other treatments, seed were treated with ApronMaxx + Vibrance (mefenoxam + fludioxonil + sedaxane); ApronMaxx + Vibrance + Cruiser (mefenoxam + fludioxonil + sedaxane + thiamethoxam); or ApronMaxx + Vibrance + Cruiser + Avicta (mefenoxam + fludioxonil + sedaxane + thiamethoxam + abamectin). ApronMaxx, Vibrance, Cruiser, and Avicta were applied at 5.0, 1.0, 1.3, and 3.0 oz/cwt, respectively.

‡ Means followed by the same letter do not significantly differ.

Understanding Taproot Decline: A Potentially Yield Limiting Soybean Disease in Arkansas

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

Abstract

Taproot decline (TRD) of soybean is a new, emerging disease with the capability to decrease yield significantly. To understand this disease, distributions of the occurrence of the disease in the soybean production areas of Arkansas were examined at the field level and within the field. The distribution of TRD incidence that has been reported and confirmed in the state to our knowledge, is in 11 counties of the Arkansas delta region. Field distributions are clustered, which is typical of soilborne diseases. It is estimated that yield losses from TRD could range from $6 to $109/ac, using a soybean price of $10.25. Seed treatment fungicide efficacy trials indicate thiabendizole, pyraclostrobin, and thiophanate-methyl products may be efficacious against TRD. A variety trial has also been conducted to identify varietal resistance and/or tolerance if any exist.

Introduction

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

The regional distribution and yield loss in Arkansas are unclear at this time. However, it has been found as far north as Craighead County, and reports from some farmers and consultants indicate yield losses as high as 10 bu./ac in fields. Currently, we do not have seed treatment fungicide or varietal recommendations for growers to combat TRD. The objectives of the following studies were to determine the distribution of TRD across the soybean production areas in Arkansas, determine disease severity on commonly planted varieties, determine the efficacy of fungicide seed treatments against TRD, and to determine the field distribution and yield impact. Understanding the regional distribution, commercially available seed treatment efficacy, and varietal susceptibilities are necessary for the successful management of this disease in Arkansas.

Procedures

All small-plot trials were conducted at the University of Arkansas System Division of Agriculture’s Rohwer Research Station on a silt-loam soil with 38-in. row-spacings and were inoculated. The inoculum was made from twice autoclaved Proso millet inoculated with a locally obtained TRD isolate and shaken daily to disseminate spores for approximately 2 weeks then dried. The inoculum was planted with the seed at a rate of 0.5 g/row-ft using a plot planter. All trials were arranged in a randomized complete block design.

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

Determining Disease Severity on Commonly Planted Varieties. Forty-three varieties were planted into plots 2 rows wide and 10-ft. long at a seeding rate of approximately 100

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seed/row, replicated 3 times. Stand counts and percent emergence data were collected on 18 May 2018 and stand counts repeated 14 June 2018. Before harvest, 10 plants per plot were dug, roots washed, and incidence of taproot decline determined on 13 September 2018. Data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Tukey's honest significant difference (HSD) at $P = 0.10$.

Determining the Efficacy of Seed Treatment Fungicides Against the Disease. A trial was planted in Asgrow 4632 on 4 May 2018. Six seed treatments and 5 in-furrow fungicides were planted into 4-row plots, 20-ft long and replicated 4 times. Plant stand data and percent emergence data were collected on 21 May 2018. Before harvest, 10 plants per plot were dug, roots washed, and incidence of taproot decline determined on 5 September 2018. The trial was harvested on 19 September 2018. Yields were adjusted to 13% moisture content for comparison. Data were subjected to ANOVA followed by means separation of fixed effects using Fisher's protected least significant difference (LSD) at $P = 0.05$.

Determining the Field Distribution and Yield Impact of the Disease in the Field. One hundred points were marked by GPS in a representative area (1–2 acres) in 6 fields with TRD. The number of diseased plants and stand losses was assessed at those points, combined with georeferenced soil of each location and were modeled for incidence and severity and interpolated using ordinary kriging. Individual classes were created, and losses assigned based on yield loss estimates. The maps were textural data collected using Veris (Soil EC 3100, Veris Technologies, Salina, Kan.) and farmer provided yield monitor data. Spatial analysis was used to determine if correlations exist between disease severity, soil factors, and yield loss. Yield data were only available for one field; therefore, the loss was estimated using a proportional vector analysis of symptomatic plants. In ArcMap (ESRI, Redlands, Calif.), the semi-variograms converted to vectors and areas of each polygon calculated. Aggregation statistics were calculated in GeoDa (Center for Spatial Data Science, University of Chicago, Chicago, Ill.).

Results and Discussion

Determining the Distribution Across the Soybean Production Area in Arkansas. The current 11 counties where TRD has been identified in the soybean production areas of Arkansas are shown in Fig. 1.

Determining Disease Severity on Commonly Planted Varieties. Taproot decline was severe with significant stand loss throughout the test. Stand counts were taken 18 May and 14 June 2018. The change in stands ranged from an increase of 31 plants (Armor 48L30) resulting in a 56.5% emergence rate to a loss of 28 plants with GoSoy 5115LL and the lowest emergence rate was 24% with GoSoy 5067LL. Varieties with a lesser incidence in the test were Hefty H47L5 and Progeny P4716LL. The difference in stands from 18 May and 14 June 2018, percent emergence, and the greatest incidence for each treatment (to show the capability of the disease) at harvest are shown in Table 1.

Determining the Efficacy of Seed Treatment Fungicides Against the Disease. The seedling disease caused by the TRD fungus was severe with significant stand loss throughout the test. The only treatment that exhibited phytotoxicity was Topguard Terra®. Both Mertect® 340F (thiabendazole) at 0.64 oz/cwt and Stamina® (pyraclostrobin) at 1.5 fl oz/cwt performed numerically, and sometimes significantly, better than other products tested as well as the untreated controls depending on the variable measured. Topsin® (thiophanate-methyl) at 20 fl oz/ac also had positive results, having lesser incidence than many treatments and having a significantly higher yield than some treatments and the highest yield numerically. Plant stand data, percent emergence assessments, the greatest incidence for each treatment (to show the capability of the disease) and yield are shown in Table 2.

Determining the Field Distribution and Yield Impact of the Disease in Fields. Disease distributions were clustered at all scales ($P = 0.05$). An example of the clustering nature of the field distribution of TRD is shown in Fig. 2. Using data from six fields where TRD had a high incidence, and using a soybean price of $10.25, losses per acre ranged from $6.43 to $109.58, indicating the disease can be destructive in some fields, and efficacious inputs to control disease profitable. In Arkansas, TRD has been found as far north as Craighead County and yield loss determined to be approximately 30% on impacted plants. Additionally, some farmer and consultant reports indicate losses could be as high as 10 bu./ac in some fields.

Practical Applications

From these studies, it is evident that Taproot Decline can be a yield-limiting disease with economic implications. With data from varietal screens documenting TRD severity, and efficacy of various seed treatments, management plans can begin to be made and combined with future data, it may be possible to minimize the impact of this disease.

Acknowledgments

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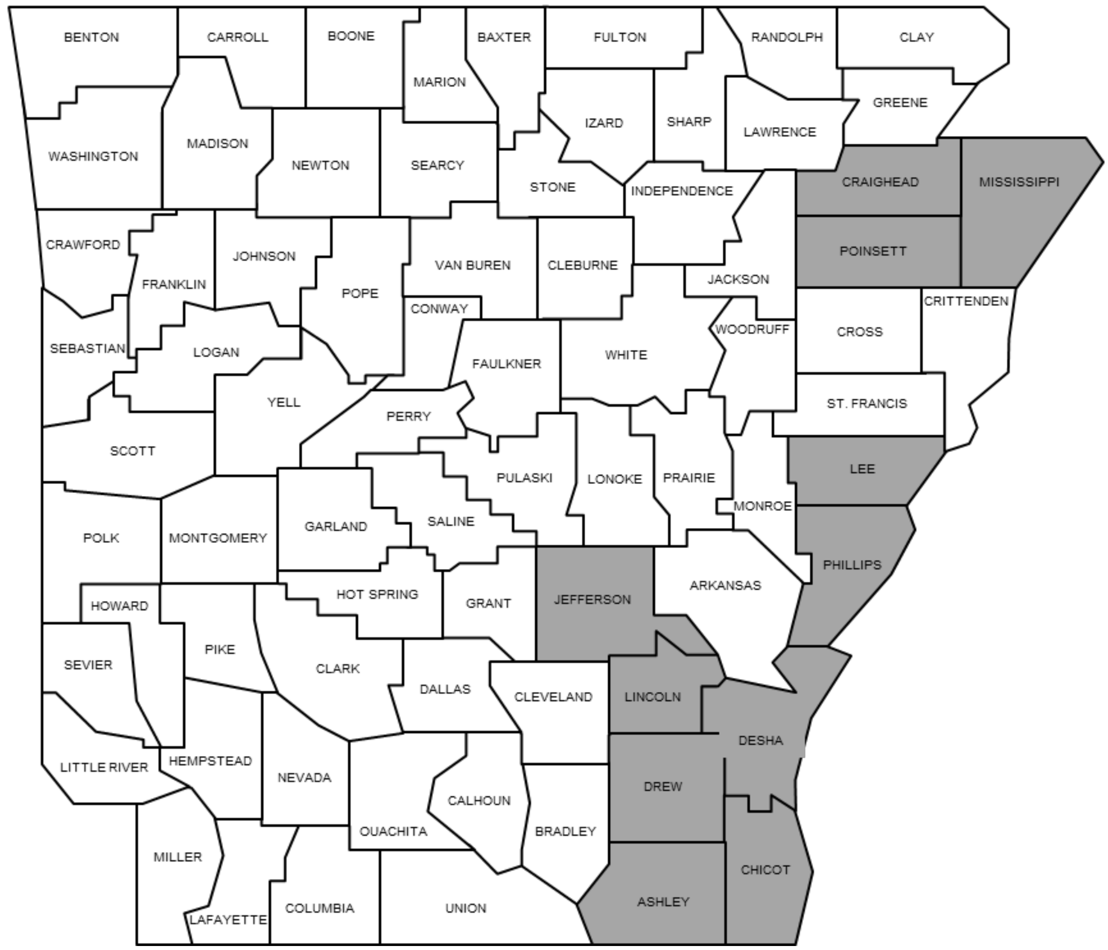

Fig 1. The current county distribution of Taproot decline in the soybean production areas of Arkansas.

Table 1. Taproot decline varietal screening data from the University of Arkansas System Division of Agriculture's Rohwer Research Station in Kelso, Arkansas, 2018.

Variety	14 June Plant Stands	Change in stands 18 May to 14 June	% Emergence[‡]	Greatest Incidence 13 September (0-10)
Armor 44L20	74.3 ab[†]	-4.5 abc	37.2 ab	8
Armor 48L30	62.5 ab	31.0 a	56.5 a	7
CZ 4222 LL	69.0 ab	-4.0 abc	34.5 ab	6
CZ 4540 LL	84.0 ab	21.0 ab	42.0 ab	5
CZ 4748 LL	83.5 ab	0.0 abc	41.8 ab	6
CZ 5147 LL	74.5 ab	12.5 abc	37.3 ab	8
CZ 5150 LL	66.5 ab	-22.5 bc	33.3 ab	5
CZ 5242 LL	71.5 ab	6.0 abc	35.8 ab	6
Delta Grow DG4781 LL	83.3 ab	-4.0 abc	41.7 ab	7
Delta Grow DG4967 LL	58.7 ab	2.0 abc	29.3 ab	8
Delta Grow DG5067 LL	48.0 b	-23.0 abc	24.0 b	7
Dyna-Gro S45LL97	84.5 ab	6.5 abc	42.3 ab	8
Dyna-Gro S49LL34	100.0 ab	10.5 abc	50.0 ab	7
Dyna-Gro S55LS75	76.5 ab	-4.5 abc	38.3 ab	6
GoSoy 43L16	76.7 ab	16.3 abc	38.3 ab	10
GoSoy 49L17	62.3 ab	7.0 abc	31.2 ab	10
GoSoy 5115LL	63.5 ab	-28.0 c	31.8 ab	10
GoSoy 56C16	74.3 ab	-12.7 abc	37.2 ab	10
GoSoy Ireane	54.0 b	0.0 abc	27.0 ab	5
GoSoy Leland	78.7 ab	6.0 abc	39.3 ab	9
HBK LL 4950	79.7 ab	0.7 abc	39.8 ab	7
HBK LL 4953	75.0 ab	-9.3 abc	37.5 ab	7
Hefty H47L5	98.5 ab	22.0 ab	49.3 ab	4
Hefty H48L3	93.0 ab	16.5 abc	46.5 ab	5
JTN-5110	87.7 ab	-6.0 abc	43.8 ab	7
Osage	101.0 ab	9.0 abc	50.5 ab	7
Pfister 48RS01	85.7 ab	-6.7 abc	42.8 ab	8
Pioneer P50T78L	77.7 ab	6.0 abc	38.8 ab	6
Progeny P4247LL	79.7 ab	-6.3 abc	39.8 ab	8
Progeny P4716LL	70.5 ab	-0.5 abc	35.3 ab	4
Progeny P4930LL	97.0 ab	-16.0 abc	48.5 ab	5
Progeny P5414LLS	92.0 ab	7.7 abc	46.0 ab	9
Progeny P5623LL	66.7 ab	-7.3 abc	33.3 ab	7
REV 45L57	80.7 ab	-3.0 abc	40.3 ab	6
REV 48A26	70.0 ab	13.0 abc	35.0 ab	9
REV 48L63	75.3 ab	-6.7 abc	37.7 ab	8
REV 49L88	57.0 ab	-11.0 abc	28.5 ab	8
S13-10590C	81.5 ab	6.5 abc	40.8 ab	7
S13-1805C	99.0 ab	19.5 abc	49.5 ab	5
S14-6391C	78.5 ab	16.0 abc	39.3 ab	5
UA 5014C	61.0 ab	-15.0 abc	30.5 ab	10
UA 5814HP	94.0 ab	10.0 abc	47.0 ab	7
USG Ellis	69.5 ab	10.5 abc	34.8 ab	7

[†] Columns followed by the same letter are not statistically significant at $P = 0.05$ as determined by Tukey's honest significant difference.

[‡] Percent emergence calculated by dividing plant stand by planting rate.

Table 2. Fungicide seed treatment efficacy against taproot decline from the University of Arkansas System Division of Agriculture's Rohwer Research Station located in Kelso, Arkansas, 2018.

Treatment and Rate	Plant Stands 21 May	% Emergence 21 May[‡]	Greatest Incidence 5 September (0-10)	Yield (bu./ac)[§]
Acquire 0.75 fl oz/cwt	102.3 ab[†]	55.0 ab	10	41.8 bc
Headline 10.8 fl oz/ac	85.3 b	43.8 b	10	44.2 ab
Ilevo 2 fl oz/cwt	90.8 b	41.3 b	8	47.3 ab
Mertect 0.64 fl oz/cwt	134.3 a	68.8 a	8	50.5 ab
Ridomil 3.7 fl oz/ac	83.5 b	45.0 b	8	42.2 b
Sercadis 4.4 fl oz/ac	102.3 ab	57.5 ab	8	49.6 ab
Stamina 1.5 fl oz/cwt	141.8 a	70.0 a	9	50.8 ab
Topguard Terra 8 fl oz/ac	24.8 c	15.3 c	4	27.0 c
Topsin 20 fl oz/ac	108.8 ab	55.0 ab	5	58.8 a
Untreated	107.3 ab	57.5 ab	9	41.0 bc
Vibrance 0.16 fl oz/cwt	102.0 ab	53.8 ab	5	40.9 bc
Vortex 0.17 fl oz/cwt	116.5 ab	55.0 ab	9	43.5 b

[†] Columns followed by the same letter are not statistically significant at $P = 0.05$ as determined by Fisher's protected least significant difference.
[‡] Percent emergence calculated by dividing plant stand by planting rate.
[§] Yields adjusted to 13% moisture content for comparison.

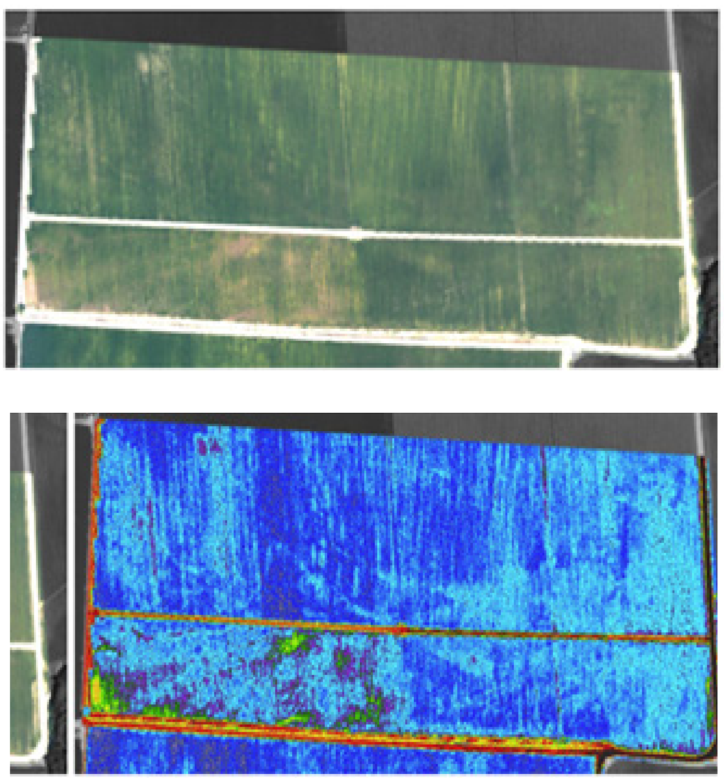

Fig. 2. Aerial images showing the aggregated nature of Taproot decline in fields near Mitchellville, Ark., in Desha Co. The image on top is a visual of the defoliation caused by the disease. The image on the bottom is an NDVI where light blue to green pixels indicate the extent of the disease.

Assessment of Target Spot, Frogeye Leaf Spot, Cercospora Leaf Blight, and Taproot Decline on Soybean in Arkansas

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

Abstract

Soybean is host to many fungal pathogens. These pathogens range in scope from insignificant to major yield reducers. The excess precipitation in August of 2018 provided the conducive environment needed for several pathogens that are common in Arkansas soybean production to cause increased damage. Eight inches of rainfall occurred in August at the University of Arkansas System Division of Agriculture's Rohwer Research Station where a varietal screen was located. These favorable conditions contributed to ratable amounts of Target spot (*Corynespora cassiicola*), Frogeye leaf spot (*Cercospora sojina*), Cercospora leaf blight (*Cercospora* spp.), and Taproot decline (*Xylaria* sp.). Soybean varieties included in this trial ranged in maturity groups from 3.6 – 6.2 and consisted of conventional soybeans and glyphosate, glufosinate, dicamba, and acetolactate synthase inhibitor resistant/tolerant varieties.

Introduction

Target spot (TS) is caused by the fungal pathogen *Corynespora cassiicola*. Target spot can be found on nearly all plant parts but is most commonly found on leaves in the lower canopy. The fungus presents as reddish-brown lesions with a yellow halo, and often with concentric rings within more mature lesions that lend to the disease's name (Mueller et. al., 2016).

Frogeye leaf spot (FLS), caused by the fungus *Cercospora sojina* can infest many plant parts but is most commonly seen during the reproductive growth stages of the plant on newly developed leaves. The disease presents as small irregular to circular shaped lesions with purple borders and light grey to brown centers. In severe cases, lesions will coalesce forming larger lesions and can cause defoliation (Mueller et. al., 2016).

Cercospora leaf blight (CLB) can be caused by multiple *Cercospora* spp. The disease infects the plant in the early vegetative stages, but symptomology does not appear until the later reproductive stages. The disease presents as a purpling of the upper leaves progressing to a leathery appearance and bronze coloring (Mueller et. al., 2016).

Taproot decline (TRD) is caused by an undescribed fungus in the genus *Xylaria* (Allen et. al, 2017). The disease presents in early vegetative stages as chlorotic or dead plants located in clusters or streaks. Additionally, in areas of symptomatic plants, gaps in plant stands are evident with mummies of dead plants between the chlorotic plants. When dead plants from TRD are extracted from the soil, the taproot will be malformed and black, if present. In the latter reproductive stages (R5 +, beginning seed development) the disease has a "leopard spot" or "sanded" appearance. As the disease progresses, above-ground symptoms include stunting and interveinal chlorosis leading to necrosis. When a plant infested with TRD is pulled from the soil at this growth stage, the taproot will often break off and have a black coating of stroma. Splitting the root or lower stem longitudinally reveals mild vascular staining, and often white mycelia are seen growing up the pith. Fungal fruiting structures referred to as "dead man's fingers" can sometimes be found in the residue from the previous year's crop as well.

All four of the diseases require free moisture (dew, rain, high humidity) for an extended period (several hours) to reproduce. Also, all of these diseases overwinter on crop debris. Therefore, the best management practices for all diseases include resistant varieties (known resistances exist for FLS and CLB), crop rotation to a non-host, tillage, and fungicide applications. Foliar fungicide applications, however, are not an option for Taproot decline, as it is a soilborne disease. Additionally, resistant populations to strobilurins exist for FLS and CLB, and fungicide applications for Target spot are often ineffective as the disease develops in the lower canopy and it is difficult to get proper fungicide coverage in the lower canopy.

Procedures

The trial was established at the University of Arkansas System Division of Agriculture's Rohwer Research Station in Kelso, Ark. in a Herbert silt-loam soil. The trial was

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planted on 24 May on 38-in. row-spacing with plots 2-rows wide and 10-ft. long. The seeding rate was 100 seed/plot. Stand counts were taken 7 June by counting all plants per plot. Disease severity assessments were taken 16 August using a percentage scale where 0 = no disease and 100 = dead plants. The trial was harvested 22 October with a plot combine. Yield data were adjusted to 13% moisture content for comparison. Data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Tukey's honest significant difference (HSD) at $P = 0.10$.

Results and Discussion

In the 3.6–4.4 maturity group (MG) (Table 1), yield was the only statistically significant variable ranging from 25.7 to 60.4 bu./ac. In the 4.5 MG (Table 2), both stands and yield had significant differences with stands ranging from 23–64 plants/plot and yields ranging from 28–57 bu./ac. Table 3 shows MGs 4.6–4.7 and no significant differences were seen. In Table 4, TRD shows statistical significance in the 4.8 MG ranging from 0–1% severity. In Table 5, MG 4.9 is shown with no significant differences. Plant stands, CLB, and Target spot all show significant differences in MGs 5.0–5.2. These data are shown in Table 6 with stands ranging from 17–69 plants/plot, CLB severity ranging from 1–7%, and TS severity ranging from 1–6%. Table 7 shows MGs 5.3–6.2 and has significant differences in plant stands ranging from 22–56 plants/plot and TS ranging from 1–6% severity.

Practical Applications

The potential for disease in soybeans is great, given a conducive environment. Soybean breeders are constantly developing new varieties with resistance genes and greater yield potential. It is important that farmers know how a variety will perform in the presence of a pathogen and a conducive environment for disease, particularly in areas with a history of a disease. These results can assist farmers in variety selection and can help minimize yield loss due to the pathogens included in this data set.

Acknowledgments

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Table 1. Soybean maturity groups 3.6–4.4 plant stand data 14 days after planting, percent Target spot (TS), Cercospora leaf blight (CLB), Frogeye leaf spot (FLS), and Taproot decline (TRD) severity, where 0 = no disease, and 100 = dead plants, and yield adjusted to 13% at the University of Arkansas System Division of Agriculture's Rohwer Research Station, 2018.

Variety	MG	Tech.	Stand	TS	CLB	FLS	TRD	Yield
Credenz CZ3601LL	3.6	LL	33	3	1	1	0	47 ab†
Credenz CZ3737LL	3.7	LL	41	4	1	1	0	45 ab
CZ3841LL	3.8	LL	49	2	2	1	0	44 ab
Armor 39-D39	3.9	Xtend	36	3	1	3	0	26 b
NKS 39-R9X	3.9	Xtend	31	4	1	5	1	49 ab
Credenz CZ4044LL	4.0	LL	25	2	2	3	1	38 ab
Armor X40D	4.0	Xtend	33	6	4	1	0	47 ab
Eagle Seed ES4060RYX	4.0	Xtend	31	3	5	2	0	52 ab
S13-2743C	4.1	Conv.	52	1	3	1	0	44 ab
Armor X41D	4.1	Xtend	29	2	1	1	0	45 ab
GDM1	4.1	Xtend	26	3	4	2	0	47 ab
Dyna-Gro S41XS98	4.1	Xtend/STS	50	3	4	1	0	50 ab
Credenz CZ4222LL	4.2	LL	33	5	2	5	0	46 ab
Progeny P4247LL	4.2	LL	46	5	2	1	0	47 ab
Armor 42-D27	4.2	Xtend	30	3	2	1	0	41 ab
Asgrow AG42X9	4.2	Xtend	40	5	4	1	0	40 ab
Eagle Seed ES4211RYX	4.2	Xtend	25	5	3	3	0	44 ab
Progeny P4255RX	4.2	Xtend	32	3	3	2	0	40 ab
S13-10590C	4.3	Conv.	39	2	3	1	0	40 ab
GoSoy 43C17S	4.3	Conv./STS	46	1	2	1	0	39 ab
Credenz CZ4308LL	4.3	LL	40	6	3	1	0	42 ab
Delta Grow DG45X35	4.3	RR	43	3	1	3	0	55 a
Armor X43D43	4.3	Xtend	33	3	4	2	0	51 ab
Asgrow AG43X8	4.3	Xtend	31	4	1	1	0	41 ab
Hefty H43X8	4.3	Xtend	39	4	3	1	0	45 ab
NK S43-V3X	4.3	Xtend	27	3	3	1	0	45 ab
Progeny P4318RX	4.3	Xtend	29	3	3	1	0	36 ab
Dyna-Gro S43XS27	4.3	Xtend/STS	20	3	3	3	0	56 a
Local Seed LS4388X	4.3	Xtend/STS	17	3	1	1	0	58 a
Local Seed AV44U4LL	4.4	LL	30	5	2	4	0	48 ab
Pioneer P44A08L	4.4	LL	45	3	2	2	1	45 ab
AgriGold G4440RX	4.4	Xtend	30	3	5	2	0	46 ab
Armor X44D36	4.4	Xtend	29	5	2	1	0	48 ab
Delta Grow DG44X25	4.4	Xtend	31	3	4	1	0	60 a
Delta Grow DG44X50	4.4	Xtend	31	6	3	1	0	39 ab
Eagle Seed ES4460RYX	4.4	Xtend	33	5	2	3	0	37 ab
Mission A4447NXSR2	4.4	Xtend	25	1	2	1	0	41 ab
Progeny P4444RXS	4.4	Xtend/STS	35	4	3	1	0	39 ab

† Columns followed by the same letter are not statistically significant at $P = 0.10$ as determined by Tukey's honest significant difference.

Table 2. Soybean maturity group 4.5 plant stand data 14 days after planting, percent Target spot (TS), Cercospora leaf blight (CLB), Frogeye leaf spot (FLS), and Taproot decline (TRD) severity, where 0 = no disease, and 100 = dead plants, and yield adjusted to 13% at the University of Arkansas System Division of Agriculture's Rohwer Research Station, 2018.

Variety	MG	Tech.	Stand	TS	CLB	FLS	TRD	Yield
GDM5	4.5	Conv.	64 a†	1	3	3	0	56 a†
GoSoy E4510S	4.5	Conv./STS	54 ab	3	2	1	0	50 ab
Credenz CZ4540LL	4.5	LL	29 ab	3	2	2	1	54 a
Credenz CZ4548LL	4.5	LL	36 ab	2	1	1	0	57 a
Delta Grow DG4587LL/STS	4.5	LL/STS	35 ab	3	1	1	0	46 ab
AgriGold G4579RX	4.5	Xtend	29 ab	5	4	1	0	43 ab
Armor X45D50	4.5	Xtend	40 ab	5	2	1	1	28 b
Asgrow AG45X8	4.5	Xtend	27 ab	3	2	3	0	49 ab
Dyna-Gro SX18845XT	4.5	Xtend	36 ab	2	4	1	0	49 ab
Hefty H45X8	4.5	Xtend	37 ab	4	4	4	0	43 ab
LG LGS4597RX	4.5	Xtend	34 ab	3	1	3	0	41 ab
Local Seed AV45U1X	4.5	Xtend	30 ab	4	3	1	0	40 ab
Local Seed LS4583X	4.5	Xtend	33 ab	2	3	1	0	50 ab
NK S45-J3X	4.5	Xtend	24 b	2	5	1	0	42 ab
NK S45-K5X	4.5	Xtend	29 ab	4	3	2	0	47 ab
Pioneer P45A19X	4.5	Xtend	29 ab	4	3	3	0	43 ab
Dyna-Gro S45XS37	4.5	Xtend/STS	27 ab	2	1	1	0	39 ab
Dyna-Gro S45XS66	4.5	Xtend/STS	32 ab	5	2	1	0	37 ab
Local Seed LS4565XS	4.5	Xtend/STS	24 b	4	1	1	1	58 a
NK S45-Z5XS	4.5	Xtend/STS	25 b	4	4	1	0	48 ab
Progeny P4570RXS	4.5	Xtend/STS	23 b	5	4	1	0	45 ab

† Columns followed by the same letter are not statistically significant at $P = 0.10$ as determined by Tukey's honest significant difference.

Table 3. Soybean maturity groups 4.6–4.7 plant stand data 14 days after planting, percent Target spot (TS), Cercospora leaf blight (CLB), Frogeye leaf spot (FLS), and Taproot decline (TRD) severity, where 0 = no disease, and 100 = dead plants, and yield adjusted to 13% at the University of Arkansas System Division of Agriculture's Rohwer Research Station, 2018.

Variety	MG	Tech.	Stand	TS	CLB	FLS	TRD	Yield
R15-818	4.6	Conv.	41	3	2	2	0	40
Credenz CZ4649LL	4.6	LL	30	4	1	1	1	47
REV46L99	4.6	LL	26	4	5	1	0	45
GDM7	4.6	RR	27	4	3	5	0	46
Pioneer P46A16R	4.6	RR1	42	3	3	3	0	44
Delta Grow DG4670RR2	4.6	RR2	31	3	5	1	0	49
AgriGold G4605RX	4.6	Xtend	51	5	3	3	0	44
AGS GS46X17	4.6	Xtend	48	3	3	1	0	48
Armor X46D63	4.6	Xtend	47	3	3	2	0	35
Asgrow AG46X6	4.6	Xtend	44	5	1	1	1	47
Delta Grow DG46X25	4.6	Xtend	44	1	3	1	0	39
Eagle Seed ES4680RYX	4.6	Xtend	29	5	2	1	0	42
LG LGS4624RX	4.6	Xtend	39	3	3	4	1	49
Local Seed LS4677X	4.6	Xtend	51	5	1	1	0	52
Local Seed LS4689X	4.6	Xtend	31	5	2	2	0	46
Mission A4637NSXR2	4.6	Xtend	26	6	3	1	0	47
Mission MEX4608	4.6	Xtend	27	6	3	1	0	40
Mission MEX4618	4.6	Xtend	35	1	4	1	0	46
Pioneer P46A57BX	4.6	Xtend	27	4	2	1	0	45
REV4679X	4.6	Xtend	30	5	3	3	0	55
Hefty H46X6	4.6	Xtend/STS	39	2	3	1	0	42
Progeny P4620RXS	4.6	Xtend/STS	34	2	2	1	0	55
GDM6	4.7	Conv.	42	4	1	1	0	40
R15-1150	4.7	Conv.	47	6	4	1	0	38
R15-2422	4.7	Conv.	37	4	3	1	0	37
Credenz CZ4748LL	4.7	LL	36	2	1	1	0	52
Local Seed AV47W3LL	4.7	LL	41	3	1	6	0	51
Pioneer P47A76L	4.7	LL	21	6	3	1	1	47
REV47L38	4.7	LL	29	2	2	1	0	43
Eagle Seed ES4777RR	4.7	RR1	27	4	3	1	1	32
S14-9051R	4.7	RR1	22	4	2	1	0	42
Petrus Seed 479GTS	4.7	RR1/STS	46	5	3	1	0	29
Delta Grow DG4790RR2	4.7	RR2	31	4	2	1	0	33
Armor X47D22	4.7	Xtend	52	4	5	1	0	46
Asgrow AG47X9	4.7	Xtend	42	3	2	1	0	50
LG C4710RX	4.7	Xtend	45	4	2	3	0	46
Local Seed AV47W2X	4.7	Xtend	27	3	3	1	0	51
Progeny P4799RXS	4.7	Xtend/STS	27	3	2	1	0	40

Table 4. Soybean maturity group 4.8 plant stand data 14 days after planting, percent Target spot (TS), Cercospora leaf blight (CLB), Frogeye leaf spot (FLS), and Taproot decline (TRD) severity, where 0 = no disease, and 100 = dead plants, and yield adjusted to 13% at the University of Arkansas System Division of Agriculture's Rohwer Research Station, 2018.

Variety	MG	Tech	Stand	TS	CLB	FLS	TRD	Yield
Credenz CZ4820LL	4.8	LL	29	5	3	3	0 b[†]	45
Delta Grow DG4880	4.8	RR1	38	4	1	1	0 b	47
Delta Grow DG4970	4.8	RR1	43	3	1	1	0 b	40
AGS GS48X18	4.8	Xtend	41	5	2	1	0 b	38
Armor X48D02	4.8	Xtend	33	5	2	4	0 b	42
Croplan RX4825	4.8	Xtend	28	7	4	1	0 b	32
Delta Grow DG48X45	4.8	Xtend	23	4	2	1	0 b	39
Dyna-Gro S48XT56	4.8	Xtend	22	3	3	3	0 ab	44
Eagle Seed ES4840RYX	4.8	Xtend	34	5	1	1	1 ab	49
Eagle Seed ES4870RYX	4.8	Xtend	40	8	3	4	0 b	30
GDM2	4.8	Xtend	34	6	1	5	0 b	50
Hefty H48X7	4.8	Xtend	33	6	3	1	0 b	44
LG C4845RX	4.8	Xtend	39	5	4	1	0 b	40
Mission MEX4808	4.8	Xtend	37	4	2	3	0 ab	42
Pioneer P48A60X	4.8	Xtend	27	5	1	1	0 ab	43
Progeny P4851RX	4.8	Xtend	29	5	4	2	0 b	43
REV 4857X	4.8	Xtend	39	3	3	3	0 ab	52
Asgrow AG 48X9	4.8	Xtend/SR	38	2	2	1	0 b	45
Dyna-Gro S48XS78	4.8	Xtend/STS	34	5	5	1	0 b	52
Local Seed LS4889XS	4.8	Xtend/STS	26	5	5	1	0 b	38
USG 7487XTS	4.8	Xtend/STS	26	2	3	2	1a	46
USG 7489XTS	4.8	Xtend/STS	34	2	2	1	0 ab	43

[†] Columns followed by the same letter are not statistically significant at $P = 0.10$ as determined by Tukey's honest significant difference.

Table 5. Soybean maturity group 4.9 plant stand data 14 days after planting, percent Target spot (TS), Cercospora leaf blight (CLB), Frogeye leaf spot (FLS), and Taproot decline (TRD) severity, where 0 = no disease, and 100 = dead plants, and yield adjusted to 13% at the University of Arkansas System Division of Agriculture's Rohwer Research Station, 2018.

Variety	MG	Tech	Stand	TS	CLB	FLS	TRD	Yield
GoSoy Ireane	4.9	Conv.	36	3	4	1	1	46
Credenz CZ4918LL	4.9	LL	42	4	1	1	0	48
Credenz CZ4938LL	4.9	LL	40	5	1	1	0	36
Delta Grow DG4967LL	4.9	LL	44	4	1	4	0	49
Dyna-Gro 49LL34	4.9	LL	33	4	1	1	0	39
Progeny P4930LL	4.9	LL	34	2	2	1	0	47
REV49L88	4.9	LL	47	4	2	2	0	43
Delta Grow DG4977LL/STS	4.9	LL/STS	48	5	1	1	0	39
Eagle Seed ES4998RR	4.9	RR1	44	5	4	1	1	38
GoSoy 49G16	4.9	RR1	54	4	2	1	1	56
Petrus 4916 GTS	4.9	RR1	34	3	2	1	0	48
TN16-520R1	4.9	RR1	40	5	4	1	0	45
AgriGold G4995RX	4.9	Xtend	36	5	3	1	0	44
Armor X49D31	4.9	Xtend	26	5	1	1	0	44
Croplan RX4927	4.9	Xtend	28	1	2	1	0	46
Croplan RX4928	4.9	Xtend	39	6	3	3	0	39
Dyna-Gro S49XT39	4.9	Xtend	33	3	2	3	0	45
GDM3	4.9	Xtend	29	5	4	2	0	40
LG LGS4989RX	4.9	Xtend	36	3	3	3	1	49
Local Seed AV49W3X	4.9	Xtend	22	5	4	1	0	51
Local Seed LS4966X	4.9	Xtend	19	4	6	1	0	45
Local Seed LS4988X	4.9	Xtend	39	5	2	1	0	40
Mission MEX4908	4.9	Xtend	29	4	1	1	0	43
Progeny P4816RX	4.9	Xtend	28	2	4	2	0	39
Progeny P4955RX	4.9	Xtend	31	3	3	1	0	43
Progeny P4994RX	4.9	Xtend	43	4	2	2	0	42
REV4927X	4.9	Xtend/SR	42	4	2	3	0	40
Asgrow AG49X9	4.9	Xtend/STS	20	2	2	2	0	48
Dyna-Gro S49XS76	4.9	Xtend/STS	29	5	1	1	0	40
Hefty H49X7S	4.9	Xtend/STS	23	5	3	2	1	57
Local Seed LS4968XS	4.9	Xtend/STS	31	7	4	3	0	56
USG7777496XTS	4.9	Xtend/STS	32	5	4	1	0	48

Table 6. Soybean maturity groups 5.0–5.2 plant stand data 14 days after planting, percent Target spot (TS), Cercospora leaf blight (CLB), Frogeye leaf spot (FLS), and Taproot decline (TRD) severity, where 0 = no disease, and 100 = dead plants, and yield adjusted to 13% at the University of Arkansas System Division of Agriculture's Rohwer Research Station, 2018.

Variety	MG	Tech	Stand	TS	CLB	FLS	TRD	Yield
GoSoy Leland	5.0	Conv.	41 a-d†	2 ab	4 ab	3	0	41
NSGAAAAA DS5018	5.0	Conv.	55 abc	1 b	3 ab	1	0	49
Pioneer P50A78L	5.0	LL	52 abc	4 ab	1 b	1	0	35
GoSoy 50G17	5.0	RR1	30 cd	4 ab	1 b	2	0	45
AgriGold G5000RX	5.0	Xtend	42 a-d	5 ab	2 ab	3	1	47
ArmorX50D13	5.0	Xtend	28 cd	5 ab	4 ab	5	0	39
Delta Grow DG52X15	5.0	Xtend	17 d	3 ab	1 b	2	0	53
Local Seed LS5087X	5.0	Xtend	38 a-d	3 ab	3 ab	1	0	50
NK S50-G9X	5.0	Xtend	37 a-d	2 ab	3 ab	1	0	45
Progeny P5018RX	5.0	Xtend	44 a-d	5 ab	4 ab	1	1	50
Progeny P5016RXS	5.0	Xtend	25 cd	4 ab	3 ab	1	1	46
GoSoy 51C17	5.1	Xtend/STS	57 abc	3 ab	3 ab	2	0	46
R13-13997	5.1	Conv.	51 a-d	1 b	2 ab	1	0	47
R15-1587	5.1	Conv.	46 a-d	2 ab	2 ab	1	0	50
Credenz CZ5147LL	5.1	LL	43 a-d	1 ab	2 b	1	0	48
Credenz CZ5150LL	5.1	LL	39 a-d	5 ab	1 b	1	0	46
Local Seed AV51W1LL	5.1	LL	33 bcd	4 ab	2 ab	0	0	48
R15-2465RR	5.1	RR1	35 bcd	6 ab	7 a	2	1	23
Delta Grow DG5170RR2	5.1	RR2	35 a-d	3 ab	3 ab	4	0	55
Armor X51D77	5.1	Xtend	24 cd	5 ab	1 b	3	0	51
AGS GS51X18	5.1	Xtend/STS	44 a-d	5 ab	3 ab	3	0	43
R13-1409	5.2	Conv.	65 ab	2 ab	1 b	2	0	55
R14-356	5.2	Conv.	69 a	1 b	2 ab	1	0	41
R15-1194	5.2	Conv.	38 a-d	2 ab	2 b	1	0	38
Credenz CZ5225LL	5.2	LL	44 a-d	1 ab	3 ab	1	1	43
R12-6751RR	5.2	RR1	45 a-d	3 ab	1 b	1	0	54
R14-1479RR	5.2	RR1	36 a-d	4 ab	1 b	2	0	45
AgriGold G5288RX	5.2	Xtend	41 a-d	6 a	5 ab	1	0	37
Armor X52D71	5.2	Xtend	36 a-d	3 ab	1 b	1	0	57
Dyna-Gro S52XT08	5.2	Xtend	27 cd	6 a	4 ab	1	0	44
Eagle Seed ES5220RYX	5.2	Xtend	31 bcd	3 ab	1 b	2	0	49
GDM4	5.2	Xtend	42 a-d	4 ab	2 b	2	0	43
Progeny P5252RX	5.2	Xtend	27 cd	5 ab	2 ab	2	0	48
Asgrow AG52X9	5.2	Xtend/SR	29 cd	5 ab	4 ab	5	0	47
Dyna-Gro SX18652XS	5.2	Xtend/STS	28 cd	3 ab	2 ab	0	0	41
Progeny P279RXS	5.2	Xtend/STS	30 cd	5 ab	3 ab	3	0	43

† Columns followed by the same letter are not statistically significant at *P* = 0.10 as determined by Tukey's honest significant difference.

Table 7. Soybean maturity groups 5.3–6.2 plant stand data 14 days after planting, percent Target spot (TS), Cercospora leaf blight (CLB), Frogeye leaf spot (FLS), and Taproot decline (TRD) severity, where 0 = no disease, and 100 = dead plants, and yield adjusted to 13% at the University of Arkansas System Division of Agriculture's Rohwer Research Station, 2018.

Variety	MG	Tech	Stand	TS	CLB	FLS	TRD	Yield
R13-818	5.3	Conv.	55 abc[†]	1 abc	2	4	0	51
R14-10150	5.3	Conv	51 abc	3 abc	3	1	0	52
R14-15079	5.3	Conv	53 abc	1 bc	3	2	0	46
R14-898	5.3	Conv	39 abc	1 bc	4	1	0	47
R15-1687	5.3	Conv	49 abc	3 abc	3	1	0	45
Credenz CZ5328LL	5.3	LL	35 abc	2 abc	4	1	0	46
Asgrow AG53X9	5.3	Xtend	29 abc	6 a	2	1	1	43
R14-1422	5.4	Conv	56 ab	1 c	2	1	0	47
R15-489	5.4	Conv.	54 abc	2 abc	3	1	0	43
Credenz CZ5445LL	5.4	LL	27abc	2 abc	1	1	0	39
REV54L18	5.4	LL	46 abc	3 abc	2	1	1	45
Progeny P5414LLS	5.4	LL/STS	44 abc	2 abc	1	1	1	50
Asgrow AG54X9	5.5	Xtend	45 abc	3 abc	2	1	0	40
Dyna-Gro SX18854XT	5.5	Xtend	36 abc	5 abc	4	1	1	43
Eagle Seed ES5420RYX	5.5	Xtend	33 abc	2 abc	3	2	1	52
Progeny P5554RX	5.5	Xtend	29 abc	5 abc	3	1	1	40
R15-5695	5.5	Conv.	58 a	1 abc	3	1	1	48
S15-10434C	5.5	Conv.	55 abc	2 abc	2	1	0	46
Eagle Seed ES5519RR	5.5	RR1	42 abc	4 abc	4	2	0	46
Delta Grow DG5580RR2	5.5	RR2	43 abc	3 abc	2	5	0	35
Delta Grow DG5585RR2	5.5	RR2	49 abc	5 ab	3	1	0	27
Armor X55D57	5.5	Xtend	32 abc	3 abc	3	1	0	44
Asgrow AG55X7	5.5	Xtend	22 c	5 abc	2	1	0	58
GoSoy 56C16	5.6	Conv.	46 abc	3 abc	1	1	0	45
Dyna-Gro S56XT99	5.6	Xtend	25 abc	6 a	4	3	0	49
Eagle Seed ES5660RYX	5.6	Xtend	25 abc	6 a	1	1	0	45
Progeny P5688RX	5.6	Xtend	23 bc	5 ab	4	3	0	50
USG 7568XT	5.6	Xtend	26 abc	3 abc	2	1	0	41
R16UARK-52	5.7	RR1	42 abc	4 abc	1	1	0	40
USG 75B75R	5.7	RR2	41 abc	5 abc	1	1	1	32
Eagle Seed ES5930RYX	5.9	Xtend	42 abc	3 abc	2	1	0	45
R14-14648	6.2	Conv.	45 abc	3 abc	2	1	0	43

[†] Columns followed by the same letter are not statistically significant at $P = 0.10$ as determined by Tukey's honest significant difference.

Determining the Value of Fungicide Application on Regional, Field Level, and Within-Field Scales

M. Patterson[1], T. N. Spurlock[1], and A. Tolbert[1]

Abstract

Fungicide strip trials were placed in Hamburg, Yorktown, Fresno, Eudora, and Rohwer, Ark. Foliar disease levels were determined across replicated fungicide treatment strips and disease distributions determined independently of fungicide treatments. Foliar diseases tended to be clustered (*P* = 0.05), in agreement with other findings (Waggoner and Rich, 1981) and disagreeing with commonly perceived thought of distribution of spatial randomness. Product efficacy also changed as disease severity changed (*P* = 0.05).

Introduction

Soybean, [*Glycine max*, (L.) Merrill] 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 cause economic losses each year. Management recommendations for foliar diseases involve cultural practices, resistant varieties, and foliar fungicide applications if warranted, after scouting. Unfortunately, scouting is not an exhaustive process. Individually, crop consultants are responsible for more cropland than ever before, with management decisions made from field subsets often not representative of whole field disease severity. Many foliar fungicides are labeled for soybean in Arkansas, with new products introduced into the market annually. Determining whether to apply a fungicide or which product is most effective for a particular disease or combination of diseases, can be a complex process for consultants and farmers. Additionally, the annual generation of data for products across many different field environments to confirm efficacy and generate actionable economic disease thresholds are required. This work aims to address these issues with two main objectives: to understand foliar disease distributions and to incorporate more efficient means of product testing by harnessing multiple field environments and disease severities in a single field location, spatially.

Procedures

Fungicide strip trials were established in Hamburg, Eudora, Yorktown, Rohwer, and Fresno, Ark. Treatments were replicated three times in a randomized complete block design. Applications were made at 10 GPA using a ground-driven sprayer. The width of each strip was determined based on the farmer's combine header width, and applications were made the entire length of each field. Disease incidence and severity ratings in the top 1/3 of the canopy were evaluated at R6 (R7 at Rohwer) at georeferenced points in each strip. Target spot (TS) height was estimated as the average height TS was found in the soil, expressed as a percentage. Disease severity ratings were based on a percentage scale where 0 = no disease and 100 = dead plants. Harvest data was provided from yield monitors located on the combine. The number of points in each field ranged from 90–200. Untreated strips were included and utilized in determining the distributions of diseases. Fungicides used in all locations were: Priaxor® (4 fl oz/ac), Tilt® (6 fl oz/ac), Priaxor + Tilt, Trivapro® (20.7 fl oz/ac), and Quilt Xcel® (21 fl oz/ac). Exceptions include Hamburg, where Stratego® YLD (4.65 fl oz/ac) was used in place of Quilt Xcel, and the Rohwer location had only two treatments, Trivapro and Priaxor + Tilt. Applications were all made at R2 except for Yorktown and Rohwer locations, which were applied at R3. Foliar disease was absent in all fields at the application on 18 June, 20 June, 5 July, and 25 July at Hamburg, Eudora, Rohwer and Fresno, and Yorktown, respectively. Disease ratings were analyzed in GeoDa using Quantitative Moran's I to determine distributions between georeferenced points. Disease ratings were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Fisher's protected least significant difference (LSD) at *P* = 0.05.

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Results and Discussion

At the Hamburg location (data are shown in Table 1), Target spot height, TS, and Cercospora leaf blight (CLB) severity were assessed on 17 August 2018, at R6. Spatial analysis indicated CLB, TS height, and TS severity were aggregated (*P* = 0.001). Target spot height was significantly lower in the Trivapro, Tilt, and Priaxor strips than the untreated. Trivapro was the only product that suppressed TS severity. Cercospora leaf blight severity data contained statistical differences, all treatments performed as well as the untreated strips, except Priaxor alone, which was significantly higher. None of the treatments had any effect on yield.

At the Eudora location, (data are shown in Table 2) on 16 August 2018, TS height, severity, and CLB severity were evaluated at R6. Ratings from georeferenced points were spatially interpolated using Quantitative Moran's I in GeoDa. This statistic indicated both TS (*P* = 0.01) and CLB (*P* = 0.09) were aggregated throughout the field. Target spot height and CLB data had no significant differences from the untreated strips. Target spot severity averaged 2% with Trivapro, and Priaxor + Tilt performed significantly better than the untreated strips. Yields averaged from 62–69 bu./ac with all treatments except Tilt performing statistically better than the untreated strips.

At Yorktown, CLB severity was assessed at an average of 1% on 24 August 2018, at R6. Spatial analysis was conducted and CLB was non-significant (*P* = 0.11) due to low incidence. Cercospora leaf blight severity was non-significant among treatments. Yield data was not available.

At Rohwer (data are shown in Table 3), CLB, and TS were evaluated 28 August 2018, at R7. The spatial analysis determined that CLB, TS, and TS height were aggregated (*P* = 0.001). Priaxor + Tilt significantly suppressed TS height compared to the untreated strips, but TS was found higher up the plants in Trivapro treated strips compared to the untreated. Target spot was present at an average severity of 2%, and Priaxor + Tilt strips contained significantly less disease than untreated strips but had significantly more CLB than all other treatments. Yield data was not available.

Target spot and CLB severity were evaluated in Fresno (data are shown in Table 4) 30 August 2018, at R6. Based on the quantitative Moran's I, TS was uniform (*P* = 0.07), TS height (*P* = 0.03) and CLB were clustered (*P* = 0.01). Target spot severity averaged 1%, and Trivapro was the only treatment different from the untreated strips. All treatments performed as well as or worse than the untreated strips in suppressing CLB. None of the treatments or disease had any effects on yield.

Practical Applications

In all locations, TS & CLB were clustered at *P* = 0.05 (except for Yorktown, which had very low incidence), in agreement with other findings (Waggoner and Rich, 1981), and disagreeing with commonly perceived thought of distribution of spatial randomness. Product efficacy also changed as disease severity changed (*P* = 0.05). This leads to a better opportunity for farmers and consultants to scout more efficiently using data collected from previous years. Fungicide strip trials allow foliar fungicides to be evaluated in different levels of disease pressure vs. a traditional plot trial where there may only be one disease severity present.

Acknowledgments

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Table 1. Fungicide strip trial treatments, disease data, and yield at Hamburg, 2018. Target spot (TS) height was estimated as the average height TS was found in the soil, expressed as a percentage. Disease severity ratings were based on a percentage scale where 0 = no disease and 100 = dead plants. Harvest data was provided from yield monitors located on the combine.

Treatments & Rate	Target spot height	Target spot severity	Cercospora leaf blight	Yield‡
	(%)	(%)	(%)	(bu./ac)
Priaxor (4 fl oz/ac)	72.7 a†	3.6 b	3.2 a	78.6
Priaxor (4 fl oz/ac) + Tilt (6 fl oz/ac)	61.0 b	2.9 b	1.9 b	80.3
Stratego YLD (4.65 fl oz/ac)	69.5 ab	3.7 a	2.0 b	79.8
Tilt (6 fl. oz/ac)	64.4 b	3.1 b	1.8 b	78.5
Trivapro (20.7 fl oz/ac)	65.2 b	2.4 c	2.3 b	79.6
Untreated	72.0 a	4.4 a	2.2 b	77.4

† Columns followed by the same letter are not statistically significant at *P* = 0.05 as determined by Fisher's protected least significant difference.

‡ Yields adjusted to 13% moisture content for comparison.

Table 2. Fungicide strip trial treatments, disease data, and yield at Eudora, 2018. Target spot (TS) height was estimated as the average height TS was found in the soil, expressed as a percentage. Disease severity ratings were based on a percentage scale where 0 = no disease and 100 = dead plants. Harvest data was provided from yield monitors located on the combine.

Treatments & Rate	Target spot height	Target spot severity	Cercospora leaf blight	Yield†
	(%)	(%)	(%)	(bu./ac)
Priaxor (4 fl oz/ac)	45.8	2.1 a	0.8	62.2 b‡
Priaxor (4 fl oz/ac) + Tilt (6 fl oz/ac)	51.7	1.8 b	0.8	68.7 a
Quilt Xcel (21 fl oz/ac)	51.7	2.0 ab	0.9	67.7 a
Tilt (6 fl oz/ac)	50.0	2.4 a	0.8	65.8 ab
Trivapro (20.7 fl oz/ac)	46.7	1.6 b	0.8	66.2 a
Untreated	50.0	2.0 a	0.8	63.3 b

† Yields adjusted to 13% moisture content for comparison.

‡ Columns followed by the same letter are not statistically significant at $P = 0.05$ as determined by Fisher's protected least significant difference.

Table 3. Fungicide strip trial treatments, and disease data at Rohwer, 2018. Target spot (TS) height was estimated as the average height TS was found in the soil, expressed as a percentage. Disease severity ratings were based on a percentage scale where 0 = no disease and 100 = dead plants. Harvest data was provided from yield monitors located on the combine.

Treatments & Rate	Target spot height	Target spot severity	Cercospora leaf blight
	(%)	(%)	(%)
Priaxor (4 fl oz/ac) + Tilt (6 fl oz/ac)	50.7 c†	1.0 b	5.5 a
Trivapro (20.7 fl oz/ac)	83.1 a	3.3 a	2.2 b
Untreated	67.8 b	2.7 a	2.9 b

† Columns followed by the same letter are not statistically significant at $P = 0.05$ as determined by Fisher's protected least significant difference.

Table 4. Fungicide strip trial treatments, disease data and yield at Fresno, 2018. Target spot (TS) height was estimated as the average height TS was found in the soil, expressed as a percentage. Disease severity ratings were based on a percentage scale where 0 = no disease and 100 = dead plants. Harvest data was provided from yield monitors located on the combine.

Treatments & Rate	Target spot height	Target spot severity	Cercospora leaf blight	Yield‡
	(%)	(%)	(%)	(bu./ac)
Priaxor (4 fl oz/ac)	80.4 bc†	1.0 b	2.0 b	54.8
Priaxor (4 fl oz/ac) + Tilt (6 fl oz/ac)	90.4 a	1.1 b	2.5 a	56.0
Quilt Xcel (21 fl oz/ac)	92.5 a	1.1 b	2.5 a	56.2
Tilt (6 fl oz/ac)	81.0 b	1.1 b	2.4 a	56.0
Trivapro (20.7 fl oz/ac)	87.4 ab	1.4 a	1.8 bc	55.6
Untreated	78.5 bc	1.1 b	2.1 b	55.6

† Columns followed by the same letter are not statistically significant at $P = 0.05$ as determined by Fisher's protected least significant difference.

‡ Yields adjusted to 13% moisture content for comparison.

Accelerated Development of Bioherbicides to Control Palmer Amaranth (Pigweed)

M. Martin[1], K. Cartwright[2], and B. Bluhm[1]

Abstract

Palmer amaranth (*Amaranthus palmeri*), a competitive pigweed native to desert regions of the southwestern United States and northern Mexico, has become one of the most significant weed pests affecting soybean, corn, and cotton producers in Arkansas. Both invasive and aggressive, its vast genetic variability has helped it evolve resistance to herbicides relatively quickly. The current tools available to control pigweed are limited and unsustainable; thus, an effective integrated weed management approach is required to achieve control. Native pigweed pathogens could provide effective biological control of these weeds, especially if the virulence of pathogens can be increased through non-transgenic means. Thus, the objectives of this research are to: (1) evaluate fungal pathogens of pigweed to identify highly aggressive isolates (potential bioherbicide strains) (2) increase the aggressiveness of selected isolates through molecular genetic (non-transgenic) approaches and (3) evaluate modified strains and select candidates to commercialize as bioherbicides of pigweed.

Introduction

Weeds significantly reduce crop yields and quality due to competition for water, sunlight, and soil nutrients. Palmer amaranth (*Amaranthus palmeri*), or pigweed, is an annual broadleaf weed that interferes with several crops, including soybean. The plant possesses many weedy characteristics including prolific seed production, rapid growth rates, prolonged emergence and seed dormancy periods, and propensity to evolve resistance to herbicides. Palmer amaranth was historically controlled by glyphosate, but resistance has evolved and become widespread. The increasing prevalence of herbicide-resistant weeds like Palmer amaranth has created a strong impetus to develop novel control strategies. As new herbicides are developed, weeds continue to evolve in response to the applied selective pressures (TeBeest, 1993). For this reason, the continuous development of novel weed control methods is essential for the ongoing maintenance of agricultural yields. The utilization of microorganisms and viruses to reach this goal has been increasingly studied over the last several decades. (Harding and Raizada, 2015).

Mycoherbicides represent a form of biological control in which a phytopathogenic fungus, or a mixture of multiple fungi, is introduced to the ecosystem to manage one or more undesirable weed species. The fungal organism(s) should not persist beyond a single growing season so that weed populations are unable to develop resistance (TeBeest, 1993). Advantages of mycoherbicides include reduced environmental impact, lower developmental costs compared to conventional herbicides, increased target specificity, and the deployment of novel herbicidal mechanisms (Cai and Gu, 2016).

To date, several mycoherbicides have been commercialized. Devine was registered by Abbot Laboratoratories in 1981 as a mycoherbicide, formulated by the soilborne plant pathogen *Phytophthora palmivora* for control of *Morrenia odorata*, or strangler vine (Ridings, 1986). Collego was developed collaboratively by the University of Arkansas System Division of Agriculture, United States Department of Agriculture (USDA), and The Upjohn Company as a post-emergence bioherbicide, formulated from an isolate of *Colletotrichum gloeosporioides f. sp. aeschynomene* for control of *Aeschynomene virginica* (known commonly as northern jointvetch) (TeBeest and Templeton, 1985). Northern jointvetch is predominantly found in rice and soybean, especially in Arkansas (Bowers, 1986; Smith, 1986). Early successes such as Devine and Collego led to high expectations for future mycoherbicide development. However, relatively few bioherbicides were registered in subsequent years. A key obstacle was consistent performance in field conditions while retaining sufficient shelf-life during production and distribution (Zorner et al., 1993). Innovative efforts, such as increasing the virulence of selected isolates through molecular genetic and non-transgenic approaches, have considerable potential to overcome such barriers to create commercially viable mycoherbicides.

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[2]ARI, Inc., Fayetteville, Ark.

Procedures

The discovery of a candidate biological control organism involves the collection of diseased plant material, pathogen isolation and identification, and culture maintenance. Mycoherbicide development involves inoculum production, culture conditions, greenhouse trials, field trials, and evaluations of host specificity (Watson, 2018). In this study, diseased pigweed plants were collected extensively from growers' fields throughout Arkansas in 2016–2018. To collect material, diseased plants were placed in sterile plastic bags and transported on ice to the laboratory. To isolate pathogens, diseased plant material was surface sterilized to prevent unwanted bacterial or saprophytic growth by rinsing with deionized water, 70% isopropanol, 20% bleach water + Tween 20, and sterile water. Pathogens were isolated from lesions on stems and leaves (Fig. 1) directly onto fresh, sterile media (V8 or potato dextrose agar amended with carbenicillin at 100 µg/mL to deter bacterial growth). All fungal cultures were cataloged and placed in long-term, cryogenic storage. Conidia were harvested by rinsing plates with sterile deionized water and conidial concentrations were determined with a hemacytometer.

Pathogenicity assays were performed in greenhouses at the University of Arkansas System Division of Agriculture to identify pathogens that were highly virulent on pigweed. In the first approach, cultures of pigweed pathogens were mixed and applied as a soil drench to trays in which pigweed seeds were sown. Pathogens were re-isolated from pigweed seedlings killed in these conditions, grown in sterile culture, and re-screened individually on pigweed plants to select candidate biological control strains. In the second approach, pathogens were evaluated individually on pigweed plants via foliar or stem inoculations to assess virulence and potential lethality.

Results and Discussion

Soil drench assays were effective at killing pigweed plants. A total of 22 pathogen isolates have been obtained thus far from pigweed seedlings that were killed with this approach. Nearly all these isolates were preliminarily determined to be members of the fungal genus *Colletotrichum* based on morphology. *Colletotrichum* is a group of fungi that have historically provided some of the most promising candidates for biological control of agricultural weeds. Currently, these 22 isolates, along with newly isolated strains, are being evaluated on pigweed plants in the greenhouse to select the isolate with the highest level of virulence (Fig. 2). Other factors of importance when scaling up for commercial production, such as growth and production of spores, are also being assessed. The highest priority is being given to pathogens that are highly virulent on stems, where girdling and subsequent plant death can occur. In early re-assessments, individual strains induced a substantial level of stress as indicated by discolored/necrotic leaves (Fig. 3). Inoculation techniques are being optimized to increase lethality.

To complete the second objective, molecular phylogenetic techniques have been performed to define the *Colletotrichum* species initially identified as biocontrol candidates. Sequencing and analysis of DNA determined most of the isolates to be *C. truncatum*. Upon confirmation that one or more isolates are sufficiently lethal on pigweed, molecular genetic approaches will proceed, in which genes involved in increasing lethality will be identified and modified non-transgenically via CRISPR-based genetic approaches.

Practical Applications

Long-term, sustainable control of pigweed in Arkansas production systems will require new products and strategies. Biological control could potentially provide a transformative level of pigweed management by itself, or it could be an effective component of an integrated pest management strategy. This study has identified promising biological control strains of fungal pathogens, and resources and personnel are in place to modify these strains through molecular genetic approaches. The outcome—a commercial biological control product that effectively suppresses pigweed—will be of widespread importance to growers in Arkansas and beyond.

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Fig. 1. Representative diseased pigweed samples collected from across Arkansas. Lesions were observed on stems and leaves.

Fig. 2. Greenhouse screening for pathogenicity on pigweed.

Fig. 3. Palmer pigweed displaying foliar discoloration and necrosis during greenhouse evaluations for biocontrol strains of fungal pathogens.

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

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

Abstract

The susceptibility of 58 soybean cultivars to the southern root-knot nematode was evaluated in 5 field trials. In all trials, the damage threshold was severe with an average population density of 379 second-stage juveniles/100 cm^3 of soil at harvest. Host susceptibility was based on the percent of root system galled at the R4–R5 growth stage. Cultivars were considered resistant if the percentage of root system galled was between 4.1% to 9.0%. In the maturity group 4 cultivar trials, Pioneer P46T59R and Terral REV 48A46 was resistant, while Pioneer 45A29L was moderately resistant in the Liberty Link™ trial. In the maturity group 5 trials, Ag Venture 52M7RSTS, Terral REV 56A58, and Terral REV 52A98 were resistant, whereas no resistant or moderately resistant cultivar was identified in the Liberty Link™ trial. These 5 resistant cultivars would be a good choice in fields with a moderate to severe damage threshold of southern root-knot nematode.

Introduction

The southern root-knot nematode (RKN), *Meloidogyne incognita*, is one of the most important nematodes of soybean in Arkansas (Kirkpatrick et al., 2014). During the 2015 cropping season, yield losses by RKN were estimated at 6.49 million bushels (Allen et al., 2017). Based on a recent survey, more than 28% of the samples collected in soybean fields in the state were infested with RKN (Kirkpatrick, 2017), which is a dramatic increase over the last survey (Robbins et al., 1987). Factors that contributed to this increase include a decrease in cotton production acres that were replaced by soybean, an increase in monoculture soybean or soybean-corn cropping systems, and an increase in the use of earlier soybean maturity groups (Kirkpatrick, 2017).

Management strategies for root-knot nematodes include an integrated approach that utilizes resistant cultivars, crop rotation, and nematicides. Since 2006, the availability of seed treated nematicides has increased; however, this delivery system is most effective at low nematode population densities or when paired with host-plant resistance at higher population densities. Crop rotation can be an effective tool when poor hosts such as some grain sorghum hybrids or peanut are used in a cropping sequence; however, these crops may not fit all production systems. The use of resistant soybean cultivars is the most economical and effective strategy to manage RKN (Kirkpatrick et al., 2014). Unfortunately, resistance is limited in the most common maturity groups (MG) grown in the state (Kirkpatrick et al., 2017) and further limited among new herbicide technology for soybean. Screening soybean cultivars for susceptibility to root-knot nematode is one of the services provided by the University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) (Kirkpatrick et al., 2017) and only provides information on those cultivars that are entered into the University of Arkansas System Division of Agriculture's Variety Testing Program. The objective of this study was to expand on the RKN susceptibility and yield response of a few glyphosate-resistant cultivars that are entered and missing from the Variety Testing Program.

Procedures

Fifty-eight soybean cultivars were evaluated in a field that was naturally infested with *Meloidogyne incognita* near Kerr, Ark. Selected cultivars were among the most common MG 4 and 5 grown in the state (Tables 1–5) and experiments were divided between MG and herbicide technologies. Fertility, irrigation, and weed management followed recommendations by the CES. Plots consisted of 4 rows, 30-ft long, spaced 30 in. apart, separated by a 5-ft fallow alley. Seeds were planted using a Kincaid Precision Voltra Vacuum plot planter (Kincaid Equipment Manufacturing, Haven, Kan.) on 9 May 2018 at a seeding rate of 150,000 seeds/ac. The experimental design was a randomized complete block design with 4 replications per cultivar. The population density of RKN at planting

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averaged 60 second-stage juveniles/100 cm^3 of soil with a final population density of 379 J2/100 cm^3 of soil. Nematode infection was based on root galling using a 0–100% scale (0–1.0% = highly 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% = highly susceptible) from 10 arbitrarily sampled roots/plot at R4-R5 growth stage. The two center rows of each plot were harvested on 22 October 2018 using a K Gleaner equipped with a Harvest Master weigh system (Harvest Master, Logan, Utah).

Data were subject to analysis of variance (ANOVA), using ARM 9 (Gylling Data Management, Inc., Brookings, S.D.). When appropriate, mean separations were performed using Tukey's honest significant difference (HSD) test at $P = 0.05$.

Results and Discussion

Of the maturity group 4 Roundup Ready/Xtend® cultivars, there was a wide range in susceptibility with 2.9–99.5% of the root system galled. Two cultivars were resistant to the southern root-knot nematode. Terral REV 48A46 and Pioneer 47T59R were resistant and had a lower ($P = 0.05$) gall rating than Delta Grow 4970 GLY, the susceptible control cultivar (Tables 1 and 2). These resistant cultivars had an average grain yield of 62 bu./ac, which was 36 bu./ac greater than the average yield (26 bu./ac) of the susceptible cultivars.

In the maturity group 4 Liberty Link™ trial, none of the cultivars were resistant to the southern root-knot nematode. Susceptibility ranged from 4.4–88.2% of the root system galled. Pioneer 45A29L was the only cultivar rated as moderately resistant and had a lower ($P = 0.05$) gall rating than Delta Grow 4990 LL, the susceptible control cultivar (Table 4). The resistant cultivar grain yield average was 70 bu./ac, which was 36 bu./ac greater than the average yield (34 bu./ac) of the susceptible cultivars.

Of the maturity group 5 Roundup Ready/Xtend cultivars, 3 were resistant. Susceptibility ranged from 3.4–96.0% of the root system galled. Terral REV 56A58, Terral REV 52A98, and Ag Venture 52M7RSTS were resistant and all had a lower ($P = 0.05$) gall rating than Delta Grow 5170 RR GENRR2Y/STS, the susceptible control cultivar (Table 3). These resistant cultivars grain yield average was 73 bu./ac, which was 50 bu./ac greater than the average yield (23 bu./ac) of the susceptible cultivars.

In the maturity group 5 Liberty Link™ cultivars, none of the cultivars were resistant or moderately resistant to root-knot nematode and susceptibility ranged from 12.5–96.7% root system galled. Cultivars with tolerance to glufosinate and resistance to southern root-knot nematode have been reported (Emerson et al., 2018); however, none were detected in this trial.

Practical Applications

Root-knot nematode is an important yield-limiting pathogen that affects soybean production in Arkansas. Based on the data from this study, selecting resistant cultivars can have a dramatic impact on yield in a root-knot nematode infested field.

Acknowledgments

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Table 1. Root gall ratings and yield from 14 Roundup Ready® and Xtend® maturity group 4 soybean cultivars grown in a root-knot nematode infested field.

Cultivar	Percent root system galled†	Susceptibility‡	Yield§
			(bu./ac)
Terral REV 48A46	2.9 c¶	R	68.5 a
Go Soy 4914 GTS	8.0 c	MR	58.6 ab
Progeny P 4444 RXS	36.1 bc	S	52.4 ab
Local Seed LSX4918X	32.4 bc	S	49.6 b
Local Seed LS4988X	79.0 ab	HS	47.8 bc
Armor 46D63	69.8 ab	HS	41.9 bcd
NK S45-J3X	86.5 a	HS	30.8 cde
Progeny P 4994 RX	87.4 a	HS	27.9 def
Armor 47D22	89.3 a	HS	24.0 ef
Asgrow AG46X7	93.7 a	HS	20.7 ef
Delta Grow 4970 GLY	72.7 ab	HS	16.2 ef
Local Seed LSX5118X	98.3 a	HS	16.2 ef
Armor 44-D40	96.3 a	HS	14.8 ef
Armor 44D36	96.5 a	HS	11.0 f

† Root gall rating severity was based on a percent scale where 0 = no galling and 100 = 100% of root system galled.
‡ Susceptibility based on percent of root system galled where 0–1.0% = highly 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% = highly 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 honest significant difference test.

Table 2. Root gall ratings and yield from 14 Roundup Ready® and Xtend® maturity group 4 soybean cultivars grown in a root-knot nematode infested field.

Cultivar	Percent root system galled†	Susceptibility‡	Yield§
			(bu./ac)
Delta Grow 4940 GLY	9.9 f¶	MS	56.8 a
Pioneer P46T59R	3.3 f	R	56.1 a
Go Soy 49G16	5.3 f	MR	55.9 a
Armor X49D31	80.2 cde	HS	42.9 ab
Progeny P 4570 RXS	80.8 cde	HS	42.3 ab
Agri Gold G4579 RX	73.1 de	HS	41.4 abc
Dyna Gro S49XT39	53.1 e	HS	40.9 abc
Pioneer P47T36R	99.5 a	HS	27.1 bcd
Armor 43D43	96.6 abc	HS	20.5 bcd
Asgrow AG47X6	83.7 bcd	HS	18.9 bcd
Local Seed LSX4518X	95.2 a-d	HS	15.3 cd
Delta Grow 4970 GLY	98.7 ab	HS	13.7 d
Hefty H49X7S	96.0 abc	HS	12.3 d
Progeny P 4255 RX	98.6 ab	HS	8.7 d

† Root gall rating severity was based on a percent scale where 0 = no galling and 100 = 100% of root system galled.
‡ Susceptibility based on percent of root system galled where 0–1.0% = highly 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% = highly 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 honest significant difference test.

Table 3. Root gall ratings and yield from 18 Roundup Ready® and Xtend® maturity group 5 soybean cultivars grown in a root-knot nematode infested field.

Cultivar	Percent root system galled†	Susceptibility‡	Yield§
			(bu./ac)
USG 7568XT	20.0 c¶	MS	79.8 a
Pioneer P54A54X	18.7 cd	MS	78.0 a
Pioneer P53T18X	7.1 cde	MR	77.0 a
Armor 55D57	13.0 cde	MS	76.8 a
Dyna Gro S56XT99	8.3 cde	MR	75.4 a
Progeny P 5554 RX	13.7 cde	MS	75.3 a
Delta Grow 5585 RR GENRR2Y/STS	14.5 cde	MS	74.7 a
Terral REV 56A58	3.6 de	R	74.5 a
Pioneer P55T81R	4.1 de	MR	73.8 a
Go Soy 50G17	8.7 cde	MR	73.4 a
Terral REV 52A98	3.6 e	R	72.5 a
Go Soy 5214	7.1 cde	MR	71.4 a
Ag Venture 52M7RSTS	3.4 e	R	70.2 a
Dyna Gro S52XT08	8.4 cde	MR	59.7 ab
Armor 52D71	76.7 b	HS	33.8 bc
Progeny P 5016 RXS	92.7 ab	HS	28.2 c
Agri Gold 5000RX	95.4 a	HS	18.2 c
Delta Grow 5170 RR GENRR2Y/STS	96.0 a	HS	10.9 c

† Root gall rating severity was based on a percent scale where 0 = no galling and 100 = 100% of root system galled.
‡ Susceptibility based on percent of root system galled where 0–1.0% = highly 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% = highly 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 honest significant difference test.

Table 4. Root gall ratings and yield from 8 Liberty Link™ maturity group 4 soybean cultivars grown in a root-knot nematode infested field.

Cultivar	Percent root system galled†	Susceptibility‡	Yield§
			(bu./ac)
Pioneer 45A29L	4.4 c¶	MR	69.7 a
Delta Grow 4977LL/STS	11.7 c	MS	61.0 a
Crendenz CZ 4222LL	38.1 bc	S	57.9 ab
Dyna Gro S49LS65	11.9 c	MS	56.5 ab
Crendenz CZ 3601LL	88.2 a	HS	45.0 b
Crendenz CZ 4540LL	66.5 ab	HS	43.5 b
Terral REV 49L88	84.8 a	HS	25.4 c
Delta Grow 4990LL	90.3 a	HS	20.9 c

† Root gall rating severity was based on a percent scale where 0 = no galling and 100 = 100% of root system galled.
‡ Susceptibility based on percent of root system galled where 0–1.0% = highly 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% = highly susceptible.
§ Adjusted to 13% moisture.
¶ Numbers within the same columns followed by the same letter are not significantly different $P = 0.05$) according to Tukey's honest significant difference test.

Table 5. Root gall ratings and yield from 4 Liberty Link™ maturity group 5 soybean cultivars grown in a root-knot nematode infested field.

Cultivar	Percent root system galled†	Susceptibility‡	Yield§
			(bu./ac)
Pioneer P52A43L	15.2 c¶	MS	70.7 a
Terral REV 54L18	12.5 c	MS	70.0 a
Crendenz CZ 5147LL	70.5 b	HS	48.9 b
Delta Grow 4990LL	96.7 a	HS	16.9 c

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

‡ Susceptibility based on percent of root system galled where 0–1.0% = highly 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% = highly 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 honest significant difference test.

Efficacy and Residual Control of Selected Insecticides for Bollworm, *Helicoverpa zea*, in Soybean, *Glycine max*

G. Lorenz[1], B. Thrash[1], N. Bateman[2], N. Taillon[1], A. Plummer[1], and K. McPherson[1]

Abstract

Field trials were conducted during the 2018 growing season to evaluate the control of several insecticides for control of corn earworm in soybean. While most of the insecticides provided adequate control at 3 and/or 6 days after treatment, the products containing chlorantraniliprole were the only ones that provided control at 16 days after treatment. Control of corn earworm with a pyrethroid was less than all the other treatments.

Introduction

Soybean bollworm, *Helicoverpa zea* (Boddie), is the most economically important insect pest of soybean, [*Glycine max* (L.) Merrill], in Arkansas (Musser et al., 2017, 2018, 2019). Corn earworm in Arkansas usually undergoes 5 generations per year. The first generation typically occurs on wild hosts such as crimson clover, *Trifolium incarnatum* L., with the subsequent generation moving into corn, *Zea mays mays* L. Host preference of soybean bollworm is positively correlated to plant maturity, and bollworm strongly prefers plants in the flowering stage with corn being the most suitable of all hosts (Johnson et al., 1975). Once corn begins to senesce, it becomes unattractive to bollworm adults as an ovipositional host. The third and fourth generations generally occur in other agronomic host crops such as soybean, cotton, *Gossypium hirsutum* (L.), and grain sorghum, *Sorghum bicolor* (L.) Moench, with the fifth generation occurring primarily on volunteer crop plants after harvest and other non-crop wild hosts (Hartstack et al., 1973). The purpose of these trials was to evaluate the control of soybean bollworm with selected insecticides and determine which insecticides provided the desired level of residual control over an extended time.

Procedures

Two trials were conducted on a grower field in Lonoke Co., Arkansas 2018. The plot size was 12.5-ft (4 rows) by 40-ft, plot design was a randomized complete block with 4 replications. The grower planted cultivar Asgrow 46X6 on 38-in. rows on 25 May. The application was made 25 July using a Mudmaster high clearance sprayer fitted with 80-02 dual flat fan nozzles at 19.5-in. spacing with a spray volume of 10 gal/ac, at 40 psi. The growth stage was R3-R4 at the time the application was made.

Soybean Bollworm Efficacy Trial #1. Treatments in the first trial (Soybean Lep #1)included: Diamond® (novaluron) at 9 oz/ac; Diamond 9 oz plus acephate at 1 lb/ac; Intrepid Edge® (spinetoram plus methoxyfenozide) 4.5 oz/ac; Prevathon® (chlorantraniliprole) 14 oz/ac; Besiege® (lambda-cyhalothrin plus chlorantraniliprole) 8 oz/ac; Cormoran® (acetamiprid plus novaluron) 9 oz/ac; Diamond 6.5 oz plus Fanfare® (bifenthrin) at 6 oz/ac; Diamond, 12 oz plus Fanfare, 5 oz; and, Diamond 9.5 oz plus Fanfare at 6 oz/ac.

Soybean Bollworm Efficacy Trial #2. Treatments in the second trial (Soybean Lep #2) included: Besiege at 7 and 9 oz/ac; Prevathon at 14 and 18 oz/ac, Intrepid Edge at 3.5 and 5 oz/ac; Steward® (indoxacarb) at 12 oz/ac; Denim® (emamectin benzoate at 8 and 12 oz/ac; Lambda® (lambda-cyhalothrin) at 1.82 oz/ac; and Lambda 1.82 oz plus acephate at 0.5 lb/ac.

Plots were evaluated at 3, 6 and 16 days after treatment (DAT) by making 25 sweeps per plot with a standard 15-in. diameter sweep net. Typically assessments are made at 3, 7, 10 and 14 DAT, however, rainfall affected the dates of evaluation. Plots were checked after the 16-day evaluation, but very low levels of corn earworms were found. The data was processed using Agriculture Research Manager v. 9 (Gylling Data Management, Inc., Brookings, S.D.) and Duncan's New Multiple Range Test ($P = 0.10$) to separate means.

Results and Discussion

Soybean Bollworm Efficacy Trial #1. At 3 DAT, the untreated check averaged 35 soybean bollworm (SBW) larvae/25 sweeps, about 7 times the threshold of 9 per 25 sweeps (Fig. 1). While all treatments reduced SBW numbers

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compared to the untreated check, the Diamond and Cormoran treatments failed to reduce the number of SBW below the threshold. Diamond is an insect growth regulator and is known to work slower compared to other insecticides in the trial. By 6 DAT, all treatments reduced SBW numbers compared to the untreated check which had dropped to 27 larvae/25 sweeps. At 16 DAT, an additional flight of moths had entered the field and new SBW larvae had hatched. Except for the Prevathon and Besiege treatment, all the treatments failed to adequately control SBW in the field below threshold compared to the untreated check.

Soybean Bollworm Efficacy Trial #2. At 3 DAT the untreated check averaged 58 larvae/25 sweeps, over 5 times threshold (Fig. 2). All treatments reduced SBW numbers below the untreated check, although Lambda failed to reduce numbers below the threshold of 9 larvae per 25 sweeps. At 6 DAT, all treatments were less than the untreated check; however, Lambda again failed to reduce numbers below the threshold. At 16 DAT, only Besiege and Prevathon at either of the rates kept SBW numbers below the threshold. None of the other treatments were different compared to the untreated check except the Lambda plus Acephate treatment, which had significantly more larvae than the untreated check.

Practical Applications

While all of the treatments in both trials provided some level of control for corn earworm at 3 and 6 DAT, only the treatments that contained chlorantraniliprole (Besiege and Prevathon) provided enough control to protect yield. In Arkansas, multiple generations of SBW in the same field are common. One application providing enough residual control to protect yield potential for growers can be very cost-effective.

Acknowledgments

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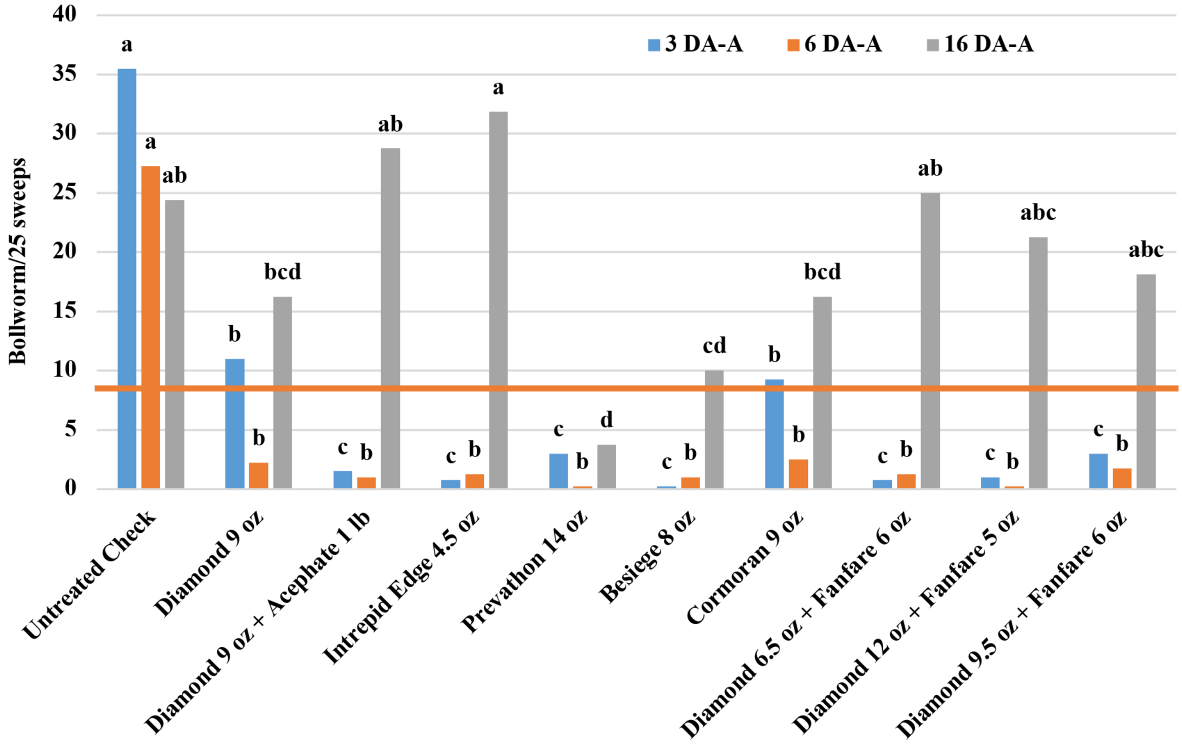

Fig. 1. Soybean bollworm efficacy trial #1 (2018) showing mean number of soybean bollworm per 25 sweeps for selected insecticides treatment at 3, 6, and 16 days after application (DAA).

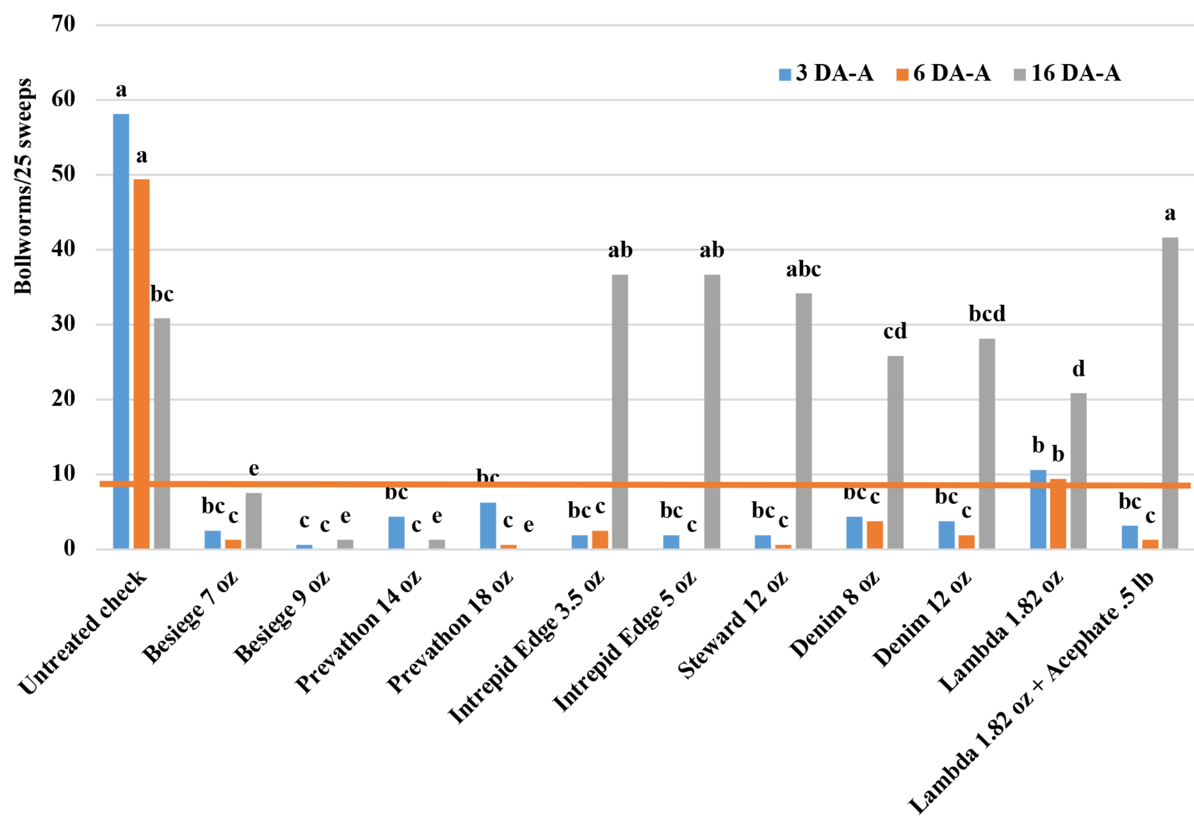

Fig. 2. Soybean bollworm efficacy trial #2 (2018) showing mean number of corn earworm per 25 sweeps for selected insecticides treatment at 3, 6, and 16 days after application (DAA).

Insects on Arkansas Soybean in 2018

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Abstract

Estimates of soybean insect losses were recorded to provide documentation of insect pressure and management practices for 2018. Corn earworm was the most damaging insect pest followed by stink bugs. The third, fourth, and fifth most damaging insect pests were bean leaf beetle, the armyworm complex, and soybean looper, respectively. Damage from all insect pests in Arkansas resulted in an estimated $218 million in losses plus cost in 2018.

Introduction

Estimates for soybean, [*Glycine max* (L.) Merrill], insects have been compiled yearly since 2009 in Arkansas and aim to provide a historical record of pest pressure and their economic impact on soybean. Arkansas' primary insect pests are corn earworm, *Helicoverpa zea* (Boddie), and a complex of stink bugs, Hemiptera: Pentatomidae. Corn earworm is typically the most costly insect pest in Arkansas soybean with stink bugs typically being the second. Green stink bug, *Chinavia hilaris* (Say), and brown stink bug, *Euschistus servus* (Say), are the species most commonly encountered in Arkansas soybean, however, red-banded stink bug, *Piezodorus guildinii* (Westwood), occasionally makes its way into the state and can cause significant damage. The third and fourth most damaging insect pests are most commonly soybean looper, *Chrysodeixis includens* (Walker), and bean leaf beetle *Ceratoma trifurcata* (Forster), although the armyworm complex, Lepidoptera: Noctuidae, will occasionally be more damaging than either. While these estimates to a certain degree are subjective, they provide value by documenting changes in pest spectrums and grower management.

Procedures

Estimates were made based on communication with the University of Arkansas System Division of Agriculture personnel, growers, consultants and industry professionals who were actively engaged in soybean production in Arkansas. Acreage, yield, and price data were taken from the Agricultural Statistics Service publications (USDA-NASS, 2018). Estimates were placed in a spreadsheet to make the various calculations. Actual formulas used in the spreadsheet were published by Musser and Catchot (2008) and Musser et al. (2014).

Results and Discussion

In 2018, 3.28 million acres of soybeans were planted in Arkansas and yielded an average of 50 bu./ac (Table 1). Insects caused a 7.98% average yield loss resulting in a total loss of over 14 million total bushels. The yield loss combined with the cost to control insects totaled an estimated $218 million. Approximately 80% of soybean acreage was scouted in Arkansas, only Louisiana and Mississippi have a larger percentage of their respective soybean acreage scouted. Acreage using an insecticide seed treatment increased from 65–75% from 2015 to 2017 but held steady at 75% in 2018. Insect pests contributing the greatest loss + costs to control were corn earworm at $27.03/ac, followed by stink bugs at $15.40/ac. When compared to 2017, stink bugs were the greatest yield reducers primarily due to red-banded stink bug comprising 35% of the total stink bug population; whereas in 2018, they comprised essentially 0% (Musser et al., 2018). This is due to the cold 2017–2018 winter which kept red-banded stink bug from overwintering in the state. Another reason for this shift is that the number of acres treated for corn earworm increased substantially, rising from 31.4% in 2017 to 45.7% in 2018 (Musser et al., 2018). The increase in corn earworm numbers is suspected to be from a persistent southerly wind carrying moths from the lower Rio Grande valley into the state. It is also likely that a greater number of moths were surviving in corn due to widespread Cry1Ac resistance, further increasing the number of moths entering soybean later in the season. A noteworthy point is a decrease in the estimated cost of one insecticide application for corn earworm. This estimate was lowered from the previous year due to the widespread use of a commercialized nucleopolyhedrovirus which provided an effective, low-cost control option

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for corn earworm. Bean leaf beetle, the armyworm complex, and soybean looper were the third, fourth, and fifth most damaging insect pests in 2018, each contributing less than 10% of the total losses + costs associated with insect pests.

Practical Applications

These estimates are valuable in documenting changes in pest spectrums, control costs, and grower management.

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Table 1. Arkansas Sovbean Insect Losses. 2018.

Pest	Acres Infested	% Acres Infested	Acres Above ET*	% Acres Above ET	Acres Treated	% Acres Treated	# of Apps/acres Treated	Cost of 1 Insecticide	% Loss Per Acre Infested	# of Apps per Total Soy Acres	Cost/Acre	Overall % Reduction	Bushel Lost/Pest	Loss + Cost	Loss + Cost/acre	% Total Loss + Cost
Armyworm complex	2,900,000	88.4%	400,000	12.2%	450,000	13.7%	1	$12.00	1.00	0.137	$1.65	0.88%	1,575,761	$20,480,029	$6.24	9.4%
Banded Cucumber Beetle	125,000	3.8%	0	0.0%	0	0.0%	0	$0.00	0.00	0.000	$0.00	0.00%	0	$0	$0.00	0.0%
Bean Leaf Beetle	3,280,000	100.0%	450,000	13.7%	525,000	16.0%	1	$12.00	1.00	0.160	$1.92	1.00%	1,782,240	$23,356,033	$7.12	10.7%
Blister Beetle	300,000	9.1%	100,000	3.0%	103,500	3.2%	1	$10.50	0.05	0.032	$0.33	0.00%	8,150	$1,164,750	$0.36	0.5%
Corn Earworm	3,000,000	91.5%	1,200,000	36.6%	1,500,000	45.7%	1.25	$14.00	4.00	0.572	$8.00	3.66%	6,520,389	$88,650,119	$27.03	40.6%
Cutworms	479,000	14.6%	200,000	6.1%	222,000	6.8%	1	$10.00	0.50	0.068	$0.68	0.07%	130,136	$3,465,402	$1.06	1.6%
Dectes Stem Borer	2,500,000	76.2%	0	0.0%	50,000	1.5%	1	$10.00	0.00	0.015	$0.15	0.00%	0	$500,000	$0.15	0.2%
Garden Webworms	150,000	4.6%	0	0.0%	0	0.0%	0	$0.00	0.00	0.000	$0.00	0.00%	0	$0	$0.00	0.0%
Grape Colaspis	3,280,000	100.0%	0	0.0%	0	0.0%	0	$0.00	0.00	0.000	$0.00	0.00%	0	$0	$0.00	0.0%
Grasshopper	3,280,000	100.0%	50,000	1.5%	35,000	1.1%	1	$12.00	0.10	0.011	$0.13	0.10%	178,224	$2,125,603	$0.65	1.0%
Green Cloverworm	3,280,000	100.0%	0	0.0%	0	0.0%	0	$10.00	0.00	0.000	$0.00	0.00%	0	$0	$0.00	0.0%
Japanese Beetle	10,000	0.3%	0	0.0%	0	0.0%	0	$0.00	0.00	0.000	$0.00	0.00%	0	$0	$0.00	0.0%
Kudzu Bug	800,000	24.4%	0	0.0%	0	0.0%	0	$0.00	0.00	0.000	$0.00	0.00%	0	$0	$0.00	0.0%
Lesser Cornstalk Borer	1,500	0.0%	0	0.0%	0	0.0%	0	$0.00	0.00	0.000	$0.00	0.00%	0	$0	$0.00	0.0%
Mexican Bean Beetle	0	0.0%	0	0.0%	0	0.0%	0	$0.00	0.00	0.000	$0.00	0.00%	0	$0	$0.00	0.0%
Potato Leafhopper	3,280,000	100.0%	0	0.0%	0	0.0%	0	$0.00	0.00	0.000	$0.00	0.00%	0	$0	$0.00	0.0%
Saltmarsh Caterpillar	3,000,000	91.5%	30,000	0.9%	40,000	1.2%	1	$12.00	0.10	0.012	$0.15	0.09%	163,010	$2,040,003	$0.62	0.9%
Seedcorn maggot	250,000	7.6%	0	0.0%	0	0.0%	0	$0.00	0.00	0.000	$0.00	0.00%	0	$0	$0.00	0.0%
Slugs	200,000	6.1%	200	0.0%	0	0.0%	0	$0.00	0.00	0.000	$0.00	0.00%	0	$0	$0.00	0.0%
Soybean Aphid	200,000	6.1%	0	0.0%	0	0.0%	0	$0.00	0.00	0.000	$0.00	0.00%	0	$0	$0.00	0.0%
Soybean Looper	2,500,000	76.2%	672,000	20.5%	725,000	22.1%	1	$17.50	0.45	0.221	$3.87	0.34%	611,286	$18,537,511	$5.65	8.5%
Spider Mites	100,000	3.0%	50,000	1.5%	65,000	2.0%	1.1	$10.00	0.00	0.022	$0.22	0.00%	0	$715,000	$0.22	0.3%
Spotted Cucumber Beetle	3,280,000	100.0%	0	0.0%	0	0.0%	0	$0.00	0.00	0.000	$0.00	0.00%	0	$0	$0.00	0.0%
Stink Bugs (see box below)	3,280,000	100.0%	1,580,000	48.2%	1,790,000	54.6%	1.1	$10.50	1.75	0.600	$6.30	1.75%	3,118,919	$50,522,557	$15.40	23.2%
Threecornered Alfalfa Hopper	3,280,000	100.0%	0	0.0%	25,000	0.8%	1	$10.00	0.00	0.008	$0.08	0.00%	0	$250,000	$0.08	0.1%
Thrips	3,280,000	100.0%	0	0.0%	0	0.0%	0	$0.00	0.00	0.000	$0.00	0.00%	0	$0	$0.00	0.0%
Trochanter Mealybug	0	0.0%	0	0.0%	0	0.0%	0	$0.00	0.00	0.000	$0.00	0.00%	0	$0	$0.00	0.0%
Velvetbean Caterpillar	2,500,000	76.2%	450,000	13.7%	480,000	14.6%	1	$10.50	0.10	0.146	$1.54	0.08%	135,841	$6,340,002	$1.93	2.9%
Other	0	0.0%	0	0.0%	0	0.0%	0	$0.00	0.00	0.000	$0.00	0.00%	0	$0	$0.00	0.0%
Automatic (no insects)	0	0.0%	0	0.0%	900,000	27.4%	0	$0.00	0.00	0.000	$0.00	0.00%	0	$0	$0.00	0.0%
*ET = Economic Threshhold									**TOTAL**	**2.003**	**$25.01**	**7.98%**	**14,223,956**	**$218,147,010**	**$66.51**	**100.0%**

SUMMARY DATA

Data Input

State	AR
Year	2018
Total Acres	3,280,000
Yield/acre	50
Price/Bushel	$9.57
% Acres Scouted	80
Scouting Fee/scouted acre	$7.50
% Acres Insect Seed Trt.	75
Seed Trt Cost/treated ac	$8.00

Yield & Management Results

Total Bushels Harvested	164,000,000
Total Bushels Lost to Insects	14,223,956
Percent Yield Loss	7.98%
Yield w/o Insects	54.34
Ave. # Spray Applications	2.003
Seed Treated Acres	2,460,000
Scouted Acres	2,624,000

Economic Results

	Total	Per Acre
Foliar Insecticides Costs	$82,023,750	$25.01
Seed Treatment Costs	$19,680,000	$6.00
Scouting costs	$19,680,000	$6.00
Total Costs	$121,383,750	$37.01
Yield Lost to insects	$136,123,260	$41.50
Total Losses + Costs	$257,507,010	$78.51

Stink Bug Composition

Species	% of SB
Brown	43
Brown Marmorated	0
Green	50
Redbanded	0
Redshouldered	7
Southern Green	0
Total (make it 100%)	100

Selected Insecticides for Control of Soybean Looper, *Chrysodeixis includens*, in Soybean

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Abstract

Studies were conducted in 2018 to evaluate selected insecticides for control of soybean looper (SBL) in soybean. In the first trial, all insecticides lowered SBL numbers compared to the untreated control (UTC) 4 and 7 days after treatment (DAT), but products containing either methoxyfenozide or chlorantraniliprole tended to have better control of SBL. Similar results were observed in the second study, although lambda-cyhalothrin did not reduce SBL numbers compared to the UTC at 7 DAT. Generic methoxyfenozide products provided the same level of control as did Intrepid® 2F and Intrepid Edge® in the second study.

Introduction

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

Procedures

Two studies were conducted in Phillips County, Arkansas to evaluate the efficacy of selected insecticides to control SBL. The field was planted with Progeny 5110RY variety soybean on 16 May. The plot size was 4 rows by 50 ft long planted on 30-in. wide rows, arranged in a randomized complete block design with 4 replications. Insecticides were applied with a Mud-Master sprayer equipped with a multiboom delivering 10 gal/ac at 40 psi through 80-02 dual flat fan nozzles with 19.5-in. spacing. Insecticides were applied on 20 August at the R5.5 growth stage. Plots were sampled with a standard 15 in. sweep net, conducting 25 sweeps per plot, 4 and 7 days after treatment (DAT).

Soybean Lopper Efficacy Trial. Treatments in this trial were: Lambda® at 3.65 oz/ac; Intrepid® 2F (methoxyfenozide) at 3 and 4 oz/ac; Prevathon® (chlorantraniliprole at 16 oz/ac; Diamond® (novaluron) at 6 oz/ac; Besiege® (chlorantraniliprole plus lambda-cyhalothrin) at 8 oz/ac; and Intrepid Edge® (spinetoram plus methoxyfenozide) at 5 oz/ac.

Methoxy Soybean Looper Trial. Treatments in this study were: Methoxy® (generic methoxyfenozide) at 2, 4, and 8 oz/ac; Intrepid® 2F at 2, 4, and 8 oz/ac; Intrepid Edge® and 3 and 4 oz/ac; Prevathon® at 14 oz/ac; Besiege® 7.5 oz/ac; and Silencer® (Lambda-cyhalothrin) at 3.65 oz/ac.

Results and Discussion

Soybean Looper Efficacy Trial. At 4 DAT the untreated check (UTC) was averaging over 60 SBL per 25 sweeps (Fig. 1). All insecticide treatments lowered SBL numbers below the UTC. Intrepid 2F at both rates, Prevathon, Besiege, and Intrepid Edge, lowered SBL numbers compared to Lambda and Diamond. A similar trend was observed at 7 DAT. All insecticide treatments lowered SBL numbers compared to the untreated check. Lambda had higher SBL numbers than all other insecticides at this rating date. Intrepid 2F at both rates and Intrepid Edge reduced SBL numbers compared to Diamond and Besiege.

Methoxy Soybean Looper Trial. At 4 DAT, the UTC was averaging over 65 SBL per 25 sweeps (Fig. 2). All insecticide treatments reduced SBL numbers compared to the UTC at

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4 DAT. Methoxy 2 oz/ac, Intrepid 2 oz/ac, and Warrior II at 3.65 oz/ac all had higher SBL numbers than the other insecticide treatments. By 7 DAT, the UTC was averaging 23 SBL per 25 sweeps. All insecticide treatments, except Warrior II, reduced SBL numbers compared to the UTC. Intrepid 2F at 4 and 8 oz/ac reduced SBL numbers compared to Warrior II, but no other differences were observed among insecticide treatments.

Practical Applications

Soybean looper is a yearly pest of late-planted soybean and can cause significant yield loss. With the current cost of soybean production and low grain prices, growers need less expensive options for controlling insect pests in soybean. Currently, SBL has confirmed resistance to multiple classes of insecticides. Products such as Prevathon and Besiege still provide some control of these pests. Intrepid and Intrepid Edge have been the standard in SBL control the past few years. Currently, there are multiple generic methoxyfenozide (Intrepid 2F) products on the market and based on these studies it appears that soybean producers could get adequate control of SBL with high rates of these generics and potentially save money.

Acknowledgments

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

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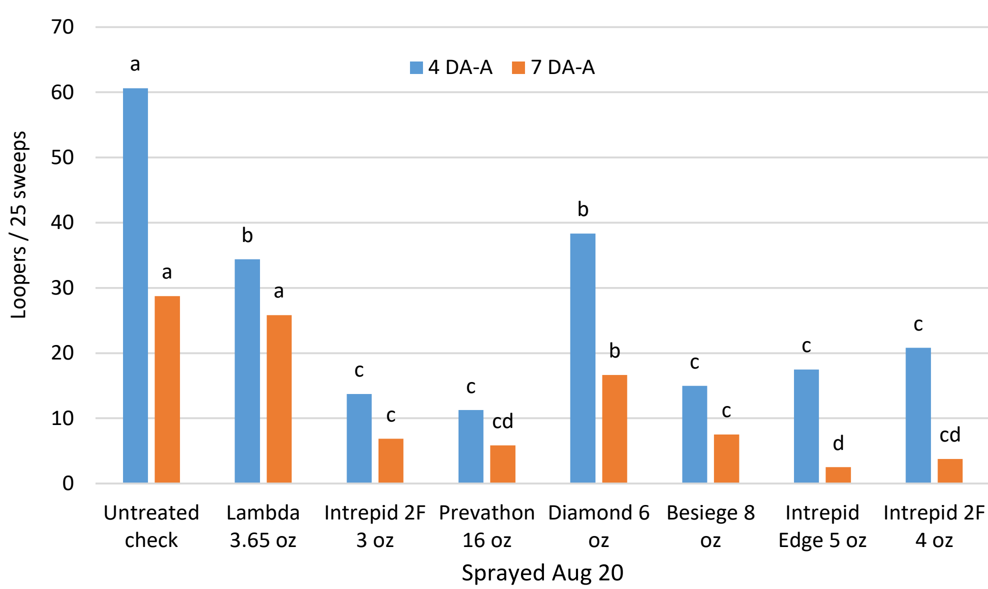

Fig. 1. Results comparing selected insecticides for control of soybean looper (Trial 1) 4 and 7 days after application (DAA) in Arkansas in 2018.

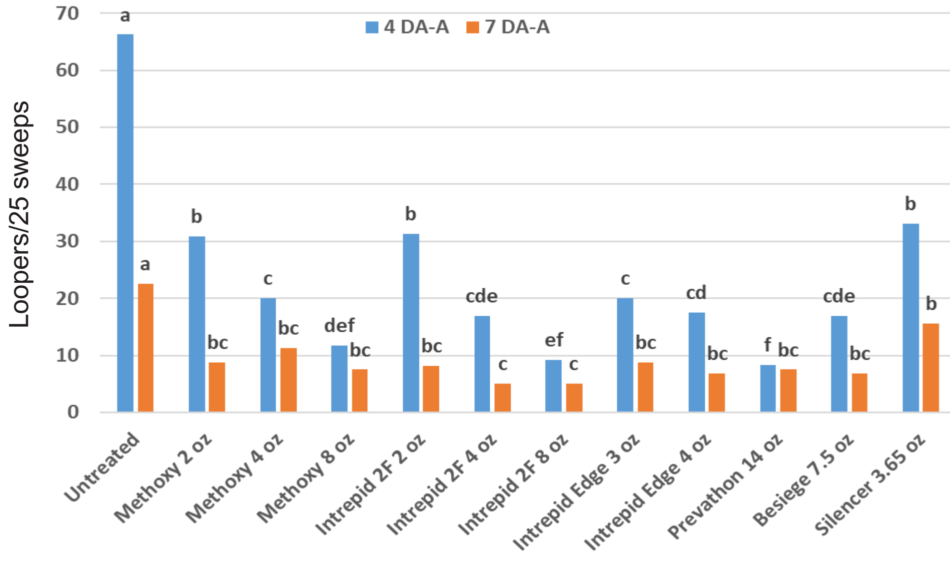

Fig. 2. A comparison among generic methoxyfenozide and current standard for control of soybean looper (Trial 2) 4 and 7 days after application (DAA) in Arkansas in 2018.

Efficacy and Crop Tolerance of Weed Control Programs Containing Glufosinate, Glyphosate, and Isoxaflutole on LibertyLink® GT27™ Soybean

A.N. McCormick[1], L.T. Barber[2], T.R. Butts[2], T.W. Dillon[3], and R.C. Scott[4]

Abstract

A new soybean technology (LibertyLink® GT27™) has been approved for commercial production in the United States to provide growers with an alternative, effective weed control program utilizing multiple modes-of-action. The objective of this research was to evaluate herbicide weed control programs containing glufosinate (Liberty®), glyphosate (Roundup PowerMax®), and isoxaflutole [a 4-hydroxyphenylpyruvate dioxygenase (HPPD) inhibiting herbicide awaiting EPA approval] for their effect on efficacy and crop tolerance in LibertyLink® GT27™ soybean. A field experiment was conducted at the University of Arkansas System Division of Agriculture's Newport Extension Center, near Newport, Arkansas in the summer of 2018. Weed control programs containing residual herbicides at both pre-emergence (PRE) and post-emergence (POST) timings provided excellent, season-long control of Palmer amaranth [*Amaranthus palmeri* (S.) Wats.] and yellow nutsedge [*Cyperus esculentus* (L.)]. Minimal visible crop injury was observed across weed control programs evaluated in this research; therefore, isoxaflutole will be an excellent addition to LibertyLink® GT27™ soybean weed control programs. A numerical decrease in Palmer amaranth control was observed from a Liberty® and Roundup PowerMax® tank-mixture compared to other herbicide programs indicating a potential antagonistic interaction occurred. Herbicide program recommendations for LibertyLink® GT27™ soybean should include a pre-emergence followed by a post-emergence application with residuals to provide season-long weed control and increase post-emergence application flexibility.

Introduction

Glufosinate and glyphosate herbicide tolerance traits (LibertyLink® and Roundup Ready®, respectively) have provided effective soybean cropping systems to successfully manage weeds and attain economical yields. However, increasing weed pressures, herbicide resistance concerns, and the continued demand for greater soybean yields have established the need for new soybean technology (Heap, 2019; Schwartz-Lazaro et al., 2018). LibertyLink® GT27™ soybean was developed as a new soybean technology with a unique herbicide trait package which includes tolerance to glufosinate (Liberty®), glyphosate (Roundup PowerMax®), and isoxaflutole herbicides. This system would incorporate isoxaflutole as a pre-emergence (PRE) herbicide to control certain broadleaf and grass weed species. Isoxaflutole is a 4-hydroxyphenylpyruvate dioxygenase (HPPD) inhibitor (Group 27) and is currently awaiting registration from the U.S. Environmental Protection Agency (BASF, 2019). The objective of this research was to evaluate herbicide weed control programs containing Liberty, Roundup PowerMax, and isoxaflutole for their effect on efficacy and crop tolerance in LibertyLink GT27 soybean.

Procedures

A field study was conducted in 2018 at the University of Arkansas System Division of Agriculture's Newport Extension Center, near Newport, Arkansas to evaluate herbicide weed control programs including PRE and post-emergence (POST) application timings in LibertyLink GT27 soybean. The design was a randomized complete block with 10 treatments (herbicide programs) and 4 replications. Herbicide programs, rates, and application timings used in this research can be found in Table 1.

Soybean was drill-seeded with a 5-foot drill and 7.5-inch row spacing on 14 June 2018 in plots measuring 7.5 by 20 feet in size. Pre-emergence herbicide applications were made on the day of planting. Post-emergence herbicides were applied when weeds reached 1–3 inches in height. A nontreated control was included as a reference for evaluating the efficacy of herbicides on weeds and the potential phytotoxicity of herbicides on soybean.

Herbicides were applied using a 4-nozzle boom with XR 110015 nozzles at 20-inch spacing calibrated to deliver 15 gallons per acre of spray volume at 20 PSI using com-

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[4] Director, Rice Research and Extension Center, Stuttgart.

pressed air. The crop was irrigated as needed. Visible ratings for weed control and crop injury were recorded 14 days after PRE (DAPRE), 7 days after POST (DAPOST), 14 DAPOST, and 28 DAPOST. For the visible weed control ratings, the rating scale was 0% to 100% where 0% = no control and 100% = complete control of weeds. For the visible crop injury ratings, the rating scale was 0% = no injury and 100% = plant death. Means were separated using Fisher's protected least significant difference test ($P \leq 0.05$) in Agriculture Research Manager (Gylling Data Management, Inc. Brookings, S.D).

Results and Discussion

Palmer amaranth (*Amaranthus palmeri* S. Wats.) was controlled by all treatments containing a PRE herbicide at 14 DAPRE (Fig. 1). At 7 DAPOST and 14 DAPOST, all treatments controlled Palmer amaranth similarly. However, the use of a PRE herbicide helped to reduce weed densities exposed to the POST herbicide and provided more POST application flexibility. This was evident as the POST application for treatment 2 (No PRE) was made on 29 June 2018, while the POST applications for treatments that received a PRE were able to be delayed until 2 July 2018. By 28 DAPOST, Palmer amaranth began to re-emerge or regrow in treatments that did not include residual herbicides at the POST application timing (Treatments 2, 3, 4, and 5) and in treatments where Liberty and Roundup PowerMax were applied in a tank-mixture (Treatments 5 and 8). Although not all of these treatments were statistically different from the maximum Palmer amaranth control observed, these numerical losses in control indicate the importance of POST-applied residuals for season-long Palmer amaranth control and that there may be an antagonistic interaction when Liberty and Roundup PowerMax is tank-mixed.

All treatments provided similar control of yellow nutsedge (*Cyperus esculentus* L.) for the entire length of the study; however numerical losses in yellow nutsedge control at 28 DAPOST in Treatments 2, 3, 4, and 5 again highlight the importance of a POST-applied residual herbicide for season-long weed control (Fig. 2). No statistical differences in soybean injury were observed across the rating timings and the maximum injury observed was only 5%, indicating injury was minor and would be commercially acceptable (Fig. 3).

Practical Applications

Herbicide programs containing a PRE followed by a POST application with a residual provided effective, season-long control of Palmer amaranth and yellow nutsedge. Additionally, herbicides used in this research caused minimal crop injury, which is evidence of the safety of these products on LibertyLink GT27 soybean. Isoxaflutole will be an excellent addition to soybean weed control programs as it is an alternative mode-of-action than currently used, provides excellent weed control, and causes minimal crop injury when applied to LibertyLink GT27 soybean. Care should be taken to avoid a Liberty and Roundup PowerMax tank-mixture if possible as a potential antagonistic interaction on weed control was observed. Herbicide program recommendations for LibertyLink GT27 soybean should use a PRE followed by a POST application with residuals as that herbicide program provided the greatest POST application flexibility and season-long weed control compared to POST-only and residual-lacking herbicide programs.

Acknowledgments

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Table 1. Herbicide program treatments to evaluate efficacy and crop tolerance of weed control programs containing glufosinate, glyphosate, and isoxaflutole on LibertyLink® GT27™ soybean.[a]

Treatment	Pre-emergence	Post-emergence
1	Nontreated control	
2	—	Liberty® + Roundup PowerMax® + AMS
3	Isoxaflutole + Sencor®	Roundup PowerMax® + AMS
4	Isoxaflutole + Sencor®	Liberty® + AMS
5	Isoxaflutole + Sencor®	Liberty® + Roundup® + AMS
6	Isoxaflutole + Sencor®	Roundup® + Outlook® + AMS
7	Isoxaflutole + Sencor®	Liberty® + Outlook® + AMS
8	Isoxaflutole + Sencor®	Liberty® + Roundup® + Outlook® + AMS
9	Isoxaflutole + Boundary®	Liberty® + Dual II Magnum® + AMS
10	Isoxaflutole + Zidua®	Liberty® + Dual II Magnum® + AMS

[a] AMS = Ammonium Sulfate; Liberty®, glufosinate, 32 fl oz/acre; Roundup PowerMax®, glyphosate, 32 fl oz/acre; AMS, ammonium sulfate, 6.8 lb/100 gal; isoxaflutole, 3 fl oz/acre; Sencor®, metribuzin, 0.33 lb/acre; Outlook®, dimethenamid-P, 12 fl oz/acre; Boundary®, metribuzin + *S*-metolachlor, 1.5 pt/acre; Dual II Magnum®, *S*-metolachlor, 1.3 pt/acre; and Zidua®, pyroxasulfone, 2 oz/acre.

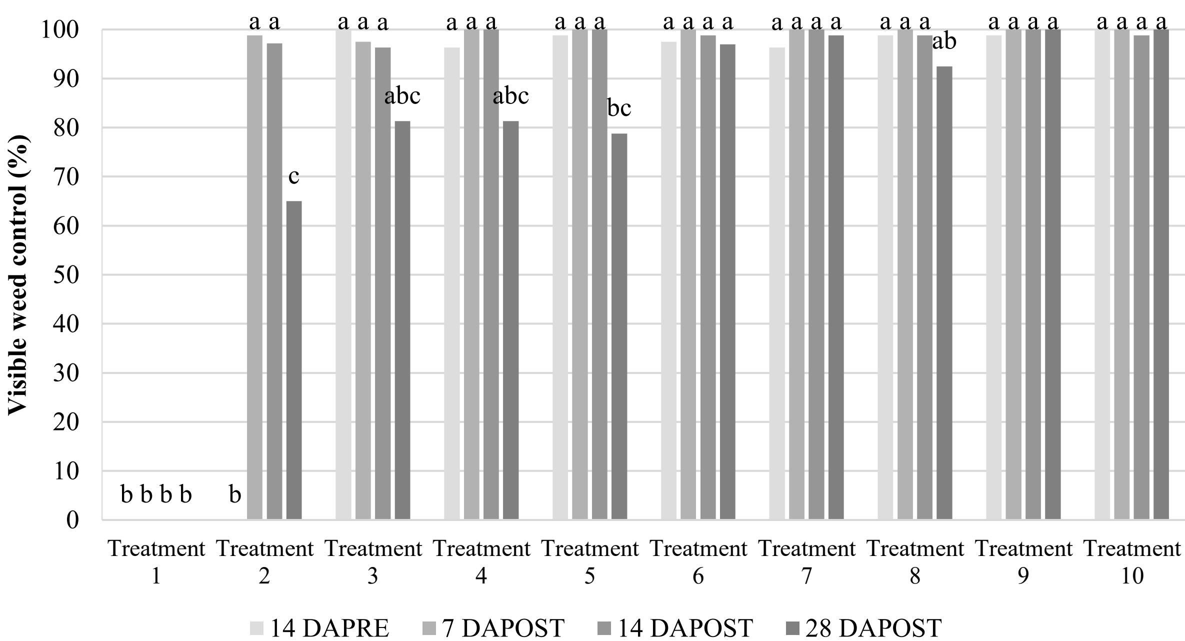

Fig. 1. Visible control ratings of Palmer amaranth at four timings from weed control programs designed for use in LibertyLink GT27 soybeans. Treatment bars with the same letter within a rating timing are not different at α = 0.05. DAPRE = days after pre-emergence application; DAPOST = days after post-emergence application.

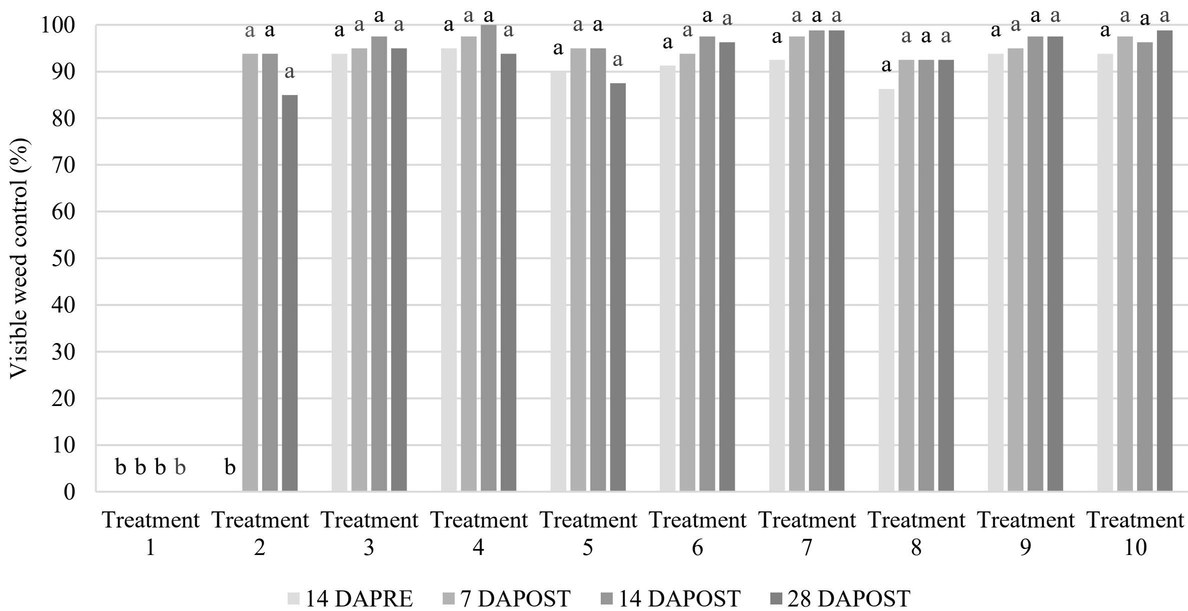

Fig. 2. Visible control ratings of yellow nutsedge at four timings from weed control programs designed for use in LibertyLink GT27 soybeans. Treatment bars with the same letter within a rating timing are not different at α = 0.05. DAPRE = days after pre-emergence application; DAPOST = days after post-emergence application.

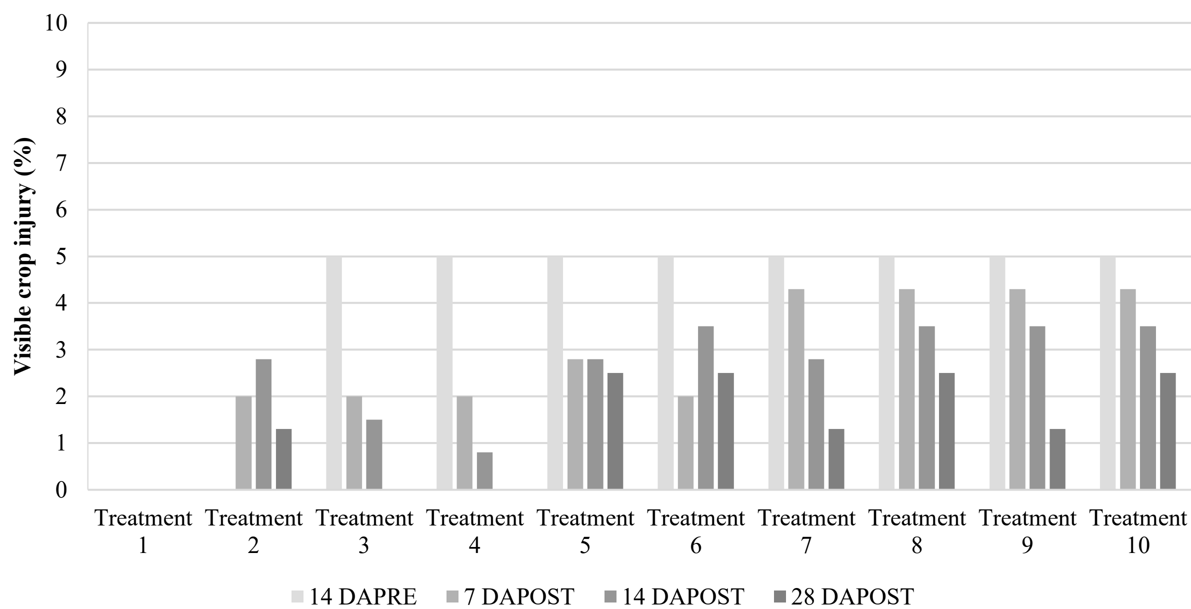

Fig. 3. Visible crop injury ratings at four timings from weed control programs designed for use in LibertyLink GT27 soybeans. No statistical difference between treatments was observed. DAPRE = days after pre-emergence application; DAPOST = days after post-emergence application.

Screening for Soybean Response to Herbicides Dissolved in Irrigation Water[1]

E.M. Grantz[2], Erik Archer[2], Ryan Grewe[2], and C.D. Willett[2]

Abstract

Tailwater recovery (TWR) system usage is on the rise in Mississippi Delta regions affected by groundwater decline. Groundwater savings benefits of TWR are clear, but potential risks of herbicide residue transport between fields resulting in cross-crop injury have not been explored. This study screened 13 herbicides for soybean response to irrigation exposure under controlled environmental conditions. Plants treated with several herbicides approved for aquatic use (penoxsulam, bispyribac sodium, and topramezone) exhibited significant injury and/or signs of potential yield loss or delayed maturity (reductions in pod-bearing nodes, total pods, and large pods) compared to control plants. Soybean producers using TWR should avoid these herbicides for aquatic weed control, or use with caution. Variability in height, pod, and node reduction were high both across herbicides and within some herbicide treatments. Severe damage to an individual plant, but no or minor damage to others within the same treatment was observed for some herbicides, including atrazine, saflufenacil, imazosulfuron, and isoxaflutole. Soybean producers using TWR may wish to exercise caution in the use of herbicides with this response pattern. Study results are preliminary and additional replication is required to assess the significance and real-world damage potential of any herbicide dissolved in irrigation. Further investigation of herbicide concentrations in TWR systems is required to assess the likelihood of crops receiving a substantial herbicide dose in irrigation.

Introduction

Tailwater recovery (TWR) system usage is on the rise in Mississippi Delta regions affected by groundwater decline, combining pumps, ditches, and storage reservoirs to recycle tailwater and field runoff and reduce groundwater use by up to 50% (Evett et al., 2003; Vories and Evett, 2010; Sullivan and Delp, 2012). These systems also pose risks of cross-crop contamination when herbicide residues are transported between fields, but the real-world potential for crop injury due to root uptake of herbicides dissolved in irrigation remains largely unknown (Bruns, 1954; Scifres et al.; 1973; Willett et al., 2019). In investigations of soybean dose-response to root uptake of dicamba, Grantz et al. (in preparation) found that injury and yield reduction were likely when the average dose to a field exceeded 0.07–0.09 lb/ac The present study's goal was to facilitate the rapid identification of other potential cross-crop contamination risks by screening a wide range of herbicides for soybean growth and reproductive response to irrigation exposure.

Procedures

In a growth chamber experiment, soybeans (V3-V4) received irrigation containing one of 13 screened herbicides (Table 1). Herbicides associated with moderate to severe sensitivity in soybean via foliar exposure were prioritized (Barber et al., 2019). Mesotrione (MES) and isoxaflutole (ISX) were selected in preparation for the release of genetically engineered tolerant MGI® and Balance Bean® soybeans. For compatibility with the growth chamber, an indeterminate, early-maturity variety was selected ('RS066R2', Renk Seed). Seeds were pretreated with CruiserMax®, an insecticide/fungicide, and Optimize®, a bacterial inoculant for nitrogen fixation, and were pre-germinated between damp paper towels at room temperature 1 wk before establishment in polyethylene pots (diameter = 4 in., height = 3.5 in.) filled with 0.77 lb sieved field soil. Pots were lined with nylon screens and placed in catchment dishes to prevent soil and water loss and herbicide cross-contamination. After planting, pots were transferred to a growth chamber, where temperature (24 °C),

[1] The use of trade names or commercial products in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the University of Arkansas System Division of Agriculture of any product or service to the exclusion of others that may be suitable.

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relative humidity (75%), and light (photosynthetically active radiation = 500–700 µmol/m/s; 12/12-h day/night interval) were maintained throughout the experiment. Soil volumetric water content was monitored and maintained within 10 – 30%.

Four plants were randomly assigned to receive one of 13 herbicide treatments. The herbicides were dissolved in 250 mL irrigation at a single concentration (0.5 mg a.i/a.e./L, 0.14 lb/ac equivalent). Concentrated stock solutions were prepared from formulated product dissolved in deionized (DI) water (Table 1), except for benzobicyclon (BZB) and ISX, which were dissolved in acetonitrile due to low water solubility. For BZB, the analytical standard of the herbicidal active ingredient, benzobicyclon hydrolysate, was used instead of the formulated product. Irrigation solutions were then prepared by diluting concentrated solutions in de-ionized (DI) water. The selected dose was within a range known to cause significant injury to soybean exposed to dicamba via irrigation (Willett et al., 2019; Grantz et al., in preparation). Irrigation was applied to the soil surface with no foliar exposure and minimal stem exposure. Eight plants were assigned to serve as controls, with 4 receiving 250-mL DI water and 4 receiving 250-mL 0.5% acetonitrile in DI water. The latter served as controls for plants treated with BZB or ISX.

Plants were assessed for symptomology 14 days after treatment (DAT) using a 0–100% scale (0% = no injury, 100% = death). Plant height to the newest node, number of pod-bearing nodes (PBN), pods (PN) and large pods (LPN; length > 0.40 in.) were recorded. Plants were terminated, bagged, dried for 9 d at 60 °C, and weighed to measure aboveground dry mass. Plant height, dry mass, PBN, and PN, ratios for treated plants were calculated by dividing by the average control value for each metric. A ratio <1 indicates a potentially negative response. A ratio >1 could indicate a positive response, but more likely reflects natural plant variability. Kruskal-Wallis analysis of variance on ranks with posthoc one-tailed comparisons to controls was used to identify significant responses to herbicide treatment.

Results and Discussion

Median plant injury 14 DAT ranged from 0–40% (Fig. 1A). No control injury correction was needed for plants irrigated with herbicides in DI water, but control plants irrigated with 0.5% acetonitrile exhibited 25–30% injury, requiring background subtraction from injury ratings for plants treated with BZB and ISX. Median height, dry mass, PBN, PN, and LPN ratios were highly variable across herbicides and ranged from 0.62–1.6, 0.42–1.4, 0–1.2, 0–1.5, and 0–0.8, respectively (Figs. 1B-C and 2A-C). Variability was also high within some herbicide treatments, indicating potentially severe damage for an individual plant, but no or minor damage for others within the same treatment. Examples include, but are not limited to, % injury for atrazine (ATR; 5–95%); height ratio for ISX (0.48–1.1); dry mass ratio for saflufenacil (SFL) and ISX (approximately 0.25–0.90); PBN ratio for ISX (0.3–1.3); PN ratio for imazosulfuron (IMA) and ISX (approximately 0.20–1.1); and LPN ratio for ATR, ISX, and SFL (0–1.0 or greater). Other herbicides exhibited large variability in effects among plants, especially in height and dry mass, but within a range of ratios that exceeded (ratio > 1) or that were near equivalent to control response, indicating similar or better performance than the controls, most notably bensulfuron methyl (BM). Variability in the latter case should not be of concern.

High variability within treatments combined with a small sample size (n = 4) resulted in a few statistically significant differences between control and treated plants in Kruskal-Wallis analyses. However, plants treated with penoxsulam (PEN), exhibited significant injury and PBN, PN, and LPN reductions. No significant reductions in height or dry mass related to herbicide exposure were detected, a likely result of spatially variable light conditions in the growth chamber environment. Reproductive damage was the most notable symptomology and comprised the remaining significant findings. Plants treated with bispyribac sodium (BS) had reduced PBN, PN, and LPN, while exposure to topramezone (TPR), quinclorac (QUN), IMA, halsulfuron-methyl (HM), and BZB resulted in reduced LPN. These findings suggest that delayed maturity is a common response to herbicide exposure in irrigation. Willett et al. (2019) observed a similar reproductive response in soybean exposed to dicamba in irrigation in growth chamber experiments, including pod absence at the highest doses. However, in follow-up field studies, soybeans produced pods at all exposure levels, and total yield loss was only seen when all plants died within a treatment unit (Grantz et al., in preparation). The extended recovery timeframe for a full-season determinate variety likely accounts for this difference.

Practical Applications

This study identifies herbicides of greatest concern for producers using TWR and future needs for scientific study. Penoxsulam was the biggest potential risk of the screened herbicides. The risk potential is further magnified because PEN is labeled for weed control in aquatic systems in the United States (Barber et al., 2019). Direct application of herbicides to a pond or ditch is the most likely scenario to result in high concentrations in irrigation. Two other herbicides approved for aquatic use, BS and TPR, are also of potential concern. Findings support the recommendation that PEN, BS, and TPR should not be used, or used with great caution, for aquatic weed control in TWR ditches or storage ponds that serve soybean production systems. Study findings are preliminary and additional replication at a range of concentrations and in field environments is required to assess the significance and real-world damage potential of any herbicide dissolved in irrigation. Further investigation of herbicide concentrations in TWR ditches and reservoirs is also required to assess the likelihood of crops receiving a substantial herbicide dose in irrigation. Lack of significant damage detected for any herbicide in the present study may reflect the limited scope of the study, and no herbicide tested can be fully endorsed as safe based on study findings. Producers using TWR may especially wish to proceed with caution when using herbicides that showed wide variability in response among the treated plants, with the range of responses including strong negative effects. These include, but are not limited to ATR, SFL, IMA, and ISX.

Acknowledgments

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Table 1. Common names and abbreviations for the herbicide active ingredients used in the screening, as well as the formulated products used to prepare herbicide treatments. Study findings may be applicable for other formulated products containing these active ingredients. Expected soybean sensitivity based on foliar exposure observations were sourced from Barber et al. (2019).

Herbicide Active Ingredient	Abbreviation	Formulated Product	Foliar Sensitivity Rating[b]
Atrazine	ATR	Aatrex®	NA
Bensulfuron-methyl	BM	Londax®	VS
Benzobicyclon	BZB	Benzobicyclon hydrolysate standard material[a]	NA
Bispyribac-sodium	BS	Regiment®	VS
Glufosinate	GLU	Liberty®	VS
Halosulfuron-methyl	HM	Permit®	VS
Imazosulfuron	IMA	League®	VS
Isoxaflutole	ISX	Balance®	NA
Mesotrione	MES	Callisto®	NA
Penoxsulam	PEN	Grasp®	VS
Quinclorac	QUN	Facet®	M
Saflufenacil	SFL	Sharpen®	S
Topramezone	TPR	Armezon®	S

[a] Benzobicyclon is a pro-herbicide, meaning the herbicide active ingredient is a degradate of the parent compound. To quantitatively dose plants treated with benzobicyclon, benzobicyclon hydrolysate standard material was used in lieu of formulated product (Rogue®) to prepare treatment solutions.

[b] VS = very sensitive, S = sensitive, M = moderately tolerant, NA = sensitivity rating not available in MP 44.

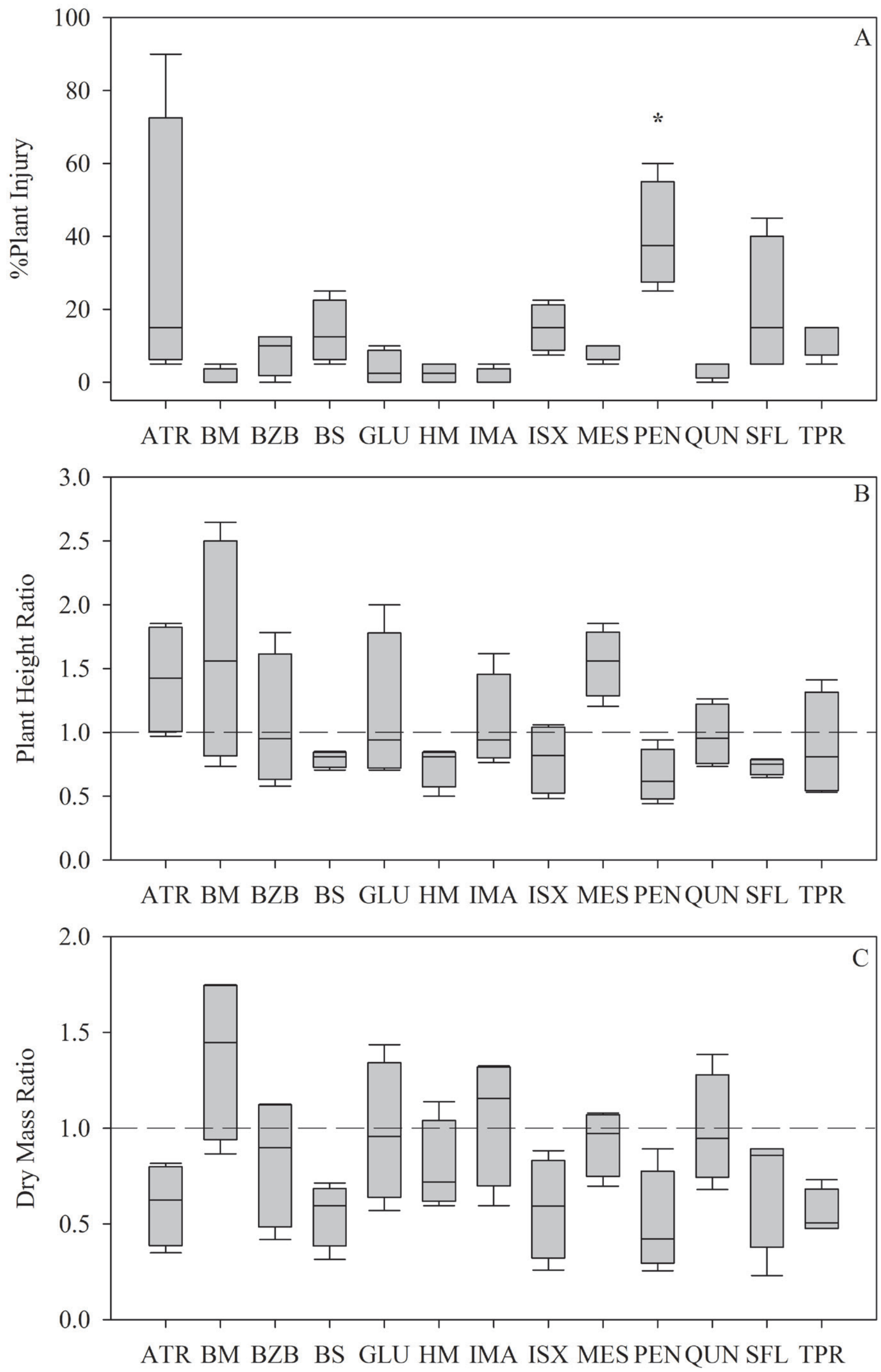

Fig. 1. Boxplots displaying the distribution of A) %plant injury ratings, B) plant height ratios, and C) dry mass ratios of plants receiving each of 13 herbicide treatments dissolved in irrigation water. The shaded area denotes the 25th–75th percentile range, while the horizontal line within the shaded area is the median. Lower and upper error bars indicate the 10th and 90th percentile estimates, respectively. The dashed line in B) and C) indicates a ratio = 1, or the ratio equal to the average control plant response. Boxplot areas extending above this line indicate plants that performed as well as or better than controls, while areas below the line indicate plants with possible herbicide damage. Herbicides flagged with an asterisk were identified by Kruskal-Wallis analyses as resulting in statistically significant (P < 0.05) injury or growth reduction in treated plants relative to controls.

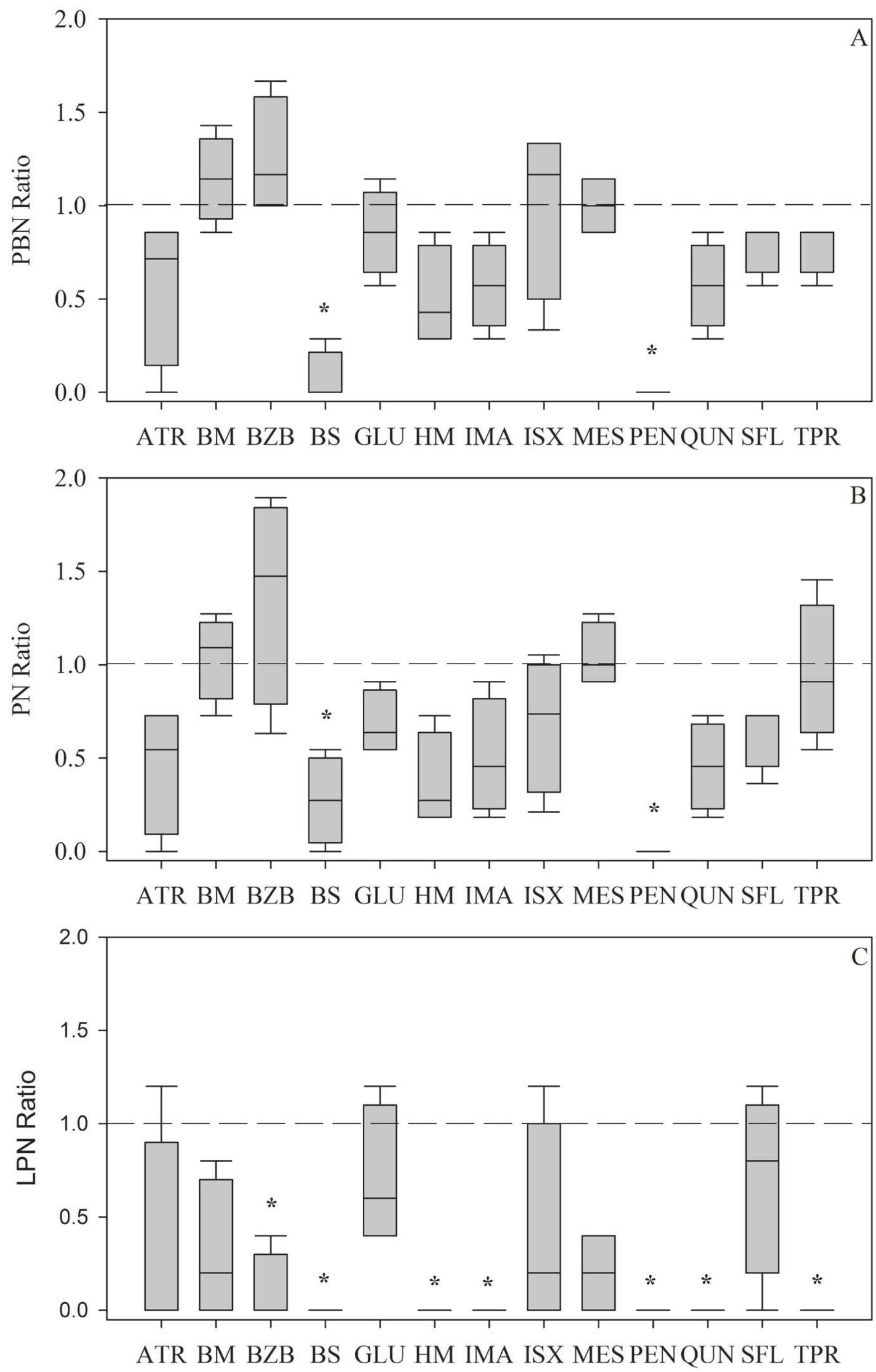

Fig. 2. Boxplots displaying the distribution of A) pod bearing node (PBN) ratios, B) pod number (PN) ratios, and C) large pod number (LPN) ratios of plants receiving each of 13 herbicide treatments dissolved in irrigation water. The shaded area denotes the 25th–75th percentile range, while the horizontal line within the shaded area is the median. Lower and upper error bars indicate the 10th and 90th percentile estimates, respectively. The dashed line in each plot indicates a ratio = 1, or the ratio equal to the average control plant response. Boxplot areas extending above this line indicate that some plants performed as well as or better than controls, while areas below the line indicate some plants exhibited possible herbicide damage. Herbicides flagged with an asterisk were identified by Kruskal-Wallis analyses as resulting in statistically significant (*P* < 0.05) reductions in PBN, PN, or LPN in treated plants relative to controls.

Palmer Amaranth Resistance to *S*-Metolachlor in Arkansas

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Abstract

Palmer amaranth accessions from Arkansas were collected in 2018 to investigate their response to the labeled rate of *S*-metolachlor (Dual Magnum®). Thirty-five accessions were collected from 14 counties. A general screening was conducted in the greenhouse using a completely randomized design, with 3 replicates and was repeated once. A dose-response study was also conducted using 7 rates of *S*-metolachlor (0, 0.15x, 0.3x, 0.5x, 1x, 1.5x, and 2x). One accession collected from an organic field was used as a susceptible standard. The dose-response was conducted using a randomized complete block design with 3 replicates and was also repeated once. The general screening data were analyzed using the GLIMMIX procedure in SAS. The[SS1] dose-response data were analyzed using the drc package of R software. Results suggest that Palmer amaranth accessions from Arkansas are not equally controlled by the labeled rate of *S*-metolachlor. Three accessions showed a significant decrease in response to the labeled rate in comparison to the susceptible standard. At least one accession required 3 times more *S*-metolachlor to be controlled 90% in comparison to the susceptible standard. Early detection of *S*-metolachlor-resistant Palmer amaranth accessions in Arkansas will help raise awareness on the loss of important herbicides for controlling troublesome weeds. To reduce the spread of *S*-metolachlor-resistant Palmer amaranth, the development and implementation of good agronomic practices (Integrated Weed Management Program) will help decrease the selection pressure exerted on Palmer amaranth populations.

Introduction

Amaranthus palmeri (S.) Wats. (hereafter referred to as Palmer amaranth) is one of the worst weeds in the Southern United States (Ward et al., 2013). Season-long interference of Palmer amaranth with corn, soybean, and cotton caused yield reductions up to 91%, 68%, and 92%, respectively (Massinga et al., 2001; Klingaman and Oliver, 1994). Palmer amaranth has many undesirable characteristics that make it particularly difficult to control. First, Palmer amaranth grows rapidly, which makes it highly competitive with most crops for light. Palmer amaranth can grow at rates greater than 3.5 cm per day and reach heights greater than, or equal to, 2 m (Norsworthy et al., 2008). Rapid growth rate allows Palmer amaranth to position its leaves above the crop canopy and maximize its light interception, thereby reducing the light quantity and altering light quality available to crops. Second, Palmer amaranth exhibits high plasticity in response to environmental conditions, growing under a wide range of climatic and edaphic conditions (Ward et al., 2013). Third, Palmer amaranth is a prolific seed producer. A single female plant can produce up to 600,000 seeds, that can replenish the soil seedbank in a single generation (Ward et al., 2013). However, the most detrimental trait of Palmer amaranth is its ability to evolve resistance to herbicides of different modes of action. To date, Palmer amaranth has evolved resistance to 7 herbicide sites of action worldwide; 4 in Arkansas (Heap, 2019). In Arkansas, Palmer amaranth has evolved resistance to post-emergence applications of acetolactate synthase (ALS), 5-enolpyruvylshikimate-3-phosphate synthase (EPSPS), microtubule-, and protoporphyrinogen oxidase (PPO) inhibitors (Heap, 2019), which reduces management options available to farmers. Consequently, residual herbicides have become the backbone of weed management programs (Norsworthy et al., 2012). Chloroacetamides belong to a family of soil-active herbicides that are widely used by farmers in the United States and worldwide. Herbicides from this chemical family inhibit the synthesis of very-long-chain fatty acids. *S*-metolachlor (2-Chloro-N-(2-ethyl-6-methylphenyl)-N-[(1S)-2-methoxy-1-methylethyl]acetamide), the most commonly used chloroacetamide, is effective on nutsedge species, annual grasses, and small-seeded broadleaf species including Palmer amaranth. *S*-metolachlor is used in corn, cotton, peanut, potato, grain and forage sorghum, and soybean, among many other crops (WSSA, 2007). *S*-metolachlor is a good alternative for controlling glyphosate-, microtubule-inhibitor-, ALS-inhibitor-, and PPO-inhibitor-resistant Palmer amaranth. However, recent field observations suggest that *S*-metolachlor

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efficacy against Palmer amaranth is compromised, which may further reduce effective weed control tools for farmers. The objectives of this research were to (1) investigate the differences in the response of Palmer amaranth accessions from Arkansas to *S*-metolachlor, and (2) determine the level of resistance in suspect populations. We hypothesized that (1) the field use rate of *S*-metolachlor is equally effective on all populations of Palmer amaranth, and (2) the doses required to control 90% of Palmer amaranth are similar.

Procedures

Thirty-five Palmer amaranth accessions were collected from 14 counties (Fig. 1) during the fall season, 2018. Palmer amaranth inflorescences were harvested from at least 10 female plants in each field. The inflorescences were air-dried, threshed, and the seeds cleaned. The experiments were conducted in the greenhouse at the University of Arkansas System Division of Agriculture's Altheimer Laboratory. General screening of *S*-metolachlor efficacy was conducted using a completely randomized design with 3 replicates and was repeated once. The screening assay had two treatments (treated and non-treated). *S*-metolachlor was applied at 1.0 lb ai/ac, using a spray chamber equipped with Teejet flat fan nozzle 1100067, calibrated to deliver 20 gal/ac, at 40 PSI and 1 mph speed. The experimental unit was one tray filled with field soil and planted with 100 seeds. Field soil (Roxana silt loam, 18.8% sand, 68.2% silt, and 12.9% clay) with a low *S*-metolachlor use history was collected from the Vegetable Research Station of the University of Arkansas System Division of Agriculture in Kibler, Ark. Soil samples were submitted to the University of Arkansas System Division of Agriculture's Soil Testing Laboratory in Fayetteville (Table 1). *S*-metolachlor was activated shortly after herbicide application by sprinkler irrigation.

A follow-up dose-response study was conducted using 7 rates of *S*-metolachlor (0, 0.15x, 0.3x, 0.5x, 1x, 1.5x, and 2x) with 1x being 1 lb ai/ac. One accession collected from an organic field in Woodruff county was used as a susceptible standard. The experimental design was a randomized complete block with 3 replicates and was repeated once. Each experimental unit, herbicide application, and activation followed the same description as previously mentioned. Emerged seedlings from each experimental unit were counted 21 days after the *S*-metolachlor application. Palmer amaranth percent control (for the screening) and percent survivors (for the dose-response) were evaluated in comparison to the corresponding non-treated checks. The screening study data were analyzed using the GLIMMIX procedure in SAS v. 9.4 (SAS Institute, Cary, N.C.). Specific contrasts were constructed to separate population means. Non-linear regression was used to model the dose-response data. A 3-parameter log-logistic model was used to relate Palmer amaranth percent survivors to *S*-metolachlor rates using the drc package (Ritz and Streibig, 2005) in R software v. 3.4.3 (R Core Team, 2017) and the LD90 values (effective rates to reduce the number of individuals by 90%) were estimated.

Results and Discussion

Palmer amaranth accessions responded differently to the labeled dose (1 lb ai/ac) of *S*-metolachlor (Fig. 2); thus, we reject our first hypothesis. Three accessions (WOO-B (Woodruff county), PHI-C (Phillips county) and CR-D (Crittenden county)) showed a significant decrease ($P < 0.0001$) in response to the labeled rate of *S*-metolachlor (Fig. 2). Dose-response analysis revealed that Crittenden D (CRI-D) was resistant to the labeled rate (Fig. 3). This accession displayed an LD90 value 3 times higher than that of the susceptible standard. Therefore, this accession required 3 times more *S*-metolachlor to attain 90% control in comparison to the susceptible standard (Fig. 3); thus, we also rejected our second hypothesis. Previous research has also reported other weed species that have evolved resistance to group 15 herbicides. In Illinois, *S*-metolachlor provided less than 27% control of waterhemp (*Amaranthus tuberculatus*) under field conditions and the *S*-metolachlor-resistant waterhemp showed a 12.9-fold resistance level compared to the susceptible standard (Strom, 2018). Also, ryegrass species (*Lolium rigidum* and *Lolium multiflorum*), black-grass (*Alopecurus myosuroides*), and barnyardgrass (*Echinochloa crus-galli*) are reported to be resistant to group 15 herbicides (Heap, 2019).

Practical Applications

The results of this study help raise awareness of the risk of selecting for *S*-metolachlor-resistant Palmer amaranth in Arkansas. Early detection of herbicide-resistant populations in fields is a crucial first step in the prevention of the spread of resistance. Palmer amaranth populations from Arkansas are not equally controlled by the labeled rate of *S*-metolachlor and some accessions require at least 3 times more *S*-metolachlor to attain 90% control compared to the susceptible standard. Growers should reduce over-reliance on *S*-metolachlor for Palmer amaranth control. To minimize the spread of *S*-metolachlor-resistant Palmer amaranth, growers need to: (1) implement an Integrated Weed Management Program that will decrease not only the frequency of *S*-metolachlor application but also its selection pressure on Palmer amaranth populations, (2) scout their fields as soon as possible to develop a better weed control program, (3) prevent Palmer amaranth plants from producing seed, thereby decreasing the soil seedbank, (4) realize that effective herbicide resources for weed control are being depleted, and (5) be aware of the rarity of discovering new herbicide molecules. Future directions for this research will be investigating the potential relationship between *S*-metolachlor soil degradation rate, soil microbial communities, and the evolution of resistance in Palmer amaranth.

Acknowledgments

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Table 1. Soil analysis data for the field soil (Roxana silt loam) used to grow Palmer amaranth, with a low *S*-metolachlor use history, collected from the Vegetable Research Station of the University of Arkansas System Division of Agriculture in Kibler, Ark.

Soil pH[a]	Soil EC[a]	Total N[b]	Total C[b]	Mehlich-3 extractable soil nutrients[c]										
				P	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu	B
	µmhos/cm	%	%	(mg/kg)										
7.3	112	0.04	0.41	111	164	1308	237	5.0	17.1	232.8	103	3.39	1.59	0.42

[a] Soil pH and EC measured in a 1:2 soil: water mixture (Sikora and Kissel, 2014).
[b] Measured by thermal combustion analysis (Provin, 2014).
[c] Extracted using Mehlich-3 method (Zhang et al., 2014).

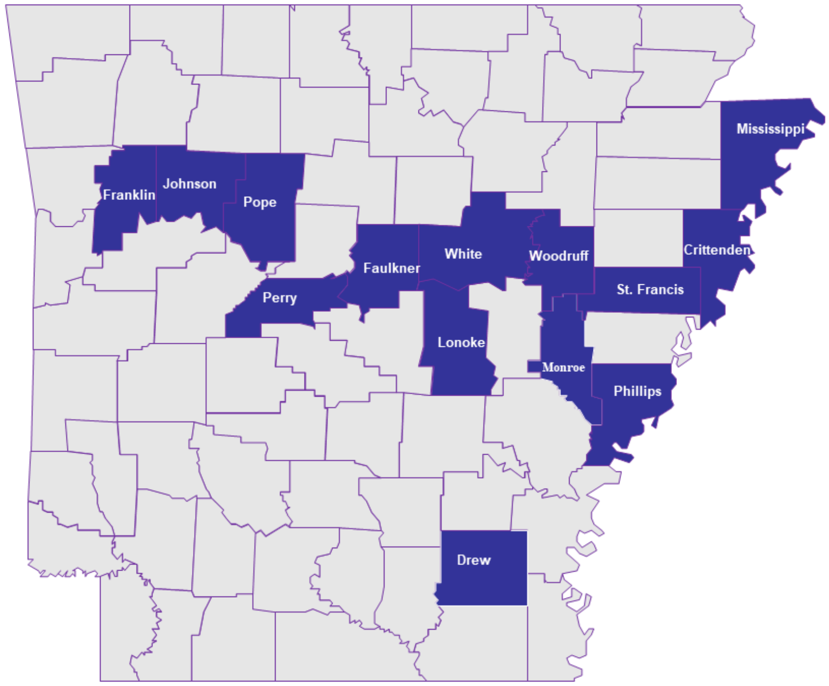

Fig. 1. Counties where Palmer amaranth seeds were collected in Fall 2018 for the S-metolachlor resistance study.

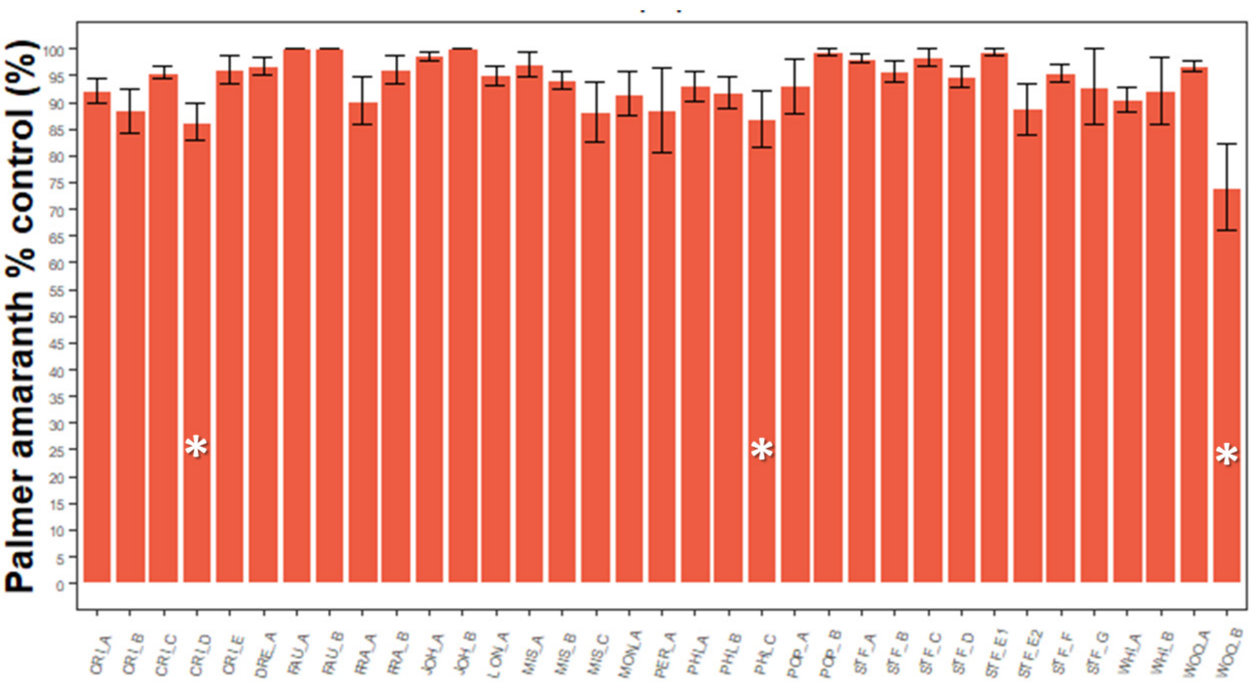

Fig. 2. Palmer amaranth % control, 21 days after application (1 lb ai/ac). Accessions that showed a significant decrease in response to the labeled rate of S-metolachlor are indicated by *. Error bars represent standard error of the mean. Abbreviations: CRI_A (Crittenden A), CRI_B (Crittenden B), CRI_C (Crittenden C), CRI_D (Crittenden D), CRI_E (Crittenden E), DRE_A (Drew A), FAU_A (Faulkner A), FAU_B (Faulkner B), FRA_A (Franklin A), FRA_B (Franklin B), JOH_A (Johnson A), JOH_B (Johnson B), LON_A (Lonoke A), MIS_A (Mississippi A), MIS_B (Mississippi B), MIS_C (Mississippi C), MON_A (Monroe A), PER_A (Perry A), PHI_A (Phillips A), PHI_B (Phillips B), PHI_C (Phillips C), POP_A (Pope A), POP_B (Pope B), STF_A (St. Francis A), STF_B (St. Francis B), STF_C (St. Francis C), STF_D (St. Francis D), STF_E1 (St. Francis E1), STF_E2 (St. Francis E2), STF_F (St. Francis F), STF_G (St. Francis G), WHI_A (White A), WHI_B (White B), WOO_A (Woodruff A), WOO_B (Woodruff B).

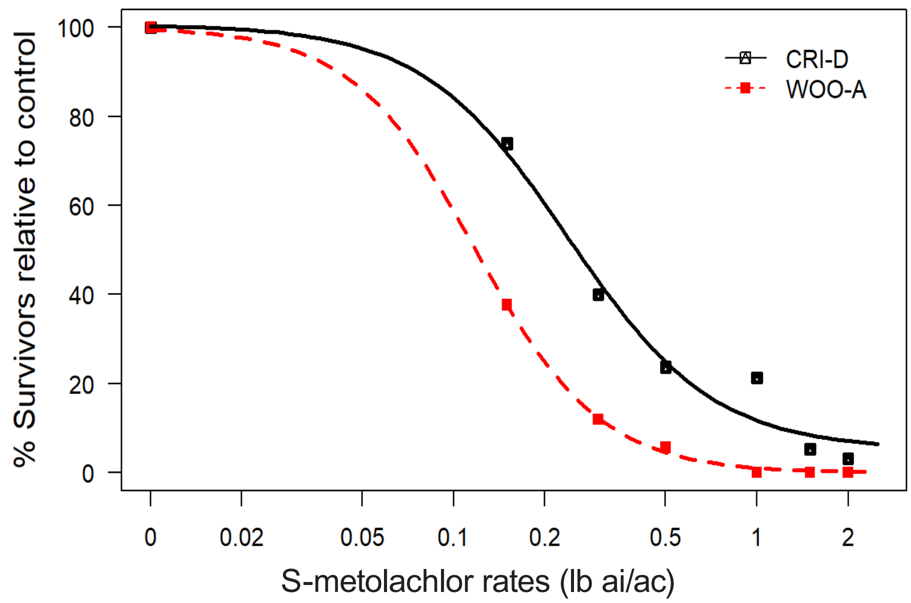

Fig. 3. S-metolachlor dose-response curves (red-dashed line for the susceptible standard and black-solid line for the resistant accession) 21 days after application.

Economic Analysis of the 2018 Arkansas Soybean Research Verification Program

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 before and within a crop growing season. The 2018 season results provide additional economic relationship insights among seasonal, herbicide, and irrigation production systems. Early-season production system fields had approximately 15% higher yields and 25% higher net returns than full-season system fields. Roundup Ready® (RR) herbicide production system fields had a 5 bushel per acre yield advantage over LibertyLink® (LL) system fields, but the field groups were virtually equal in net returns. Irrigated versus non-irrigated system comparisons indicated equal yields. Lower total cost levels associated with non-irrigated system fields gave them a 29% higher net return per acre. Early-season irrigated production systems had yields and net returns equivalent to non-irrigated fields, but full-season irrigated were lower in both respects.

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 four irrigated soybean fields. Records have been compiled each succeeding year from the fields of participating cooperators until over 600 individual fields now comprise the state data set. Among other goals, the program seeks to validate CES standard soybean production recommendations and demonstrate their benefits to state producers. Studies of the annual program reports have shown that SRVP producers consistently exceed the state average soybean yields, even as both measures have trended upward (Stark et al., 2008). Specific production practice trends have also been identified using the SRVP database such as herbicide use rates (Stark et al., 2011). Cooperating producers in each yearly cohort are identified by their county extension agent for agriculture. Each producer receives timely management guidance from state SRVP coordinators regularly and from state extension specialists as needed. Economic analysis has been the 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. An extension economist compiles the data into the spreadsheet used for the annual cost of production budget development. Measures of profitability and production efficiency are calculated for each cooperator's field and grouped by soybean production system.

Procedures

Twenty-one cooperating soybean producers from across Arkansas provided input quantities and production practices utilized in the 2018 growing season. Production from one field was considered unmarketable at harvest due to field damage and the data was excluded from the state report. A state average soybean market price was estimated by compiling daily forward booking and cash market prices for the 2018 crop. The collection period was 1 Jan. through 31 Oct. for the weekly soybean market report published on the Arkansas Row Crops Blog (Stark, 2018). Data was entered into the 2018 Arkansas soybean enterprise budgets for each respective production system (Watkins, 2018). Input prices and production practice charges were primarily estimated by the budget values. Missing values were estimated using a combination of industry representative quotes and values taken from the Mississippi State Budget Generator program for 2018 (Laughlin and Spurlock, 2018). Summary reports, by field, were generated and compiled to generate system results.

Results and Discussion

The 20 fields included in the 2018 Arkansas Soybean Research Verification Program report (Elkins et al., 2018) spanned 8 different production systems based on combinations of seasonal, herbicide, and irrigation characteristics (Table 1). The system combination utilizing a full-season,

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Roundup Ready® (RR) technology seed, and furrow irrigation was most common with 9 fields. Three fields were full-season, LibertyLink® (LL) seed, and center pivot irrigation. The full-season, Liberty Link® (LL) seed, and dryland irrigation system and the early-season, LibertyLink® (LL) seed, and furrow irrigation system combinations were found on 2 fields each. The remaining four combinations, respectively, each occurred on only one field.

All economic comparisons were developed from soybean forward book and cash market prices for the 2018 crop reported by Stark in weekly and monthly summary market reports (2018). The soybean forward book and cash market price for the 2018 crop averaged $9.36 per bushel from 1 Jan. through 31 Oct. 2018. Market price multiplied by yield gave field revenues. No grade reductions or premiums were included. All yields were standardized to 13% moisture content. Readers should note that the small number of fields in total and numbers within groups of fields represented in this study do not permit standard statistical analysis. Yield and economic results are presented by grouping only for discussion purposes.

Economic comparisons are drawn across seasonal, herbicide, and irrigation characteristics (Tables 2, 3, and 4). The values for yield, revenue, total variable cost, total fixed cost, total cost, and return to land & management are discussed.

Season Comparisons. The three early-season fields had almost 10 bu./ac higher average yields than the 17 full-season (Table 2). Revenue was $103/ac higher, but both variable and fixed costs also exceeded the corresponding costs on full-season fields. Return to land and management was over $69 per acre higher on early-season fields. These economic results, while not as large, are consistent with 2017 and support CES recommendations for early systems in Arkansas.

Herbicide Comparisons. Roundup Ready® (RR) and Liberty Link® (LL) herbicide systems were approximately equal with 11 RR and 9 LL fields (Table 3). Yield comparisons by herbicide showed the RR fields had a 5 bu./ac advantage over LL in 2018. This contradicts 2017 data where yields were essentially the same. The RR fields in 2018 were over $26/ac more expensive, $17/ac more in variable costs and $9/ac in fixed costs. Returns to land and management gave a $5/ac advantage to Roundup Ready® herbicide fields. One sharp difference that influenced the respective herbicide results was a yield advantage of 21 bu./ac on the lone RR non-irrigated field over the two LL non-irrigated fields.

Irrigation Comparisons. 2018 was an unusual year with dryland (non-irrigated) fields receiving substantial and timely rainfall. Irrigation systems employed by growers in the 2018 program were predominantly furrow (13 fields) along with center pivot (3 fields) and flood (1 field). Three program fields were non-irrigated (Table 4). The seventeen irrigated fields averaged 61.6 bu./ac compared to 69.2 bu./ac for the three non-irrigated fields. Revenue was approximately $10 higher per acre for non-irrigated fields, but substantial cost differences were seen for irrigated versus non-irrigated. Total variable costs averaged $261.87/ac over all irrigated fields compared to $232.04 on non-irrigated. Total fixed costs differed similarly with irrigated fields at $88.69/ac and non-irrigated averaging $63.24. The combination of costs left irrigated fields at an average total cost of $350.55/ac compared to $295.29/ac for non-irrigated. Return to land and management averaged $65 higher per acre for non-irrigated fields over irrigated.

Overall Comparisons. The 2018 Arkansas Soybean Research Verification Program fields had a 62.8 bu./ac statewide average yield. Revenue averaged $578.71/ac generated from this production. Total variable costs averaged $257.65 and total fixed costs averaged $84.89 for an average total cost per acre of $342.54. These revenue and cost averages left producers with an average per acre return to land and management of $236.17 across all production systems.

Practical Applications

The results of state research verification programs can provide valuable information to producers statewide. 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. Soybean Research Verification Program Production System Combinations, 2018.

Season	Early	Full	Full	Full	Full	Full	Full	Early
Herbicide	RR	RR	RR	LL	LL	LL	LL	LL
Irrigation	Furrow	Furrow	Dryland	C Pivot	Dryland	Furrow	Flood	Furrow
# Fields	1	9	1	3	2	1	1	2

Production Systems: Early = Early Season; Full = Full Season; RR = Roundup Ready;
LL = Liberty Link; Furrow = Furrow Irrigation; Dryland = Non-Irrigation;
C Pivot = Center Pivot Irrigation; Flood = Flood Irrigation.
Source: 2018 Arkansas Soybean Research Verification Program Report.

Table 2. Soybean Research Verification Program Economic Results by Seasonal System, 2018.

Seasonal Production System	**Early-Season**	**Full-Season**
Number of Fields	3	17
Yield (bu.)	71.3	61.8
Revenue ($)	667.52	564.34
Total Variable Costs ($)	287.45	251.26
Total Fixed Costs ($)	90.26	82.79
Total Costs ($)	377.71	334.05
Returns to Land and Management ($)	289.81	230.29

Source: 2018 Arkansas Soybean Research Verification Program Report.

Table 3. Soybean Research Verification Program Economic Results by Herbicide System, 2018.

Herbicide Production System	**Roundup Ready®**	**Liberty Link®**
Number of Fields	11	9
Yield (bu.)	65.1	60.0
Revenue ($)	592.96	561.29
Total Variable Costs ($)	265.58	247.96
Total Fixed Costs ($)	88.90	79.98
Total Costs ($)	354.48	327.94
Returns to Land and Management ($)	238.47	233.35

Source: 2018 Arkansas Soybean Research Verification Program Report.

Table 4. Soybean Research Verification Program Economic Results by Irrigation System, 2018.

Irrigation Production System	**Irrigated**	**Non-Irrigated**
Number of Fields	17	3
Yields (bu.)	61.6	69.2
Revenue ($)	576.20	586.56
Total Variable Costs ($)	261.87	232.04
Total Fixed Costs ($)	88.69	63.24
Total Costs ($)	350.55	295.29
Returns to Land and Management ($)	225.69	291.27

Source: 2018 Arkansas Soybean Research Verification Program Report.

Assessment of Strategies to Address Future Irrigation Water Shortage in the Arkansas Delta

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Abstract

Conversion to surface water irrigation has been identified as one of the critical initiatives to address the decline in groundwater supply in Arkansas. Using the Arkansas Irrigation Use Survey conducted by the principal investigators with collaborators, this study uses statistical analysis to estimate Arkansas agricultural producers' willingness to pay (WTP) for off-farm surface water and examine which factors have predictive powers of producers' WTP for irrigation water. The estimated mean WTP for irrigation water is $33.21/acre-foot. The comparison indicates a significant share of producers is likely to have higher WTP for surface water than the average pumping cost in the study area. Producers located in areas with fewer groundwater resources have higher WTP. Producers that are more concerned with a water shortage occurring in the state in the next 10 years have higher WTP. A somewhat unexpected result is that participation in the Conservation Reserve Program predicts lower WTP. One possible explanation is that farmers see the transfer of land out of crop production as a more viable financial decision when groundwater supply decreases.

Introduction

Irrigation is an important input in Arkansas's crop production. Nearly 86% of irrigation water in Arkansas in 2013 was sourced from groundwater in the Mississippi River Valley alluvial aquifer (MRVAA), (NASS, 2014). However, the continuous and unsustainable pumping has put the MRVAA in danger by withdrawing at rates greater than the natural rate of recharge. In the 2014 Arkansas Water Plan by the Arkansas Natural Resources Commission (ANRC), an annual gap in groundwater as large as 8.6 billion cubic meters (7 million acre-feet) is projected for 2050 and most of the expected shortfall is attributed to agriculture (ANRC, 2015). To combat growing projected scarcity, two critical initiatives have been identified: conservation measures to improve on-farm irrigation efficiency and infrastructure-based solutions to convert to surface water (ANRC, 2015). Surface water in Arkansas is relatively abundant and is allocated to farmers based on riparian water rights. The ANRC (2015) estimates that average annual excess surface water available for interbasin transfer and non-riparian use is about 7.6 million acre-feet. Currently, the purchase of off-farm surface water is relatively rare in Arkansas. In the Farm and Ranch Irrigation survey conducted by the United States Department of Agriculture National Agricultural Statistics Service (USDA-NASS) only 4.82% of all farms reported utilization of off-farm surface water in Arkansas in 2012 (USDA-NASS, 2014).

In total, ANRC (2015) estimates that the construction of needed infrastructure to shift groundwater irrigation to surface water irrigation in the nine major river basins of eastern Arkansas will cost between $3.4 and $7.7 billion. Financing these projects has grown increasingly difficult because of decreases in the availability of federal grants, cost-share, and loans (ANRC, 2015). As such, understanding the nature of water use and quantifying the full value of irrigation water to agricultural producers in the Delta will be critical for continued funding and long-run success of irrigation district projects, as well as the long-run viability of agricultural production in Arkansas.

This study has two objectives: 1) to estimate Arkansas agricultural producers' willingness to pay (WTP) for off-farm surface water; 2) to examine which factors have predictive powers of producers' WTP for irrigation water. This study is the first to provide estimates of Arkansas producers' WTP for irrigation water. In areas where infrastructure needs to be constructed to deliver surface water, estimates of the economic value of irrigation water to producers would be needed to conduct a cost-benefit analysis of such projects as well as assess the financial viability of surface water irrigation

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systems. Our research findings also help water policymakers design policies to facilitate infrastructure projects that bring surface water to farming communities in Arkansas.

Procedures

The dataset comes from the Arkansas Irrigation Use Survey conducted by the principal investigators (PIs) with collaborators from Mississippi State University. The survey was completed in October 2016 via telephone interviews. Potential survey respondents come from the water user database managed by the ANRC and all commercial crop growers identified by Dun & Bradstreet records for the state of Arkansas. The final sample size is 199 producers that completed the survey in its entirety.

The key information used in this study comes from the WTP section. Each producer first answered an initial question "Would you be willing to pay $___ per acre-foot of water to purchase water from an irrigation district?" When a respondent answered "yes" ("no"), the question was repeated at a higher (lower) bid value with a 50% increment; by increasing the interval between the first and second bid as the initial bid level increases, we control for acquiescence bias (Alhassan et al., 2013; Lee et al., 2015). For respondents who answered "no" to the initial bid and "no" to the following lower bid, a third WTP question with a nominal bid amount of 50¢/acre-foot was used to determine whether true WTP was zero or if the respondent was offering a protest bid. To reduce starting point bias, when a respondent was interviewed, one out of the six values in the unit of $/acre-foot (10, 20, 30, 40, 50, 60) was randomly selected to ask the producer (Aprahamian et al., 2007; Flachaire and Hollard, 2006). This range of values was tested in a pilot survey and confirmed as appropriate. The responses to the questions are summarized in Table 1.

The mean WTP, E(WTP), is related to the cumulative density function, $F(\cdot)$ as

$$E(WTP) = \int[1-F(b)]db \qquad \textit{Eq. 1.}$$

where b is any positive amount of money and F(b) is $Prob(WTP \leq b)$. With the assumption of a logistic distribution,

$$Prob(WTP \leq b) = 1/[1+\exp(-\alpha-\beta b-z'\delta)] \qquad \textit{Eq. 2.}$$

where z is the vector of variables that measure farm and producer characteristics such as farm location, total irrigated acres, crop mix, year of farming, gross income, education, producers' awareness of and past participation in conservation programs and producers' rating of the severity of water shortage in Arkansas. Using Eqs. (1) and (2), the mean WTP can be imputed as (Koss and Khawaja, 2001):

$$E(WTP) = -\ln[1+ \exp(\alpha+z'\delta)]/\beta \qquad \textit{Eq. 3.}$$

The parameters needed to calculate WTP, α, β and δ, are estimated using the method of maximum likelihood estimation (MLE). In MLE, the log-likelihood function, the sum of the probabilities of observing each data point in the log form, is maximized. For each observation, a "yes" response to the question "Would you be willing to pay $___ per acre-foot of water to purchase water from an irrigation district?" means a respondent's WTP is greater than or equals the amount listed in the question (Hanemann et al., 1991; Koss and Khawaja, 2001). The estimation is done using the STATA statistic software package. Summary statistics of variables are reported in Table 2.

Results and Discussion

Table 3 reports the results of the maximum likelihood estimation (MLE). If the sign of the estimated coefficient of a variable is positive, it means the variable has a positive effect on the level of WTP. The size of the effect of a variable on WTP is determined by the size of its coefficient as well as the coefficients of other variables. The coefficient of the bid variable is negative and statistically significant at the 1% level, indicating that respondents are more likely to say no to a large bid. A producer located east of Crowley's Ridge is less likely to say yes to any bid. This is probably because groundwater resources are more abundant in areas east of Crowley's Ridge and so producers are likely to exhibit lower WTP. The coefficient of the respondent's rating of groundwater shortage in the state is positive and statistically significant at the 5% level, indicating greater willingness to pay for irrigation water when groundwater resources are perceived as scarce. Respondents who indicated awareness of Arkansas' tax credit program for construction of on-farm surface water infrastructure display a greater likelihood to answer yes to a higher bid. These results highlight the importance of increasing extension efforts to raise awareness of the growing and long-term groundwater scarcity in the Delta as well as providing information that explains financial or technical assistance available to farmers who wish to transition to surface water irrigation.

A somewhat unexpected result is that Arkansas producers' WTP for irrigation water from irrigation districts decreases if they have participated in the Conservation Reserve Program (CRP). Previous studies have shown that producers who participate in conservation programs, such as the CRP, have better access to conservation information and make production decisions based on the impact of their choices in future periods (Lubbell et al., 2013). One possible explanation for this finding is that farmers see the transfer of land out of crop production as a more viable financial decision when groundwater supply decreases. The squared term of years of farming experience is added to investigate if it has a nonlinear effect on WTP. The estimated coefficients are both statistically significant at 1%. The coefficient of years of farming experience is positive and that of the squared term is negative, revealing an inverted U-shaped relationship between years of farming experience and WTP. The values of estimated coefficients indicate that the turning point is 38. That is, in contrast to findings from previous studies that age is strictly negatively correlated with WTP for irrigation water (Mesa-Jurado et al., 2012), we find that WTP for water from irrigation districts increases with years of farming experience until approximately 38 years of experience, after which, WTP decreases with years of farming experience.

The estimation results are used to derive the willingness to pay for each observation. Of producers sampled, the minimum WTP is $3.09/acre-foot and the maximum WTP is $78.98/acre-foot. The mean WTP is $33.21/acre-foot (Table 4). One important finding is that for a significant share of the producers, the estimated WTP for surface water is likely to be greater than the energy cost they are currently paying to pump groundwater from the Aquifer. The Arkansas Irrigation Use Survey did not collect information on pumping costs by the producer. Using the data on the depth-to-groundwater from the Natural Resources Conservation Service (Swaim et al., 2016) and energy prices, we calculate the pumping cost producers are currently paying to pump groundwater out. About 72% of our sample producers use both electric and diesel pumps, 12% use electric pumps and 13% uses diesel pumps. For most producers, it is more expensive to pump using diesel fuel. The price of diesel used for the calculations is $3.77/gallon, which is about the 80th percentile of the weekly diesel prices between 1994 and 2016 reported by the U.S. Energy Information Administration. Thus, our estimates of pumping costs are on the high end of the distribution of pumping costs. The estimated pumping cost for the Arkansas Delta is $22.17/acre-foot, which is about the 29th percentile using the distribution of the estimated WTPs. This means 71% of the sample producers have estimated WTPs higher than the estimated average pumping cost.

The comparison is also carried out for Lonoke County, which is located to the west of Crowley's Ridge and has the greatest average depth-to-groundwater in Arkansas. Although the median WTP is lower than the average pumping cost ($42.03/acre-foot versus $45.62/acre-foot), 28% of the sample producers have estimated WTP higher than the estimated average pumping cost in the county with the greatest average depth-to-groundwater. Mississippi County is located east of Crowley's Ridge, where the average depth-to-ground water is as shallow as 16 feet and pumping costs rarely exceed $9/acre-foot. The estimated median WTP is $24.81/acre-foot, much higher than the average pumping cost of $8.9/acre-foot. Thus, even in areas of the state where groundwater is most abundant, producers' WTP for surface water is likely to exceed the energy cost paid to pump groundwater from the aquifer.

Practical Applications

The most significant finding of this study is that for the majority of the sample producers, their estimated WTP for surface water is likely to be greater than the average pumping cost of groundwater producers are currently paying. Our study also identifies a set of factors that influence producers' WTP. For example, higher awareness of water shortage problems seems to predict increases in producers' WTP for irrigation water. This finding highlights the importance of continued outreach by the extension service to increase awareness of water problems in Arkansas. While producers are aware of growing state-level groundwater scarcity, few producers believe that scarcity is a problem that directly impacts their farm operations.

The finding that participation in the CRP decreases WTP could have important policy implications. While large water savings could be achieved by increasing producers' awareness of the CRP, such practices may also decrease the level of producers' WTP for water from irrigation districts. If the downward influence on the WTP of such programs is to the extent that irrigation districts cannot set the price of surface water to a level that allows them to recover the cost of delivering water, then the financial viability of such projects may be hampered. Similar conflicts may also arise between conservation programs that focus on improving irrigation efficiency and programs that focus on conversions to surface water. Both types of programs would positively impact the health of the MRVAA by reducing groundwater use or moving producers towards surface water resources. However, the effectiveness or viability of one program may be negatively influenced by the existence of the other program. If such changes limit the revenue earned by irrigation districts, the financial viability of such projects may also be limited. Policymakers and extension need to take such unintended consequences into account when promoting these programs. For example, conservation programs that focus on improving irrigation efficiency may be more fruitful in areas where conversion to surface water is not an option (e.g., due to lack of infrastructure).

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Table 1. Number of Yes and No Responses at Each Bid Level

		Bid		**Yes**	**(%)**	**No**	**(%)**	**Total Responses**
		(¢/m^3)	**($/ac-ft)**					
	Lower bid:	0.4	5	2	(0.33)	4	(0.67)	
Bid Set 1	Initial bid:	0.8	10	14	(0.70)	6	(0.30)	20
	Upper bid:	1.2	15	10	(0.71)	4	(0.29)	
	Lower bid:	0.8	10	5	(0.63)	3	(0.38)	
Bid Set 2	Initial bid:	1.6	20	5	(0.38)	8	(0.62)	13
	Upper bid:	2.4	30	4	(0.80)	1	(0.20)	
	Lower bid:	1.2	15	5	(0.56)	4	(0.44)	
Bid Set 3	Initial bid:	2.4	30	9	(0.50)	9	(0.50)	18
	Upper bid:	3.6	45	5	0.56	4	(0.44)	
	Lower bid:	1.6	20	7	(0.44)	9	(0.56)	
Bid Set 4	Initial bid:	3.2	40	9	(0.36)	16	(0.64)	25
	Upper bid:	4.9	60	6	(0.67)	3	(0.33)	
	Lower bid:	2.0	25	5	(0.38)	8	(0.62)	
Bid Set 5	Initial bid:	4.1	50	5	(0.28)	13	(0.72)	18
	Upper bid:	6.1	75	2	(0.40)	3	(0.60)	
	Lower bid:	2.4	30	3	(0.23)	10	(0.77)	
Bid Set 6	Initial bid:	4.9	60	7	(0.35)	13	(0.65)	20
	Upper bid:	7.3	90	1	(0.14)	6	(0.86)	

Out of the 199 producers that completed the survey, 6 respondents refused to answer both willingness to pay (WTP) questions and 1 refused to answer the second bid level. Twenty-four respondents answered “no” to this third question. Of the remaining 169 respondents, 54 registered “don’t know” responses to one or more of the proposed bid levels. All three groups of respondents were excluded from analysis. In total, 114 respondents were retained for final analysis.

Table 2. Variable Definitions and Summary Statistics

Variable	Description	Mean	St. Dev.	Min.	Max.
Crowley's Ridge	Binary variable where 1 = lives in a county to the east (in part or fully) of Crowley's Ridge, 0 = not	0.3421	0.4765	0	1
Years Farming	Total years of farming experience	30.91	14.41	1	60
Years Farming, Squared	The square of total years of farming experience	1161.35	909.89	0	3,600
Gross Income	Binary variable where 1 = gross income from all sources is greater than $75,000 and less than or equal to $150,000, 0 =not	0.4123	0.4944	0	1
Percent Farm Income	Percent of gross income from farming	81.69	26.23	0	100
Bachelor's or Higher	Binary variable where 1 = education greater than or equal to a Bachelor's degree, 0 = not	0.5614	0.4984	0	1
Total Hectares	Total irrigated in 2015	939.2	774.5	0	4,046.80
Percent Rice	Percent irrigated rice production of total hectares in 2015	27.51	26.42	0	100
Percent Soybean	Percent irrigated soybean production of total hectares in 2015	53.93	27.37	0	100
Awareness of State Tax Credit	Binary variable where 1 = is aware of state tax credit program, 0 = not	0.4825	0.5019	0	1
Conservation, CRP	Binary variable where 1 = has participated in the Conservation Reserve Program, 0 = not	0.4912	0.5021	0	1
Groundwater Shortage	Respondent rating of the severity of water shortage in Arkansas, from 0 = no shortage to 5 = severe shortage, in the state	2.66	1.96	0	5

Table 3. Maximum Likelihood Estimation Results

	Coefficient	Standard Error
Intercept	-1.6836	1.3816
Bid	-0.0615***	0.0076
Crowley's Ridge	-1.0586**	0.4356
Years Farming	0.2124***	0.0655
Years Farming, Squared	-0.0029***	0.001
Gross Income	0.4595	0.3985
Percent Farm Income	-0.1928	0.7644
Bachelor's or Higher	0.504	0.424
Total Irrigated Hectares	-0.0001**	0.0000405
Percent Rice	-0.1014	0.9423
Percent Soybean	0.8202	0.9423
Awareness of State Tax Credit	1.1214***	0.4175
Conservation, CRP	-1.1974***	0.4186
Groundwater Shortage	0.2044**	0.0985

***, **, and * denote levels of statistical significance at 1%, 5%, and 10% respectively.

Table 4. Willingness to pay (WTP) and average groundwater pumping cost.

Region	Average Depth-to-groundwater [a]	Estimated Cost of Pumping [b]	Estimated WTP	Percentile in the Distribution of Estimated WTP
Arkansas Delta	12.3m (40.49 ft)	1.8¢/m^3 ($22.17/acft)	2.7¢/m^3 ($33.21/acft) [c]	29th
Lonoke County (greatest average depth-to-groundwater in Arkansas)	25.6m (83.35 ft)	3.7¢/m^3 ($45.62/acft)	3.4¢/m^3 ($42.03/acft) [d]	72th
Mississippi County (lowest average depth-to-groundwater in Arkansas)	4.9m (16.22 ft)	0.7¢/m^3 ($8.9/acft)	2.0¢/m^3 ($24.81/acft) [d]	5th

[a] Data on the depth-to-groundwater are obtained from Arkansas Natural Resources Commission (Swaim et al., 2016).
[b] Pumping cost is computed using the average depth-to-groundwater and the cost of diesel fuel reported by the Energy Information Administration.
[c] Mean willingness to pay (WTP) is reported.
[d] Due to small sample size in each of the two counties, median WTP is reported.

Producer Preferences for Alternative Irrigation Practices

K. Kovacs[1]

Abstract

A bivariate sample selection model addresses peer network effects on participation and the intensity of use of alternative irrigation practices in Arkansas. The use of scientific scheduling and more efficient row-crop irrigation systems allows producers to manage water resources better. We find a positive relationship between belonging to a peer network of the same irrigation practice and participation in that practice. The intensity of the use of alternative irrigation techniques depends on the crop types associated with practice and income.

Introduction

One common solution policymakers have relied on to sustain groundwater levels is subsidies to increase the use of efficient irrigation techniques. The foundation for improving irrigation efficiency is measuring how much of the water applied to the field eventually reaches the plant (Bryant et al., 2017). We examine which factors, especially peer networks, influence Arkansas producers' use and the proportion of irrigated land that uses an alternative irrigation technique. A producer is in a peer network for an irrigation practice if he or she knows a family member, friend, or neighbor who uses the irrigation practice. Belonging to a peer network does not necessarily mean that the producer also uses the practice. The relationship between belonging to a peer network and the use of an irrigation practice could come about before or after a producer adopts an irrigation practice. Although the causality of the relationship is not known, the analysis helps establish whether there is a relationship and how strong it is.

Between 2007 and 2012, Arkansas' irrigated base expanded by 7.7%, and only Mississippi had a higher percentage increase (USDA-NASS, 2014). Of the more than 55 million acres of irrigated farmland in the United States in 2012, 8.6% is in Arkansas, and about three out of five cropland acres in Arkansas are irrigated (West et al., 2016). In terms of the total volume of water applied for irrigation, Arkansas ranks third in the United States with 6.45 million acre-feet of water applied, and the average amount of water applied per acre in 2012 was 16 inches. (USDA-NASS, 2014). While groundwater levels to the Mississippi Alluvial Aquifer remain high close to the Mississippi River, the Arkansas Natural Resources Commission (ANRC) identifies critical groundwater areas with depths to groundwater of 66 feet to 150 feet (ANRC, 2018). According to a national survey by the USDA, roughly 36% of farms and 45% of irrigated acres in Arkansas use at least one efficient irrigation practice (USDA-NASS, 2014). The most common practices include precision leveling or zero-grade leveling with 22% of irrigated acres followed by tailwater recovery systems, diking, and alternate row crop irrigation with 18% of irrigated acres (USDA-NASS, 2014).

This study examines two categories of efficient irrigation practices: 1) irrigation scheduling, and 2) row crop irrigation practices. The category for irrigation scheduling has two specific groups that are i) soil moisture sensors and ii) evapotranspiration (ET)/atmometers, computerized scheduling, or Woodruff Charts (ETCW). The row crop irrigation practices category includes computerized hole selection, center pivot systems, and surge irrigation. The irrigation alternatives we analyze can aid in enhanced water application to fields (Schaible and Aillery, 2012). By identifying which factors relate to the use of these practices, we can gain insight into the technology adoption process that becomes more critical as reliance on groundwater increases. Also, we study the share of land irrigated by these alternative irrigation practices in conjunction with the uses to understand what motivates producers to expand the use of their irrigation practices.

Procedures

The dataset comes from the Arkansas Irrigation Use Survey conducted by the principal investigators with collaborators from Mississippi State University. The survey was completed in October 2016 via telephone interviews. Potential survey respondents come from the water user database managed by the ANRC and all commercial crop growers identified by Dun & Bradstreet records for the state of Arkansas. The final sample size was 199 producers that completed the survey in its entirety.

The dependent variables shown in Table 1 have two types: (1) binary, for use, and (2) share, for the proportion of irri-

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gated land that uses an irrigation practice, which is on a scale between zero and one. There are 174 observations for the binary variables, while the share variables have an observation when there is participation. Only 13% of respondents use scientific scheduling, with 8% using soil moisture sensors, and 6% using one or more of the atmometers, computerized scheduling, and Woodruff Charts. Given the use of scientific scheduling, the share of irrigated land that uses the scheduling ranges from 2% to 5% of irrigated acres. Surge irrigation has the lowest use of the row crop irrigation practices, 18%, and the lowest share of irrigated land given the use of the practice at 2%. Computerized hole selection use and center pivot use are 34% and 38% of producers, respectively. Their shares of irrigated land are 11% for computerized hole selection and 9% for center pivot systems.

Peer networks explanatory variables shown in Table 2 with less than 50% of respondents answering in the affirmative are alternate wetting and drying (35%) and surge irrigation (37%). Most variables for the peer networks have a mean between 55% and 75%, with precision leveling the highest at 90%. There are also explanatory variables included in our analysis to control for crop choice. This includes the proportion of producers growing cotton (d_cotton) and sorghum (d_sorghum). Other control variables include irrigation practices and other farm management characteristics such as the shares of end blocking (share_eb), total reservoirs (tot_res), and whether a producer switched from center pivot to furrow irrigation (d_piv_fur). Additional variables are the share of acres deep tilled (share_deeptill), share of acres fertilized by gypsum (share_gypusm), and the use of electric or diesel pumps (d_electric, d_diesel). High-income level (d_income_high) includes producers with a total income above $200,000. Producers with a middle-income level (d_income_mid) had a total income between $75,000 and $200,000, and this represented the largest share of income at 42%. Some producers did not report income (d_income_na).

In a sample selection model, the dependent variable in the participation equation, y_1, is an incompletely observed value of a latent dependent variable y_1^*, where the observation rule is:

$$y_1 = \begin{cases} 1 \ \textit{if}\ y_1^* > 0 \\ 0 \ \textit{if}\ y_1^* \leq 0 \end{cases}$$

and a resultant outcome equation that

$$y_2 = \begin{cases} y_2^* \ \textit{if}\ y_1^* > 0 \\ -^* \ \textit{if}\ y_1^* \leq 0 \end{cases}$$

This model specifies that y_2 is observed when $y_1^* > 0$, whereas y_2 has no meaningful value when $y_1^* \leq 0$. The latent variables y_1^* and y_2^* indicate that the mechanism motivating participation (y_1^*) and the share of acres for a particular irrigation technique (y_2^*) is not observed for all sample observations. The standard approach specifies a linear model with additive errors for the latent variables, so $y_1^* = x_1' \beta_1 + \varepsilon_1$, and $y_2^* = x_2' \beta_2 + \varepsilon_2$, with need for non-standard estimation methods of β_2 if ε_1 and ε_2 are correlated (Heckman, 1979).

The marginal effects for the participation equation show the change in the probability of participation in response to a unit increase in a given explanatory variable. Marginal effects for the outcome equation are the expected change in y_2 for a change in an explanatory variable, conditional on participation in the use of the irrigation practice. If the independent variable appears in both the participation and outcome equations, there is an expected change in y_2 from direct effect from the explanatory variable in the outcome equation and an indirect effect from the explanatory variable in the participation equation, if there is a correlation in the error terms for the two equations. The maximum likelihood estimation for bivariate sample selection model uses Stata® version 13.1 (StataCorp LLC., College Station, Texas.)

Results and Discussion

The role of peer networks is evident in the use and share of overall scientific scheduling (Table 3). Belonging to a peer network of scientific scheduling users has a positive relationship with its use. Indeed, belonging to a peer network for a dependent variable in question typically has a positive relationship with use since most users of an irrigation practice have close peers who also use the practice. Also, belonging to a peer network of computerized hole selection, a newer technology like scientific scheduling, and a center pivot peer network has a positive effect on the share of farmland that uses scientific scheduling. However, belonging to peer networks of older practices like end blocking, zero grade leveling, and flowmeters have negative effects on the share of farmland that uses scientific scheduling. Belonging to a multiple inlet peer network group has a positive relationship with the use of scientific scheduling and, more specifically, soil moisture sensors. This may be due to multiple inlet irrigation being relatively common practice to increase irrigation efficiency, so most users of scientific scheduling would know someone who uses the technique.

Center pivots are an efficiency-enhancing irrigation practice and producers with peers who use this practice would thus also be more interested in scientific scheduling. Also, producers who switched from center pivot to furrow irrigation are more likely to have larger shares of land using scientific scheduling and soil moisture sensors. This is a reasonable relationship since those who made the switch would be looking to cut down on the high costs of center pivots but still have an interest in irrigating efficiently. Growing cotton has a negative relationship with the share of farmland in scientific scheduling that a producer uses, and this suggests that non-cotton producers switching away from center pivots are more likely to adopt scientific scheduling.

There is a relatively high, positive impact that the share of irrigated sorghum has on the share of farmland that uses soil moisture sensors. However, operations with a larger share of sorghum have a lower share of acres using ETCW. Producers with a high-income level have a positive relationship with scientific scheduling. Additionally, having a high-income level results in a positive relationship regarding the share of farmland that uses overall scientific scheduling as well as soil moisture sensors and ETCW. Having a high-income level allows producers to invest in these scheduling practices, as well as use more of it once adopted.

Only a few variables were significant with the use and share of computerized hole selection (Table 4). As expected, belonging to a peer network of computerized hole selection users has a positive relationship with its use. Since computerized hole selection is a newer practice, it makes sense that its users come from a more specialized group. The share of gypsum has a positive relationship with the share of farmland in computerized hole selection. Producers use gypsum to dilute the salinity and replenish these soils. Too much water applied to the furrows without computerized hole selection can increase the salinity of the soils. Gypsum and increasing intensity of use of computerized hole selection are then both ways to address saline soils, and this may explain why a larger share of gypsum use is positively correlated with computerized hole selection.

Those in scientific scheduling peer networks are less likely to use center pivots. These irrigation practices may be substitute approaches to increase irrigation efficiency. Cultivation of sorghum positively relates to center pivot use. This may be simply because the farming of sorghum and cotton occurs together, and much of the cotton production occurs close to the Mississippi river where center pivots are more common. Belonging to end blocking and tailwater recovery peer networks have negative relationships with the share of center pivots. End blocking is a conservation practice for furrow irrigation, so producers would not be mixing the two, and tailwater recovery systems are common in rice production areas where center pivots are not usually in use. Support for this claim is that the relationship between tail-water recovery system use and center pivot use is negative. The middle-income level increases the use, but high income is not significant, so additional income beyond middle-income does not seem to provide extra incentive to adopt.

The use of surge irrigation has a positive relationship with belonging to a peer network of its users, but the magnitude is lower than the coefficient magnitude for the computerized hole selection or the center pivot. Perhaps for rarer irrigation techniques, the role of the peer network is weaker, but high income leads to a greater intensity of surge irrigation once adopted. Surge irrigation use has a positive relationship with the use of electric motors on pumps, and the use of diesel pumps creates a negative relationship with the share of surge irrigation. There is a negative relationship with the share of deep tillage on the farm. Producers do not mix these practices. They will either use surge irrigation or deep tillage since deep tillage is already a practice used to improve water infiltration.

Practical Applications

We observe throughout the study that there is a relatively large, positive relationship between belonging to the dependent variable's peer network and the use of that irrigation practice, but this does not hold for the share of farmland that uses the practice. This applies to scientific scheduling and all three-row crop irrigation systems. However, none of the dependent variables for the share of farmland has this relationship with their peer networks. It seems that belonging to a peer network of the irrigation practice influences participation, and the magnitudes of the peer networks regarding participation were larger than the magnitudes of the control variables. However, other factors more strongly affect the share of farmland in that irrigation practice.

Income levels above $75,000 play a role in both continued use and intensity of use. Scientific scheduling use increases with a high-income level, while center pivot use increases with a middle-income level. Having only the middle-income level be significant indicates that these techniques have thresholds between $75,000 and $200,000, but having more income than $200,000 does not provide any greater incentive for producers to employ these techniques. The share of land with scientific scheduling rises with producer income for the middle and also the high-income levels. The share of farmland in surge irrigation rises if the producer income level is high. Scientific scheduling and surge irrigation are uncommon practices with capital costs, and higher income levels may help producers overcome the uncertainty and capital costs that come with increasing the share of farmland that uses these practices.

Share of farmland in scientific scheduling was positively impacted by the producer belonging to row crop peer networks like computerized hole selection, center pivot, and surge irrigation, and belonging to an end-blocking peer network was the lone row crop technique which negatively affects scientific scheduling. Peer networks groups associated with rice, like flowmeters and zero-grade leveling, had a negative impact on the share of scientific scheduling. Rice producers are less likely to invest in row crop scheduling practices. Producers using center pivots, a row crop technique, have a lower share of farmland irrigated by center pivots if the producers belong to a peer network of alternate wetting and drying or end blocking techniques. Alternative wetting and drying are for rice cultivation where center pivots are less common, and end blocking is an old conservation technique for furrow irrigation.

The analysis does not allow us to determine what the direction of the relationship is between the peer network and the use or share of farmland that uses the irrigation practice. The producer may use the practice because their peers do, or the producer may have joined the peer network group after implementing the practice on their farm. Having data over many years would help us know when the adoption of an irrigation practice occurred and when the producers' relationship with their particular peer network began. Also, we could analyze the evolution of peer networks over time: how the size of the network changes, or how the directionality of the information exchange in the network occurs. Control variables such as the farm-level cost of water, weather or climate change considerations, and soil type would also be helpful. Peer networks appear influential in Arkansas producers' use of alternative irrigation practices and the share of land using those practices. Learning more about how these peer network relationships operate may prove essential as reliance on the Mississippi alluvial aquifer grows and the depth to groundwater increases.

Acknowledgments

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Table 1. Summary statistics of dependent variables.

Variable	Definition	Mean	Std. Dev.
share_sci_sche_ac	share of scientifically scheduled acres on total irrigated acres	0.05	0.20
d_sci_sche_ac	= 1 uses a scientific scheduling technique	0.13	--
share_sms	share of soil moisture sensors on total irrigated acres	0.02	0.13
d_sms	= 1 uses soil moisture sensors	0.08	--
share_etcw	share of ET/atmometers, computerized scheduling, and/or woodruff charts on total irrigated acres	0.03	0.15
d_etcw	= 1 uses ET/atmometers, computerized scheduling, and/or woodruff charts	0.06	--
share_surge	share of surge irrigation on total irrigated acres	0.02	0.10
d_surge	= 1 uses surge irrigation	0.18	--
share_chs	share of computerized hole selection on total irrigated acres	0.11	0.23
d_chs	= 1 used computerized hole selection	0.34	--
share_cp	share of center pivots on total irrigated acres	0.09	0.22
d_cp	= 1 used center pivots	0.38	--

ET= Evapotranspiration.
Number of observations: 174. Standard deviation for binary variables is blank because this is a redundant transformation of the mean.

Table 2. Summary statistics for explanatory variables.

Variable	Definition	Mean	Std. Dev.
d_pnet_alt	=1 close family members, friends, or neighbor producers (peer network) has used alternate wetting and drying for rice irrigation in the past 10 years	0.35	--
d_pnet _chs	=1 close family members, friends, or neighbor producers (peer network) has used computerized hole selection on in the past 10 years	0.56	--
d_pnet _cp	=1 close family members, friends, or neighbor producers (peer network) has used center pivot in the past 10 years	0.67	--
d_pnet _end	=1 close family members, friends, or neighbor producers (peer network) has used end-blocking in the past 10 years	0.55	--
d_pnet _fm	=1 close family members, friends, or neighbor producers (peer network) has used flowmeters in the past 10 years	0.66	--
d_pnet _mi	=1 close family members, friends, or neighbor producers (peer network) has used multiple-inlet rice irrigation in the past 10 years	0.70	--
d_pnet _precision	=1 close family members, friends, or neighbor producers (peer network) has used precision leveling in the past 10 years	0.90	--
d_pnet _res	=1 close family members, friends, or neighbor producers (peer network) has used a storage reservoir in the past 10 years	0.65	--
d_pnet _sched	=1 close family members, friends, or neighbor producers (peer network) has used scientific scheduling in the past 10 years	0.53	--
d_pnet _surge	=1 close family members, friends, or neighbor producers (peer network) has used surge irrigation in the past 10 years	0.37	--
d_pnet _twr	=1 close family members, friends, or neighbor producers (peer network) has used a tail-water recovery system in the past 10 years	0.71	--
d_pnet _zg	=1 close family members, friends, or neighbor producers (peer network) has used zero grade leveling in the past 10 years	0.75	--
d_diesel	= 1 uses diesel motor for pumps	0.91	--
d_electric	= 1 uses electric motor for pumps	0.88	--
d_cotton	= 1 grows cotton	0.13	--
d_sorghum	= 1 grows sorghum	0.08	--
share_irr_sorghum	share of irrigated sorghum on total irrigated acres	0.01	0.06
share_deeptill	share of deeptill use on total irrigated acres	0.20	0.34
share_gypsum	share of gypsum use on total irrigated acres	0.01	0.07
tot_res	number of reservoirs on the farm	0.38	0.49
d_twr	=1 has a tailwater recovery system	0.49	--
d_piv_fur	=1 switched any acreage from pivot irrigation to furrow irrigation	0.18	--
d_income_high	=1 2014 household income from all sources before taxes is > $200,000	0.14	--
d_income_mid	=1 2014 household income from all sources before taxes is > $75,000 and < $200,000	0.42	--
d_income_na	=1 unreported 2014 household income from all sources before taxes	0.24	--

Number of observations: 174. Standard deviation for binary variables is blank because this is a redundant transformation of the mean.

Table 3. Coefficient estimates for the scientific scheduling models.

Variables	Scientific scheduling	Soil moisture sensors	ET/atmometer, computerized scheduling, and woodruff charts
Participation equation			
d_pnet_mi	1.36** (0.021)	1.19** (0.084)	0.705 (0.140)
d_pnet_sched	1.06** (0.020)	--	--
d_piv_fur	1.05** (0.005)	1.35** (0.004)	--
d_income_high	1.08** (0.040)	--	--
Outcome equation			
d_pnet_chs	0.401 (0.253)	--	--
d_pnet_cp	0.706*** (0.000)	--	--
d_pnet_end	-0.211** (0.043)	--	--
d_pnet_fm	-0.652*** (0.001)	--	--
d_pnet_surge	--	--	0.345** (0.007)
d_pnet_zg	-0.787*** (0.000)	-0.606*** (0.000)	--
d_cotton	-0.644*** (0.000)	--	--
d_income_high	0.729*** (0.000)	--	--
d_income_mid	0.393*** (0.010)	--	--
d_income_na	1.02*** (0.001)	--	--
share_irr_sorghum	-1.71 (1.179)	8.58* (0.084)	-3.61** (0.005)

Note: *, **, *** represents significance at 10%, 5%, and 1% levels, respectively.
ET = Evapotranspiration

Table 4. Coefficient estimates for row crop irrigation systems models
Table 4. Coefficient estimates for row crop irrigation systems models.

Variables	Computerized Hole Selection	Center Pivot	Surge Irrigation
Participation equation			
d_pnet_chs	1.80*** (0.000)	--	--
d_pnet_cp	--	1.69*** (0.000)	--
d_pnet_end	--	--	0.476 (0.107)
d_pnet_sched	--	-0.440* (0.083)	--
d_pnet_surge	--	--	1.46*** (0.000)
d_pnet_zg	--	--	-0.916*** (0.008)
d_cotton	--	2.02*** (0.000)	--
d_electric	0.499 (0.214)	--	0.834* (0.075)
d_income_mid	--	0.545* (0.094)	--
d_sorghum	--	1.01** (0.027)	--
d_twr	--	-0.736*** (0.004)	--
share_deeptill	0.498 (0.149)	--	-0.974* (0.073)
Outcome equation			
d_pnet_alt	--	-0.131** (0.047)	--
d_pnet_end	--	-0.279*** (0.000)	--
d_ag_edu	--	0.184*** (0.006)	
d_twr	--	-0.026 (0.533)	--
d_diesel	--	-0.433*** (0.003)	-0.560*** (0.000)
d_income_high	--	--	0.169** (0.051)
share_gypsum	0.813** (0.020)	--	--
share_irr_sorghum	-1.36** (0.038)	--	--

Note: *, **, *** represents significance at 10%, 5%, and 1% levels, respectively.

Sap Flow and Moisture Use by Soybean During Late Reproductive Growth: Implications for Improved Irrigation Management

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

Abstract

Heat balance stem flow gauges were used to measure soybean [*Glycine max* (L.) Merrill] sap flow at Marianna Arkansas in 2017 and 2018. The dynamics of sap flow in relation to plant morphology and weather conditions during the reproductive growth stages influence decisions about efficient irrigation management and other inputs for soybean high yields. Sap flow was highly correlated to solar radiation and potential evapotranspiration with maximum rates observed during full pod and beginning seed fill growth stages (R4-R5). A solar radiation efficiency (SRE) value, calculated as hourly sap flow rate per Watt-hour of solar radiation (g/Wh^2), is proposed. The SRE relates to crop water demand and hydraulic resistance of the soil-root-stem-leaf-pod-seed pathway. Solar radiation efficiency values ranged from 0–1.2 g/Wh^2. Soil moisture, growth stage, time of day, and weather conditions influenced the SRE, with higher values observed in the morning, late afternoon, and during R5 growth. Further research is needed to better understand the relationship between sap flow and soil moisture, air and canopy temperatures.

Introduction

An understanding of soybean [*Glycine max* (L.) Merrill] water dynamics in relation to soil moisture and weather conditions during the reproductive growth stages can improve irrigation water management. The water demand of soybean plants varies with growth stage and weather conditions (Payero and Irmak, 2013). In controlled environment studies, transpiration rates of soybean and maize [*Zea mays*, (L)] declined rapidly at high soil matric potential then dropped more slowly as the soil dried (Cohen et al., 1990). Other researchers detail sap flow regulation by soil moisture, solar radiation, air temperatures, and vapor pressure deficits (Angadi et al., 2003; Zhao et al., 2017). Sap flow rates of soybean and upland cotton [*Gossypium hirsutum,* (L.)] were lower in humid conditions than arid conditions in both species (Akihiro and Wang, 2002). The rate of energy use to water evaporation in leaves ranges from 20–40% (Brown and Gillespie, 1995; Mohd et al., 2007). Among different sap flow measuring methods, the thermal method (Aasamaa and Sõber, 2011), using plant stem electric heaters and temperature sensors, is relatively accurate and easy to use in field conditions. These technologies can be effective tools to further our understanding of moisture use by soybean. The objectives of this study are to investigate late-season reproductive moisture dynamics of soybean in relation to plant and environmental conditions using sap flow monitoring and the implications for improved late-season irrigation and pest management.

Procedures

Soybean were planted in 2017 and 2018 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station in Marianna to measure crop water demand by irrigated soybean in Arkansas. Soybean (Dyna-Gro 39RY43) was planted on 19 April 2017. Potential evapotranspiration (ET) was recorded hourly using atmometers. Watermark™ soil moisture sensors at 6- 12- 18- and 30-cm depths (Spectrum Technologies, Inc., Aurora, Ill.) recorded soil moisture (-cbars) hourly. Total soil moisture was calculated using retention equations derived from gravimetric core sampling. Sap flow was monitored from R5 until R8 growth using the Dynamax Flow 32 1-K system (Dynamax Inc., Fresno, Calif.). The Flow 32-1K has a data logger, a multiplexer for 8 Dynagages, and AVRD for sensor heater voltage in a weatherproof enclosure. The SGB-9 WS 9 mm diameter sap flow sensors were randomly installed on plants where stem diameters allowed within reach of the system. Weather parameters were recorded with WatchDog 2900 ET Weather Station (Spectrum Technologies, Aurora, Ill.) installed adja-

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cent to the field. The 2018 experiments examined sap flow relationships across different maturity groups and planting dates. Four different soybean varieties, P55A49X, P35T75X, P40A47X, and P48A60X were planted on 2 May, 4 May, 28 May, and 30 June 2018 respectively. Sap flow was monitored from R2 until R8 growth stages using SGA5-WS 5-mm diameter or SGB9-WS 9-mm diameter sensors, depending on basal stem diameter. Soil moisture was monitored at 0, 12, 18, and 30 inches using Watermark™ moisture sensors and using soil sample cores to measure gravimetric water content. The soil water balance during the different growth stages in both irrigated and not irrigated dry-land soybean plots was also determined.

Results and Discussion

Daily and total sap flow rates for each observed soybean variety in 2017 and 2018 are provided in Table 1. Overall, increasing sap flows were observed from R2 to R6 growth stages, then decreasing from R6.5 to R7. Negligible sap flow was observed at R8, presumably from capillary effects since all leaves had senesced. Maximum daily plant water use may reach 0.29 inches per day depending on weather conditions and plant growth stages. Peak sap flows occurred around 13:00 hrs (1:00 p.m.) on sunny days throughout the season. Sap flow highly positively correlated with solar radiation and evapotranspiration, and negatively correlated with soil moisture. A solar radiation efficiency (SRE) value was derived to express sap flow rates per watt of incoming solar radiation:

$$SRE=Q_{ev}/W_i \qquad \text{Eq. 1}$$

Where SRE is the solar radiation efficiency expressing the grams of hourly sap flow (Q_{ev}) per unit of solar radiation. The SRE is an indication of crop water demand in relation to tortuosity of water movement from the soil through root, stem, leaf, pod and seed tissue. Solar radiation efficiency values ranged from 0 (at night) to 1.2 g/Wh_2 during the day, with peaks occurring around 10:00 h (mid-morning) and 20:00 h, just before sunset (Fig. 1). The SRE was influenced by the growth stage, soil moisture supply, time of the day, and weather. Solar radiation efficiency is relatively higher in the morning hours because there is sufficient water in the plant leaf cells and water resistance is low at this time of the day. As water evaporates from the leaves, moisture demand and sap flow increase and an apparent transpiration resistance occurs resulting in lower SRE values in the afternoon hours. For 2017, the ratio of sap flow, calculated to a moisture use value based on plant population, to estimated crop evapotranspiration from atmometer (alfalfa reference) data ranged from 0.9–1.3 during R5-R6.9, then dropped to 0.2 from R6.9 to R7 (Table 2). The data reveal continuous moisture demand for soybean up to R6.9 when demand drops significantly. Total sap flow during the observed soybean growth stages approximates the calculated soil water balance amounts for these periods of soybean growth with different planting timings. The relationship between soybean yields with different planting dates versus plant water use (or sap flow) through R2-R8 growth stages is illustrated in Fig. 2. There appears to be a relationship between soybean yield and water use.

Practical Applications

The research is increasing our knowledge of the moisture dynamics of soybean from early to late seed fill growth, which are critical times concerning final yield and profits. The findings show that moisture uptake by soybean is sensitive to sunlight interception, evapotranspiration, growth stage, and soil moisture. Most revealing was that significant moisture uptake by soybean can still occur from R6.5 to R6.9 growth stage (about 7 days). Final irrigation just after the R 6.5 growth stage may increase seed weight in situations where soil moisture is near irrigation thresholds and climatic conditions favor high water demand. Sap flow analyses of soybean could help to explain plant water use–yield relations with different planting dates providing for recommendations in water limiting situations to gain the most yield potential. Also, this data can be used to develop recommendations for terminating irrigation as the direct measurements can quantify residual soil available water to finish a crop based on the growth stage. One interesting finding that has useful application is the relationship between water use and yield. Early planted group 3.5 beans yielded 70 bu./ac but had 15.34 inches of sap flow during the R2-R8 growth stages, while later planted group 4.8 beans yielded 45 bu./ac and only used 8.3 inches. Including a yield or planting date factor into recommendations to better estimate the last irrigation of the season may be a useful application of this work. More research is needed to refine our crop moisture use models and irrigation recommendations for optimum use of limited resources.

Acknowledgments

We are grateful to Arkansas soybean growers for their financial support for this research provided through the soybean checkoff funds administered by the Arkansas Soybean Research and Promotion Board. Much needed support was also provided by the University of Arkansas System Division of Agriculture. This material is based upon work that is supported by the National Institute of food and Agriculture, U.S. Department of Agriculture, under award number 1014608, Water Quantity and Quality Research to support Sustainable Irrigated Agricultural Production.

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Table 1. Summary of measured sap flow (in) in relation to soybean growth stage for 2017 and 2018, Lon Mann Cotton Research Station, Marianna, Arkansas.

Year	**2018**								**2017**	
Variety	**P55A49X**		**P35T75X**		**P40A47X**		**P48A60X**		**Dyna-Gro 39RY43**	
Planted date	5/2/2018		5/4/2018		5/28/2018		6/30/2018		4/16/2017	
Harvested date	9/16/2018		8/28/2018		9/16/2018		10/20/2018		9/21/2017	
Plant-Harvest days	137		116		111		112		158	
Growth Stages	average	sum	average	sum	average	sum	average	sum	average	sum
R2			0.22	1.97	0.26	2.42				
R3			0.26	2.81	0.27	3.01	0.26	2.35		
R4			0.28	2.22	0.27	2.13	0.25	2.03		
R5			0.26	1.83	0.27	1.61	0.15	1.07	0.29	5.27
R6			0.29	2.31	0.14	1.14	0.23	1.86	0.14	1.83
R6.5	0.26	2.31	0.23	1.85	0.12	0.93	0.07	0.58	0.15	1.64
R6.9	0.11	0.66	0.26	1.02	0.12	0.46	0.02	0.17	0.07	0.49
R7	0.11	0.44	0.08	1.01	0.04	0.50		0.04	0.03	0.48
R8	0.04	0.20	0.06	0.32	0.00	0.02		0.02	0.02	0.27
Totals										
R5-R8				8.34		4.67		3.74		9.98
R2-R8				15.34		12.23		8.13		
R6-5-R-8		3.61		4.20		1.91		0.81		2.88
Averages										
R5-R8			0.20		0.11		0.12		0.13	
R2-R8			0.21		0.17		0.17			
R6-5-R-8	0.13		0.16		0.07		0.05		0.07	

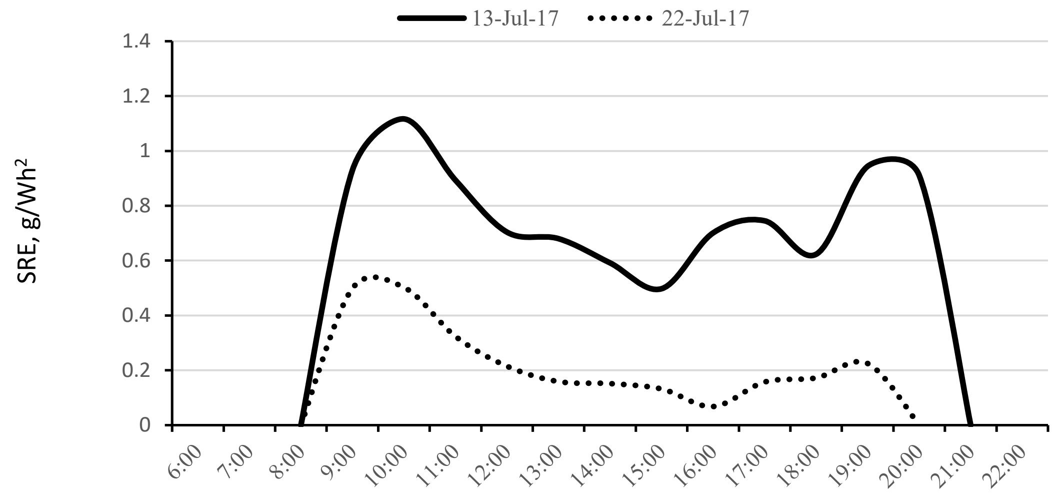

Fig. 1. Solar radiation efficiency for soybean on 13 July 2017 and 22 July 2017, University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas.

Table 2. Relationship of measured sap flow and crop evapotranspiration, measured by atmometers ('ETgage®'), during soybean seed fill in 2017, University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas.

	Sap Flow		Crop Evapotranspiration		
	Daily	Sum	Daily	Sum	
Growth Stage	----------------------------------	inches	--------------------------------------		Sap Flow/ET
R5	0.29	5.27	0.23	4.06	1.3
R6	0.14	3.96	0.17	4.63	0.9
R6-R6.5	0.18	1.83	0.16	1.58	1.2
R6.5-R6.9	0.15	1.64	0.16	1.74	0.9
R6.9-R7	0.07	0.49	0.19	1.31	0.4
R7	0.03	0.48	0.14	2.16	0.2
R8	0.02	0.27	0.17	1.88	0.1

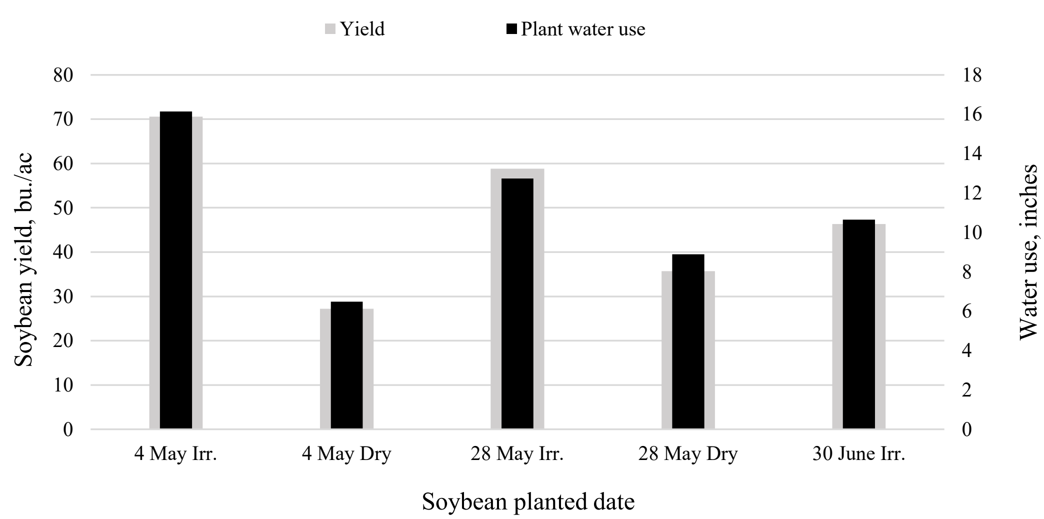

Fig. 2. Soybean yield and soybean plants water use (sap flow) through R2-R8 growth stages.

Classification of Soybean Chloride Sensitivity using Leaf Chloride Concentration of Field-Grown Soybean

N.A. Slaton[1], T.L. Roberts[1], A. Smartt[1], L. Martin[2], C. Greuner[1], R.D. Bond[1], and J.A. Still[1]

Abstract

Soybean [*Glycine max* (L.) Merrill] cultivars 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 preliminary 1 to 5 rating system was developed and implemented on 135 varieties belonging to relative maturity groups 4.6 to 5.4 based on trifoliolate leaf-Cl concentrations included in the University of Arkansas System Division of Agriculture's Rohwer Research Station location of the 2018 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 54, 8, 20, 34, and 19 varieties, respectively. Chloride concentrations of 30 individual plants of 12 varieties support the hypothesis that multiple genes may control plant Cl uptake and explains the wide range of leaflet-Cl concentrations in composite plant samples.

Introduction

Soybean cultivars have historically been categorized as being chloride (Cl) includers, excluders or a 'mixed' population. Cox (2017) showed that this three-class categorization and the method of assigning the trait inaccurately categorize 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 highlighted the varying levels of Cl inclusion and exclusion across a wide range of soybean cultivars. Individual plants of some commercial varieties are mixed populations with some plants being strong includers with high Cl concentrations, some being strong excluders with very low Cl concentrations, and some plants having intermediate Cl concentrations. The large range of Cl concentrations in individual plants suggests that there may be multiple genes that regulate Cl uptake. Traditional methods of assessing the Cl sensitivity of soybean cultivars involve short greenhouse trials (completed before reproductive growth begins) with a limited number of plants (5), which limits the scope and applicability of the results. Our research objectives were to examine the leaf-Cl concentration of commercial soybean varieties in a field production setting to assign a numerical rating from 1 to 5 and assess the uniformity of individual plant-Cl concentrations among plants of selected varieties.

Procedures

All varieties entered in the Arkansas Soybean Variety Performance trials in the mid- and late 4 (4.6-4.7 and 4.8-4.9, respectively) and early 5 (5.0-5.4) maturity groups were sampled at the Rohwer Research Station in 2018. Soybean was planted on 2 May 2018 in a field having soil mapped as a Desha silt loam following corn (*Zea mays* L.) in the rotation. Soybean was planted on beds spaced 38 inches apart with each plot having two rows. Plots were furrow irrigated three times based on an irrigation scheduling program and managed using the University of Arkansas System Division of Agriculture's Cooperative Extension Service guidelines for furrow-irrigated soybean. The variety trial was segregated by maturity group and each cultivar was represented in each of three blocks. Additional details of this trial along with yield data are available from Bond et al. (2019).

A composite sample was comprised of one recently matured (top three nodes) trifoliolate leaflet (no petiole) collected from 10 individual plants in each plot and placed in a

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labeled paper bag on 18 and 19 July when soybean was in the R3 to R4 stages. Twelve varieties were selected for more intensive sampling where the top four trifoliate leaves (including petiole) from a single plant comprised a composite sample from 30 individual plants (10 plants/replicate) to examine individual plant variability. Plant samples were oven-dried, ground to pass a 1-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 means, and the standard deviation was calculated for each variety and Cl concentration was ranked from lowest to highest (Fig. 1). 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. The Cl concentration ranges corresponding to ratings of 1 through 5 were <400 ppm, 401–1400 ppm, 1401–2400 ppm, 2401–3400 ppm, and >3400 ppm.

For the 30 individual plants, the leaf-Cl concentration means and standard deviations were calculated for each of the 12 varieties and the individual Cl concentrations were allocated into 5 concentration ranges to examine the distribution and frequency of plant-Cl concentration. The distribution and range of individual plants within each Cl range suggest whether the genes conferring Cl uptake were uniform among plants within the population.

Results and Discussion

The mean leaflet-Cl concentrations ranged from 54 to 4103 ppm Cl across the 135 varieties sampled in the three maturity group trials (Tables 1–3). In general, the standard deviation increased linearly as the mean Cl concentration increased (R^2 = 0.73) suggesting greater variability in variety Cl concentrations for mixed and includer varieties than in excluder varieties. The variety Cl concentrations within each maturity group research area showed distinct spatial variability with the mean and variability increasing from West (block 1) to East (block 3). For example, the 4.8 and 4.9 maturity group soybean trial averaged 2686 ppm Cl in block 1, 1466 ppm Cl in block 2, and 933 ppm in block 3. The mid 4 (4.6 and 4.7) and early 5 (5.0–5.4) maturity groups showed the same trend with means of 3019 and 2080 ppm Cl, 1964 and 1361 ppm Cl, and 955 and 995 ppm Cl for blocks 1, 2, and 3, respectively. This spatial variability suggests that Cl uptake is greatest at the low end of the field furthest from the water source. To validate the typical spatial variability caused by soil or irrigation water, leaf samples should be collected along the water gradient in commercial fields. These results also suggest that the lower ends of the field are most prone to injury or yield loss from Cl- and should be the first areas scouted for possible symptomology. The assigned rating of 1 represents excluder varieties with a nearly pure population of plants that have very low Cl concentrations. The very low standard deviation for cultivars 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 cultivar rating will likely change from one year to the next as the fields used for the variety trials, rainfall amounts and timing, total irrigation water use, environmental factors, and irrigation water Cl concentrations may change from one year to the next. Future field-based assessments of Cl sensitivity should include varieties that have known includer and excluder plant populations as "checks" to help calibrate the 1 to 5 category ratings as field and environmental conditions can change the total Cl accumulated.

The individual plant-Cl concentrations clearly show that varieties with very low leaf-Cl concentrations usually have very consistent individual plant-Cl concentrations and that as the mean Cl concentration increases the percentage of plants in the highest Cl concentration range also increases (Table 4). The mean Cl concentrations between the composite and 30 individual plants were very similar. The 1–5 rating system provided different interpretation or ratings of several varieties that were categorized as 'mixed' using the three-tier rating system including Eagle 4870RYX, which was field rated as a strong excluder (Table 2) and Credenz 4820LL (Table 2), Hefty 46H6 (Table 1) and Progeny 4930LL (Table 2), which were field rated as moderate (4) or strong (5) includers.

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 proposed 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 field-grown plants than the three-tier rating system of includer, excluder, and mixed. The new rating system will especially benefit growers that farm with marginal irrigation water high in Cl concentration.

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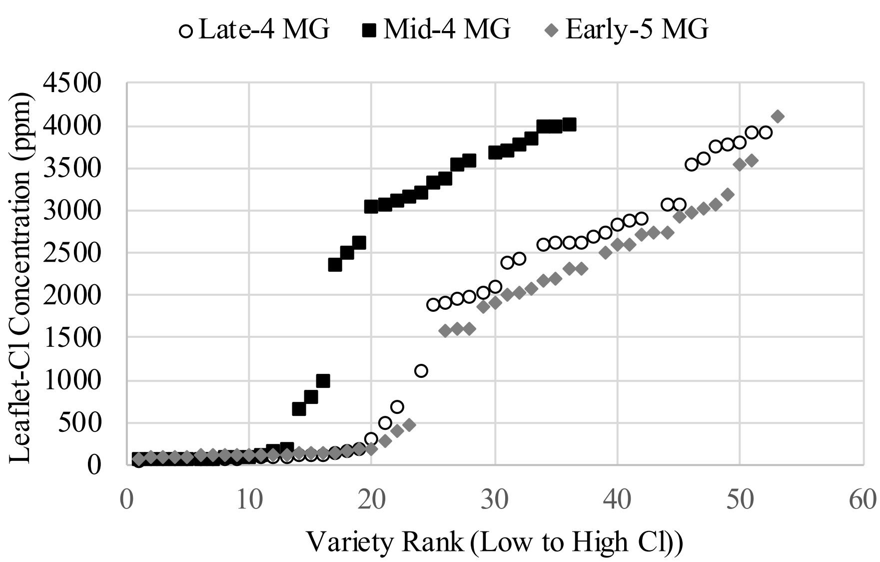

Fig. 1. Numerical ranking of leaflet-Cl concentrations (from low to high) of varieties in three maturity group categories planted in the 2018 Soybean Variety Performance Trials located at the University of Arkansas System Division of Agriculture's Rohwer Research Station.

Table 1. Mean and standard deviation (SD) of leaflet chloride (Cl) concentrations and preliminary rating for maturity group 4.6 and 4.7 cultivars as determined from field-grown plants at the University of Arkansas System Division of Agriculture's Rohwer Research Station Soybean Variety Performance trial in 2018. Rating of 1 means strong excluder and rating of 5 means strong includer.

Variety[a]	Mean	SD	Rating	Variety[a]	Mean	SD	Rating
	ppm	ppm			ppm	ppm	
Progeny 4620RXS	64	13	1	Hefty 46x6	2493	1709	4
Pioneer 47A76L	65	6	1	R15-1150	2616	956	4
Pioneer 46A57BX	65	3	1	DG 4670RR2	3051	2943	4
Pioneer 46A16R	68	13	1	R15-2422	3061	1324	4
REV 47L38	72	8	1	Credenz 4748LL	3126	2973	4
Asgrow 46X6	74	15	1	Eagle 4680RYX	3159	1964	4
AV 47W3LL	77	5	1	Local Seed 4689X	3221	2260	4
AV 47W2X	85	17	1	Asgrow 47X9	3326	2922	4
R15-818	90	11	1	AgriGold 4605RX	3385	1166	4
Credenz 4649LL	92	26	1	LGC 4710RX	3547	2844	5
AGS 46X17	119	38	1	Local Seed 4677X	3579	1388	5
Armor X46D63	158	173	1	DG 46X25	3686	2131	5
Eagle 4777RR	196	135	1	Armor X47D22	3715	2028	5
S14-9051R	667	525	2	LGS 4624RX	3775	2323	5
Petrus 479GTS	795	779	2	DG 4790RR2	3857	1604	5
REV 46L99	1000	452	2	GDM7	3978	1987	5
Progeny 4799RXS	2357	1798	3	REV 4679X	3989	2833	5
Hefty 46x6	2493	1709	4	GDM6	4024	1585	5
R15-1150	2616	956	4				

[a] Abbreviations: AV, Ag Venture; AGS, Stratton Seed; DG, Delta Grow; Eagle, Eagle Seed; GDM, GDM Seeds Inc.; LGS, LG Seeds; R, University of Arkansas; REV, Terral Seed; S, University of Missouri.

Table 2. Mean and standard deviation (SD) of leaflet chloride (Cl) concentrations and preliminary rating for maturity group 4.8 and 4.9 cultivars as determined from field-grown plants at the University of Arkansas System Division of Agriculture's Rohwer Research Station Soybean Variety Performance trial in 2018. Rating of 1 means strong excluder and rating of 5 means strong includer.

Variety[a]	Mean	SD	Rating	Variety[a]	Mean	SD	Rating
	ppm	ppm			ppm	ppm	
USG 7489XTS	54	6	1	Armor X48D02	1880	255	3
REV 4857X	61	12	1	Credenz 4938LL	1905	730	3
REV 49L88	61	10	1	AV 49W3X	1965	3287	3
Dyna S48XT56	63	18	1	Eagle 4840RYX	1972	971	3
Hefty 48x7	73	22	1	Asgrow 49X9	2019	1187	3
Pioneer 48A60X	75	27	1	Local Seed 4889XS	2102	349	3
Delta 4880	77	32	1	Hefty 49x7	2392	780	3
Progeny 4994RX	78	17	1	AgriGold 4995RX	2430	1305	4
GoSoy 49G16	80	18	1	USG 7496XTS	2594	1477	4
Local Seed 4988X	84	19	1	GDM2	2618	862	4
Dyna S48XS78	86	35	1	Delta 4970	2620	1114	4
REV 4927X	91	36	1	LGS 4989RX	2627	1520	4
Petrus Seed 4916GTS	93	26	1	Credenz 4820LL	2685	1535	4
Delta 48X45	109	31	1	GDM3	2743	1623	4
Progeny 4816RX	113	84	1	Dyna S49XS76	2840	1040	4
TN 16520R1	116	14	1	Armor X49D31	2889	1264	4
Local Seed 4966X	139	136	1	Local Seed 4968XS	2898	2771	4
Eagle Seed 4870RYX	174	117	1	Dyna S49LL34	3058	2057	4
GoSoy Ireane	179	152	1	Delta 4967LL	3063	2396	4
Asgrow 48X9	317	406	1	Progeny 4851RX	3543	1218	5
LGS C4845RX	504	717	2	Progeny 4955RX	3601	1833	5
USG 7487XTS	694	292	2	Dyna S49XT39	3744	1832	5
Delta 4977LL	1121	880	2	Eagle 4998RR	3780	1371	5
				Credenz 4918LL	3812	1736	5
				AGS 48X18	3912	2311	5
				Progeny 4930LL	3926	2838	5

[a] Abbreviations: AV, Ag Venture; AGS and GoSoy, Stratton Seeds; Delta, Delta Grow; Dyna, Dyna Gro; Eagle, Eagle Seed; GDM, GDM Seeds Inc.; LGS, LG Seeds; R, University of Arkansas; REV, Terral Seed; S, University of Missouri; TN, University of Tennessee; USG, UniSouth Genetics, Inc.

Table 3. Mean and standard deviation (SD) of leaflet chloride (Cl) concentrations and preliminary rating for maturity group 5.0 to 5.4 cultivars as determined from field-grown plants at the University of Arkansas System Division of Agriculture's Rohwer Research Station Soybean Variety Performance trial in 2018. Rating of 1 means strong excluder and rating of 5 means strong includer.

Variety[a]	Mean	SD	Rating	Variety[a]	Mean	SD	Rating
	ppm	ppm			ppm	ppm	
REV 54L18	77	12	1	AGSGS 51X18	1571	417	3
Credenz 5225LL	89	51	1	AgriGold 5000RX	1597	272	3
Credenz 5147LL	90	7	1	Dyna SX18854XT	1597	861	3
Credenz 5445LL	101	16	1	Delta 52X15	1867	257	3
Delta 5170RR2	105	18	1	Armor X50D13	1919	545	3
R13-13997-2	107	14	1	AgriGold 5288RX	1996	592	3
R14-14797RR	108	18	1	Armor X52D71	2024	597	3
Pioneer 50A78L	108	58	1	R15-1687	2088	484	3
Progeny 5554RX	110	18	1	Asgrow 52X9	2176	684	3
AV 51W1LL	115	13	1	R14-10150	2186	1390	3
R14-1422	118	50	1	Progeny 5279RXS	2314	371	3
R13-1409	126	17	1	Asgrow 53X9	2314	1505	3
R12-6751RR	129	40	1	Eagle 5220RYX	2506	979	4
Progeny 5414LLS	141	18	1	R14-15079	2596	1379	4
R15-1587	144	99	1	Credenz 5150LL	2603	1451	4
Asgrow 54X9	147	74	1	Eagle 5420RYX	2724	487	4
R14-898	147	27	1	Progeny 5016RXS	2731	1872	4
GoSoy 50G17	155	57	1	GDM4	2744	1392	4
Credenz 5328LL	178	104	1	Dyna SX18652XS	2932	1181	4
R15-2465RR	189	62	1	Progeny 5018RX	2967	1059	4
R13-818	293	343	1	Local Seed 5087X	3016	1785	4
GoSoy 51C17	409	480	2	R15-489	3062	1121	4
R15-1194	472	229	2	Progeny 5252RX	3175	2157	4
				Armor X51D77	3543	1894	5
				R14-356	3597	1303	5
				Dyna S52XT08	4103	1252	5

[a] Abbreviations: AV, Ag Venture; AGS and GoSoy, Stratton Seeds; Delta, Delta Grow; Dyna, Dyna Gro; Eagle, Eagle Seed; GDM, GDM Seeds Inc.; LGS, LG Seeds; R, University of Arkansas; REV, Terral Seed; S, University of Missouri; USG, TN, University of Tennessee; USG, UniSouth Genetics, Inc.

Table 4. Mean and standard deviation (SD) of leaflet chloride (Cl) concentrations and preliminary rating for maturity group 5.0 to 5.4 cultivars as determined from field-grown plants at the University of Arkansas System Division of Agriculture's Rohwer Research Station Soybean Variety Performance trial in 2018. Rating of 1 means strong excluder and rating of 5 means strong includer.

				Leaf Cl Concentration Range (ppm)				
Cultivar	Rating[a]	Mean	SD	0–400	401–1400	1401–2400	2401–3400	>3400
		----ppm Cl-----		-------------------- % of total plants --------------------				
Eagle 4870RYX	M	54	21	100	0	0	0	0
Pioneer 46A15R	E	69	26	100	0	0	0	0
Dyna-Gro 48XT56	E	90	56	100	0	0	0	0
R14-147977RR	E	108	37	100	0	0	0	0
GoSoy Ireane	E	254	662	97	0	0	0	3
Credenz 5150LL	I	1922	1050	0	43	33	10	13
Dyna-Gro 49LL34	M	2592	2147	3	27	37	7	27
Credenz 4820LL	M	3010	175	0	10	43	27	20
Dyna-Gro 49XS76	I	3069	1522	0	3	40	27	30
Hefty 46H6	M	3259	2298	0	20	40	7	33
Credenz 4748LL	I	3287	1941	0	13	30	17	40
Progeny 4930LL	M	4019	2388	0	27	7	10	57

[a] Rating, the prior rating of each cultivar assigned to the commercial variety using the three-tier system: I = includer; E = excluder; and M = mixed.

Soybean Response to Aspire® and Muriate of Potash Application Time

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Abstract

Fertilizer potassium (K) is sometimes applied in the fall for summer-grown crops like soybean [*Glycine max* (L.) Merrill]. The research objective was to examine the effect of fertilizer source and application time on soybean yield and leaf-nutrient concentration. Fertilizer treatments including a no-fertilizer control and three treatments including 60 lb K_2O/acre, or K and 0.5 lb/ac of boron (B) were applied in either October (fall) or April (Spring) to a silt loam soil with low soil-test K. Yield was not affected by fertilizer application time but was affected by fertilizer source with soybean receiving Aspire fertilizer (69 bu./ac) or muriate of potash plus granular B (69 bu./ac) producing equal yields that were similar to K alone (68 bu./ac) and greater than the no-fertilizer control (63 bu./ac). Leaflet-K concentrations were equal among treatments receiving fertilizer K regardless of source or application time. Leaflet-B concentrations were similar between fall and spring application times (32 ppm) for soybean fertilized with Aspire and greater than treatments that received no B (20 ppm). Fall- and spring-applied K and B fertilizers produce similar crop yields and soybean-plant nutrition benefits.

Introduction

The right time of fertilizer application is one of the 4 Rs of nutrient stewardship. Fertilizer sales data from the Arkansas State Plant Board show that the majority of phosphorus (P) and potassium (K) fertilizer is sold, and likely applied to production fields, between February and July. Each fall growers ask whether fall application of fertilizer P and K is equal to spring application before or at planting. Our previous work showed that soybean responded equally to fall, winter, and spring applications of fertilizer K (Slaton et al., 2010a,b). The standard recommendation regarding K application time is that fertilizer K may be applied in fall or spring unless the field is prone to natural flooding, will be flooded for waterfowl habitat, the soil has very low cation exchange capacity, or the soil is very low in K and K deficiency has been a problem. It is interesting to note that K loss in field runoff water can be substantial (Sharpley et al., 2019).

A recent question was asked regarding whether fall and spring applications of Aspire® (0-0-58-0.5B; The Mosaic Company, Plymouth, Minn.) would provide equal B availability to soybean. None of our prior soybean research has examined fall versus spring application times of B fertilizer. The objective of this research was to compare soybean-leaflet-nutrient concentration and yield response to fertilizer application time (fall vs spring) and fertilizer K source (muriate of potash vs Aspire).

Procedures

Soybean was grown in a single trial at the University of Arkansas System Division of Agriculture's Pine Tree Research Station on a Calhoun silt loam. The trial site was conventionally tilled in mid-October 2017, plot boundaries were marked, and each plot was assigned a treatment. Composite soil samples were collected from the 0- to 4-inch depth in each plot (n = 6) designated as a no-fertilizer control. The mean soil chemical property values were 7.2 pH, 14 ppm Mehlich-3 P, 75 ppm Mehlich-3 K (13 ppm standard deviation), 6 ppm Mehlich-3 S, 0.3 ppm Mehlich-3 B, 16 cmolc/kg cation exchange capacity by summation, and 1.9% organic matter by loss on ignition. Triple superphosphate was broadcast at planting to supply 50 lb P_2O_5/ac.

On 31 October 2017, the fall fertilizer treatments were applied to a crusted soil surface (due to rain following the prior tillage). The spring fertilizer application was made to the soil surface on 11 April 2019. The trial included four fertilizer sources including no-K or -B fertilizer, 60 lb K_2O/ac as muriate of potash (60% K_2O), 60 lb K_2O/ac as muriate of potash plus 0.5 lb B/ac as Granubor 2 (14.3% B), and 60 lb K_2O/ac as Aspire®. Soybean was drill seeded into a no-till seedbed on 17 April 2018 with Pioneer 40A47X soybean. Individual plots were 30 ft long and contained five rows of soybean spaced 15 in. apart. The emerged plant population averaged 92,000 plants/ac. Soybean was flood irrigated as needed during the growing season.

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Trifoliolate leaflet samples from selected treatments in blocks 1 through 4 were collected at the R4-R5 stage on 24 July. Tissue samples consisted of the mature trifoliolate leaflets taken from one of the top three nodes from 10 plants per plot. Leaflet tissue was digested with concentrated HNO_3 and 30% H_2O_2 and analyzed for K and B by inductively coupled plasma spectroscopy. Four of the five soybean rows were harvested with a small plot combine on 17 September 2018. Grain yield was adjusted to 13% moisture before yields were calculated.

The trial was a randomized complete block design with a 2 (K timing) by 4 (K source) factorial arrangement and contained six blocks. Analysis of variance was performed on grain yield with K application time and K source as fixed effects and block as a random effect. Leaflet-K and -B concentration data were analyzed as a randomized complete block design because samples were collected from only one no-K or -B control and both the fall and spring applications of muriate of potash and Aspire. Differences were interpreted as significant when the fixed-effects *P*-value was ≤ 0.10. When appropriate, means were separated by Fisher's least significant difference. Six plots on the outside perimeter of the trial were omitted due to continual and excessive foliage removal from deer browsing.

Results and Discussion

Leaflet-K concentrations were equal among all treatments that received muriate of potash or Aspire applied in the fall or spring, which were all greater than soybean that received no K (Table 1). Leaflet samples were collected 56 days after the R1 stage as predicted by SoyMap (Popp et al., 2016). At this stage, the leaflet-K concentrations predicted to produce 95% and 90% of maximum yield were 1.04% and 0.91% K, respectively, (Slaton, unpublished data) indicating that near maximum yield was produced by 60 lb K_2O/ac. Soybean fertilized with Aspire applied in the fall or spring had equal leaflet-B concentrations that were greater than all other treatments, which had B concentrations near the critical leaflet-B concentration of 20 ppm.

Soybean grain yield was affected only by the main effect of fertilizer source, averaged across the fall and spring application times (Table 2). Soybean receiving both K and B produced greater yields than soybean receiving no K or B. The time of fertilizer application had no significant influence on soybean yield ($P = 0.6823$). For treatments that included K (excluding the control), the mean soybean yield for fall applications was 69 bu./ac compared to 68 bu./ac for spring-applied fertilizer.

Practical Applications

Results of this single trial confirmed that fertilizer K may be applied in the fall or spring to silt loam soils with below optimal soil-test K with equal yield and crop nutrition results. New information resulting from this trial was that B applied as Aspire in the fall or spring provided similar plant B nutrition. These findings suggest that growers can apply fertilizer K and B in the fall or spring with equal results.

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Table 1. Soybean leaflet-K and -B concentrations at the R4 to R5 growth stage as affected by fertilizer treatment.

Fertilizer K source	Application time	K rate	B rate	Tissue concentration K	Tissue concentration B
		lb K_2O/ac	lb B/ac	ppm K	ppm B
None	None	0	0	0.753	21.6
Muriate of Potash	Fall	60	0	0.987	20.7
Aspire	Fall	60	0.5	0.967	32.3
Muriate of Potash	Spring	60	0	0.962	20.8
Aspire®	Spring	60	0.5	0.971	32.0
			LSD 0.10	0.078	2.7
			P-value	0.0007	<0.0001

Table 2. Soybean yield as affected by the main effect of fertilizer source, averaged across fall and spring application times.

Fertilizer source	K rate	B rate	Grain yield
	lb K_2O/ac	lb B/ac	bu./ac
None	0	0	63
Muriate of Potash	60	0	68
Muriate of Potash + B	60	0.5	69
Aspire®	60	0.5	69
		LSD 0.10	4.5
		P-value	0.013

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