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Jeremy Ross, Editor

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Cover photo: Soybean hand-pollinations in Fayetteville, Ark. Inter-crossing soybeans is the first step of a breeding program. Every year, 300 to 400 new populations are started by making hand pollinations in the field. It takes about 5 minutes for a technician to pollinate one soybean flower, and about 50 flowers are needed for each pollination. Hand-pollinating soybean is probably the most time-consuming amongst row crops. Photo credit: Fred Miller, University of Arkansas System Division of Agriculture, Fayetteville, Ark.

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Arkansas Agricultural Experiment Station, University of Arkansas System Division of Agriculture, Fayetteville. Mark J. Cochran, Vice President for Agriculture; Jean-François Meullenet, Interim AAES Director and Associate Vice-President for Agriculture–Research. WWW/CC2018.

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Preface

The 2016 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 report in this publication will appear in other University of Arkansas System Division of Agriculture's Arkansas Agricultural Experiment Station publications. This duplication is the result of the overlap in research coverage between disciplines and our effort to inform Arkansas soybean producers of the research being conducted with funds from the Soybean Check-off Program. This publication also contains research funded by industry, federal, and state agencies.

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

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

Extend 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.

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The Arkansas Soybean Promotion Board

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Introduction

Arkansas is the leading soybean-producing state in the mid-southern United States. Arkansas ranked 11th in soybean production in 2016 when compared to the other soybean-producing states in the U.S. The state represents 3.4% of the total U.S. soybean production and 3.8% of the total acres planted to soybean in 2016. The 2016 state soybean average was 47 bushels per acre, 2.5 bushels per acre less than the state record soybean yield set in 2014. The top five soybean-producing counties in 2016 were Mississippi, Phillips, Poinsett, Crittenden, Arkansas Counties. These five counties accounted for 34.7% of soybean production in Arkansas in 2016.

While the final State average soybean yield was good, many challenges presented themselves throughout the 2016 growing season. The early planting progress was on par with the 5-year average, but with exceptional environmental conditions during May and June the later planting progress exceeded the 5-year average by as much as 25%. The 2016 soybean crop was expected to be an excellent crop until rainy, cloudy weather persisted for over 14 days during mid-August. Because of the this unseasonal weather pattern, many soybean producers had increased foliar disease pressure, flooded fields, pod splitting, and seed sprouting within pods. Flooding in Clay, Jackson, Lawrence, Randolph, and White Counties caused estimated economic losses totaling $10,000,000. This loss was due to reproductive soybean plants being completely under water for more than 48 hours and reduced seed quality at harvest. In addition, foliar diseases such as aerial web blight, Cercospora leaf blight, anthracnose, pod and stem blight, Frogeye leaf spot, and target spot developed rapidly and caused some yield decline. In addition to increased late-season disease issues, many fields in the state were treated for several insect pest including corn earworms, other caterpillar species, and stinkbugs. Redbanded stinkbugs were reported further north late in the growing season than ever before. Additional populations of Palmer amaranth population with protoporphyrinogen oxidase (PPO)-resistance were identified in 2016; thus, almost every row crop county in Eastern Arkansas has 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. Dicamba tolerant soybean were introduced during the 2016 growing season without any dicamba product labeled for over-the-top application. Several reports of off-label dicamba applications were reported to the Arkansas State Plant Board during 2016.

Table 1. Arkansas soybean acreage, yield, and production, by County, 2015-2016.[a]

	All Planted		Harvested		Yield		Production	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**
County	*Acres*		*Acres*		*Bushels*		*Bushels*	
Arkansas	160,200	163,000	160,100	162,800	53.9	54.4	8,626,400	8,854,000
Ashley	57,200	48,400	56,600	48,400	56.1	58.2	3,174,400	2,819,000
Chicot	162,400	143,800	161,300	143,600	53	52.7	8,541,000	7,573,000
Clay	117,900	109,100	117,700	107,600	49.9	46.8	5,873,000	5,035,000
Craighead	139,600	107,700	139,400	105,300	52	48.8	7,242,000	5,136,000
Crittenden	184,200	202,900	181,800	202,800	43.7	43.7	7,942,000	8,872,000
Cross	136,600	149,800	136,400	149,600	48.2	47.7	6,570,000	7,133,000
Desha	165,900	143,300	165,400	143,300	61.1	55.7	10,100,000	7,988,000
Drew	36,800	33,300	36,800	33,300	57	53.5	2,096,600	1,781,000
Greene	66,300	67,300	66,100	66,300	45.2	43.8	2,985,000	2,906,000
Independence	28,900	26,900	28,600	24,300	40.8	38.6	1,166,000	937,000
Jackson	114,600	122,400	114,000	121,000	40.5	39.2	4,618,000	4,745,000
Jefferson	110,400	83,700	105,300	83,600	60.6	52.1	6,378,000	4,359,000
Lawrence	50,700	58,400	50,400	55,500	37.9	35.7	1,908,000	1,981,000
Lee	133,500	137,300	131,300	136,700	47.6	43.5	6,247,000	5,940,000
Lincoln	77,000	62,900	76,800	62,800	58.3	56.3	4,474,000	3,537,000
Lonoke	112,500	106,600	111,500	105,900	46.4	46.3	5,168,600	4,906,000
Mississippi	297,300	273,200	294,900	272,900	53	48.9	15,621,000	13,345,000
Monroe	101,100	106,000	100,600	105,500	46.4	43.2	4,663,000	4,561,000
Phillips	203,800	213,500	201,000	211,300	47.1	48.9	9,469,000	10,325,000
Poinsett	183,400	179,600	183,000	179,400	51.8	51.0	9,477,000	9,153,000
Prairie	103,900	99,900	103,600	99,400	47.9	50.0	4,967,000	4,966,000
Randolph	35,900	34,400	35,700	29,900	45.2	38.0	1,614,000	1,135,000
Saint Francis	125,500	147,000	125,300	145,000	43.4	44.5	5,444,000	6,458,000
White	32,400	35,000	32,200	33,100	39.8	37.9	1,280,000	1,254,000
Woodruff	121,700	115,500	121,400	114,500	40.7	35.7	4,937,000	4,085,000
Other Counties[b]	55,200	47,500	52,900	46,700	31.8	36.8	1,741,000	1,838,900
State Totals	3,200,000	3,130,000	3,170,000	3,100,000	49.0	47.0	155,330,000	145,700,000

[a]Data obtained from USDA-NASS, 2017.
[b]Benton, Conway, Crawford, Faulkner, Franklin, Lafayette, Logan, Perry, Pope, and Yell Counties.

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Developing Profitable Irrigated Rotational Cropping Systems

J. Kelley[1]

Abstract

A long-term field trial evaluating yield and resulting economic outcomes of eight rotational cropping systems that include soybean, wheat, corn, and grain sorghum was initiated at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, near Marianna, Arkansas in April of 2013. Wheat yields from wheat harvested in June 2014 did not differ when planted following corn, grain sorghum, or early-season soybean the previous year and averaged 72 bu/ac. In 2015, wheat yields following corn were slightly lower than when following other crops, but all rotations had similar yields. Corn yield was not impacted by previous crop in 2014 or 2015 with average yields of 248 and 220 bu/ac respectively; however in 2016, corn planted following corn yielded significantly less than when planted following early planted soybean or double-crop soybean. The reason for reduced corn yields is unknown as no foliar diseases were noted and all inputs were identical between treatments. Significant yield differences were seen for early-season soybean yields depending on the previous crop. In 2014, early-season soybean planted in April yielded only 43 bu/ac when following soybean, but yielded 64 bu/ac when following corn or grain sorghum. In 2015 and 2016, early-season soybean yields did not differ between rotations. In 2014, double-crop soybean following double-crop soybean only made 30 bu/ac but double-crop soybean that followed corn or grain sorghum produced 39 and 40 bu/ac respectively. In 2015 and 2016, a similar trend was seen with double-crop soybean following double-crop soybean yielding less than those following corn or grain sorghum. Differences in soybean yields were likely in part caused by high soybean cyst nematode levels. Economic analysis of profitability of each cropping system evaluated is ongoing.

Introduction

In Arkansas and the mid-South region, most of the crop rotation studies in past years have focused on cotton and have shown greater yields when crop rotation is used. Reasons for increased cotton yields generally involved reduction in reniform nematodes, less disease pressure and/or increased soil fertility, or from unknown reasons. As crop makeup continues to shift based on economic decisions, more information is needed for producers on which crop rotation produces the greatest yields and profitability under mid-South irrigated conditions. There is a lack of long-term crop rotation research that documents how corn, soybean, wheat, and grain sorghum rotations perform in the mid-South. A comprehensive evaluation of crop rotation systems in the mid-South is needed to provide non-biased and economic information for Arkansas producers.

Procedures

A long-term field trial evaluating yield and resulting economic outcomes of eight rotational cropping systems that Arkansas producers may use was initiated at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station near Marianna, Arkansas in April of 2013.

The eight rotational cropping systems evaluated include;

1. *Corn-Soybean-Corn-Soybean*. Corn planted in March/April, then early-season group 4 soybean the following year.
2. *Corn-Wheat- Double-Crop Soybean-Corn*. Corn planted in March/April,wheat planted following corn harvest, double-crop soybean planted after wheat harvest, and corn planted the following year.
3. *Soybean-Wheat-Double-Crop Soybean-Wheat*. Early-season group 4 soybean, wheat planted after soybean harvest, double-crop soybean after wheat harvest.
4. *Grain Sorghum-Wheat-Double-Crop Soybean-Grain Sorghum*. April planted grain sorghum, wheat planted following grain sorghum harvest, double-crop soybean planted after wheat harvest and full-season grain sorghum planted the following year.
5. *Continuous Corn*. Corn planted in March/April every year.
6. *Continuous Soybean*. Early-planted group 4 soybean planted in April every year.
7. *Grain Sorghum-Soybean-Grain Sorghum-Soybean. Full-season Grain Sorghum*, followed by early planted group 4 soybean planted the following year.
8. *Soybean-Wheat-Double-Crop Grain Sorghum-Soybean*. Group 4 soybean planted in April, wheat planted following soybean harvest, double-crop grain sorghum planted after wheat harvest followed by early planted group 4 soybean the following year.

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The soil in the experiment area is a Memphis silt loam which is typical for the area. The field had previously been cropped to soybean in 2012. Crop rotation treatments were replicated four times within a randomized complete block design, all treatments were conducted each year, and plots size was 25 ft wide (8 rows wide) by 200 ft long. All plots were conventionally tilled and summer crops were planted on raised beds on 38-in. row spacing. Wheat plots planted each fall were also planted on 38-in. wide raised beds and planted with a grain drill with 6-in. row spacing at 120 lbs of seed/ac. Summer crops were furrow irrigated as needed according to the University of Arkansas System Division of Agriculture's Cooperative Extension Services' (CES) irrigation scheduler program. Normal production practices such as planting dates, seeding rates, weed control, insect control, and fertilizer recommendations for each crop followed current CES recommendations. Harvest yield data was collected from the center two rows of each plot and remaining standing crops were harvested with a commercial combine. Soil nematode samples were taken at trial initiation from all plots after harvest in the fall and analysis showed high levels of soybean cyst nematode in most plots that were above the economic threshold of 500 nematodes/100cm3 of soil (data not shown).

Results and Discussion

The results discussed below are from 2014 to 2016 and represent the first three years of yield data from this project (Tables 1-3). Wheat yields in June 2014 ranged from 69 to 75 bu/ac and previous crop did not have an impact on yield. Similar results were seen in 2015, but wheat following corn was slightly lower yielding than when following soybeans. Due to dry and then wet conditions in the fall of 2015, wheat was not able to be planted timely and therefore was not planted. Wheat harvest in 2014 was delayed by the lateness of the crop and rainfall at harvest, which delayed double-crop soybean planting until 7 July, reducing the overall yield potential; however, significant differences in yield were seen based on previous crop. In 2014, double-crop soybean averaged 39 and 40 bu/ac respectively, when following corn or grain sorghum and only 30 bu/ac when following early-season soybean the previous year. In 2015, a similar trend was seen with double-crop soybean generally yielding less when following double-crop soybean the previous year. In 2016, to simulate double-crop soybean planting since wheat was not planted the fall before, soybean planting was delayed until early June to represent a double-crop planting time. Double-crop soybean yields in 2016 did not differ from previous crop and ranged from 46 bu/ac following double-crop soybeans the previous year to 49 and 50 bu/ac, respectively, following corn or grain sorghum.

In 2014, yields of early-season soybean varied greatly depending on which crop had been planted the previous year. When early-season soybean followed corn or grain sorghum, yields were 64 bu/ac compared to only 43 bu/ac for when following early-season soybean. In 2015, no differences in early-planted soybean yield were seen between any rotations with yields ranging from 49 to 51 bu/ac. In 2016, early planted soybean yields did not statistically differ between rotations with soybean followed by soybean yielding 47 bu/ac compared to 52 and 56 bu/ac, respectively, for corn and grain sorghum.

Corn yield did not vary based on previous crop in 2014 or 2015, with very high average yields of 248 and 220 bu/ac, respectively. In 2016, corn following corn yield was significantly lower than when following early planted soybean or double-crop soybean. The reduced yield of corn following corn (4th consecutive year of corn) was not obvious as no differences in foliar disease was seen and all other inputs were identical. The reduction in yield for continuous corn was expected based on previous research that has been conducted in the Midwest. More years of data are needed to verify the trend of lower corn yields when corn is planted following corn.

Full-season grain sorghum is grown as a rotational crop and will always be following soybean. Average grain sorghum yields in 2014 and 2015 were very good and averaged 143 and 123 bu/ac respectively. In 2016, rainfall in mid-August at maturity caused approximately 30% sprout damage and reduced grain quality and yield. Full-season grain sorghum averaged 112 and 113 bu/ac, respectively, when planted following double-crop soybean and early planted soybean and did not differ between the two rotations. Double-crop grain sorghum was greatly impacted by sugarcane aphid in 2014 and was not harvested. In 2015, double-crop grain sorghum planted in early June yielded 88 bu/ac. Sugarcane aphids were controlled; however several insecticide applications were needed. In 2016, double-crop grain sorghum was planted in early June to simulate a double crop planting time since wheat was not planted the fall before. A sugarcane aphid tolerant grain sorghum hybrid (DKS 37-07) was planted. The planting of a sugarcane tolerant hybrid reduced the need for foliar insecticide sprays to control aphids, but sorghum midge and headworms still needed insecticides for control. Yield of double-crop grain sorghum averaged 92 bu/ac in 2016. Grain quality was excellent and no sprout damage was seen like in the full-season grain sorghum.

Economic analysis is ongoing and is not included in this report at this time.

Practical Applications

As producers search for the most profitable production system, data from this project will provide local yield and corresponding economic data to help guide decisions on ways to improve profitability of irrigated cropping systems for Arkansas and mid-South crop producers.

Acknowledgements

Funding for this project was provided by the Arkansas Soybean, Corn and Sorghum, and Wheat Research Promotion Boards and is greatly appreciated. Support also provided by the University of Arkansas System Division of Agriculture.

Table 1. Wheat, corn, grain sorghum, early-season soybean, and double-crop soybean yields from 2014 based on previous crops grown in 2013.

Previous Crop in 2013	Wheat	Corn	Grain Sorghum	Early-Season Soybean	Double-Crop Soybean
	-----	-----	bu/ac	-----	-----
Early-Season Soybean	75	250	143	43	30
Corn	72	245	---	64	39
Grain Sorghum	69	---	---	64	40
LSD (0.05)	NSD	NSD	---	13	4

Table 2. Wheat, corn, grain sorghum, early-season soybean, double-crop soybean and double-crop grain sorghum yields from 2015 based on previous crop grown in 2014.

Previous Crop in 2014	Wheat	Corn	Grain Sorghum	Early-Season Soybean	Double-Crop Soybean	Double-Crop Sorghum
	-----	-----	bu/ac	-----	-----	-----
Early-Season Soybean	72	221	119	49	---	88
Corn	68	224	---	49	43	---
Grain Sorghum	73	---	---	51	42	---
Double-Crop Soybean	69	214	126	---	38	---
Double-Crop Sorghum	---	---	---	50	---	---
LSD (0.05)	4	NSD	NSD	NSD	NSD	---

Table 3. Wheat, corn, grain sorghum, early-season soybean, double-crop soybean and double- crop grain sorghum yields from 2016 based on previous crop grown in 2015.

Previous Crop in 2015	Wheat*	Corn	Grain Sorghum	Early-Season Soybean	Double-Crop Soybean	Double-Crop Sorghum
	-----	-----	bu/ac	-----	-----	-----
Early-Season Soybean	--	207	113	47	---	92
Corn	--	181	---	52	49	---
Grain Sorghum	--	---	---	56	50	---
Double-Crop Soybean	--	198	112	---	46	---
Double-Crop Sorghum	---	---	---	54	---	---
LSD (0.05)		20	NSD	NSD	NSD	---

*Due to wet conditions in the fall of 2015, wheat was not able to be planted timely and was not planted. Double-crop soybean and double-crop grain sorghum was planted in June to simulate a double-crop planting date.

Seed Nutrient Concentration Differences among High- and Average-Yielding Areas of Soybean Production in Arkansas

T.C. Adams[1], K.R. Brye[2], L.C. Purcell[2], and W.J. Ross[3]

Abstract

Continued increases in average soybean [*Glycine max* (L.) Merr.] yield will depend on decreasing the yield gap, defined as the difference between current and potential yield, which is the yield of a cultivar grown with the best technologies without limitations on nutrient and water availability and with biological stresses effectively controlled. Research in annual state yield contest fields can provide critical information about yield potentials and plant response differences between ultra-high and average producing areas. Therefore, the objective of this study was to assess seed concentration differences between high- and average-yield areas across soybean growth stages. During the 2015 growing season, in each of seven regions of the "Grow for the Green" yield contest in Arkansas, one contest-entered, high-yield (HY) area in close proximity to one average-yield (AY) area were plant-sampled at the mid-R5, mid-R6, and harvest maturity (HM) growth stages. Grain yields in AY areas ranged from 40 to 98 bu ac^{-1} (2688 to 6585 kg ha^{-1}; 13% moisture) and averaged 69 bu ac^{-1} (4664 kg ha^{-1}), while yields in HY areas ranged from 42 to 109 bu ac^{-1} (2822 to 7324 kg ha^{-1}) and averaged 82 bu ac^{-1} (5647 kg ha^{-1}). Among all growth stages and yield areas, seed potassium (K) concentration was greatest ($P < 0.05$) in HY areas at mid-R5 across regions 1.95% (19.5 g kg^{-1}). Averaged across growth stage, seed boron (B) concentration was greater ($P < 0.05$) in HY 31.76 ppm (31.76 mg kg^{-1}), while seed carbon (C) concentration was greater ($P < 0.05$) in AY areas (48.9%; 489 g kg^{-1}) across regions. Averaged across yield area, seed P, Ca, Fe, Mn, Zn, Cu, and B concentrations were at least 9% greater ($P < 0.05$) at mid-R5, while seed N concentration was greatest ($P < 0.05$) at HM (5.76%; 57.6 g kg^{-1}) than at the other two growth stages. Results of this study demonstrated differences in seed nutrient concentrations across growth stages between HY and AY areas that can be used by producers to maximize soybean yields in all production scenarios.

Introduction

From 1924 to 2012, the average United States (U.S.) soybean [*Glycine max* (L.) Merr.] yield increased annually by 0.34 bu ac^{-1} yr^{-1} (23 kg ha^{-1} yr^{-1}), from 11 to 39 bu ac^{-1} (739 to 2661 kg ha^{-1}; Egli, 2008; van Roekel and Purcell, 2014). However, soybean yields greater than 100 bu ac^{-1} (6719 kg ha^{-1}) have been reported in yield contests in multiple states in the past three years. Until recently, research focusing on managing soybean for high-yield production has concentrated on maximizing light interception and crop growth rate before the mid-R5 reproductive stage (Fehr et al., 1971) to provide the maximum level of photosynthate for translocation to seeds (Westgate, 2001). Although choosing the correct row spacing, plant population, variety, and planting day of year perhaps achieves the greatest amount of photosynthate, the resulting correct combination is dependent on achieving the greatest efficiency for seed formation and resulting final yield (Westgate, 2001). Better understanding of the physiological framework for grain yield determination in soybean provides a guide for understanding the effect of management practices and growing conditions on final yield.

Yield-contest data provide unique, alternative information about achieving maximum crop yields. In 1966, the first soybean yield contest in the U.S. was held nationwide when two producers achieved yields of 92 bu ac^{-1} (6203 kg ha^{-1}) in Chenoa, Illinois. and Hamburg, Iowa (Cooper, 2003). Yields greater than 100 bu ac^{-1} (6719 kg ha^{-1}) were recorded during the 1968 National Yield Soybean Contest, when 102 and 109 bu ac^{-1} (6890 and 7310 kg ha^{-1}) were harvested in Rolling Prairie, Indiana and Ozark, Missouri, respectively (Cooper, 2003). Nationwide, yield contests are currently conducted in 14 states, including Arkansas (van Roekel and Purcell, 2014).

Conducting research in producers' fields that produce ultra-high soybean yields in Arkansas may provide relevant information for other producers who are striving to achieve soybean yields equal to or greater than a recent world record yield (171 bu ac^{-1} or 11543 kg ha^{-1}), which was harvested in Georgia in 2016 (Haire, 2016). Arkansas soybean growers have the potential to approach, match, or even exceed recent world record yields. Additionally, through characterization of plant property and mechanism differences that occur in contest-/high-yield management areas as well as in average-yield areas in the same or adjacent fields, consistencies and patterns in soybean physiology may be observed that explain large yields occurring under similar and/or different management practices. Therefore, the objective of this study was to evaluate seed elemental concentration differences between high- and average-yield areas across soybean growth stages [i.e., mid-R5, mid-R6, and harvest maturity (HM)].

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Procedures

In late spring to early summer 2015, one producer in each of the seven regions of the "Grow for the Green" yield contest (Fig. 1) was identified as a willing cooperator who had a field area entered into the 2015 yield contest, as well as an average-yielding area within the same field or in an adjacent field. The high- (HY) and average-yielding (AY) areas per producer within a region were used for subsequent plant sampling purposes. The HY areas were specifically managed for the yield contest, while the AY areas may have been managed similarly or differently.

During the 2015 growing season, sample points were established in a five-point diamond formation within each HY and AY area in each of the seven statewide yield contest regions. Three of the five points were in the same row approximately 68 yd (62 m) apart from one another, and the other two points were perpendicular to the middle row approximately 42 yd (38 m) in the opposite direction from the mid-point of the middle row. At each point, five plants were collected within a row at the mid-R5 and mid-R6 growth stages, as defined by Fehr et al. (1971), and also at harvest maturity (HM). For all three growth stages, the total above-ground plant material was dried at ~131 ^{o}F (55 ^{o}C) for 7 d and then seeds were removed. A subsample of the seed material was ground in a coffee grinder to pass a 1-mm mesh sieve, and N and C concentrations were determined by high-temperature combustion using a VarioMax CN analyzer (Elementar Americas Inc., Mt. Laurel, N.J.). For determination of elemental seed-tissue concentrations (i.e., P, K, Ca, Mg, S, Na, Fe, Mn, Zn, Cu, and B), seeds were digested using concentrated nitric acid and analyzed by inductively coupled, argon-plasma spectrometry (ICAP, Spectro Analytical Instruments, Spectro Arcos ICP, Kleve, Germany).

For processing soybean seed from the mid-R5 and mid-R6 sample dates, pods were removed from stems and vigorously shaken in plastic jars with rubber stoppers to remove seeds from pods. Seeds were then placed on a series of sieves to remove any pod material remaining with the seed samples. Seed samples were next laid out on trays and the smallest seed material was eliminated by lightly orally blowing across the surface of the tray. This process effectively removed seed that was still in the lag phase of growth, before the linear period between the mid-R5 and mid-R6 growth stages.

A two-factor analysis of variance (ANOVA), assuming a completely random design, was conducted using SAS (version 9.3, SAS Institute, Inc., Cary, N.C.) to evaluate the effects of yield area (i.e., HY and AY areas), growth stage (i.e., mid-R5, mid-R6, and HM) and their interactions on measured seed nutrient (i.e., C, N, P, K, Ca, Mg, S, Na, Fe, Mn, Zn, Cu, and B) concentrations. Significance was judged at $P < 0.05$. When appropriate, means were separated by least significant difference at $\alpha = 0.05$. For the purposes of these analyses, region was treated as a random variable, as there was no replication within a region. Therefore, results apply to combined data across all regions.

Results and Discussion

For the fields sampled in the 2015 "Grow for the Green" yield contest, soybean yields in the AY areas ranged from 40 bu ac^{-1} (2688 kg ha^{-1}) in Region 2 to 98 bu ac-1 (6585 kg ha^{-1}) in Region 6 (Table 1; Fig. 1). The mean yield for all AY areas was 69 bu ac^{-1} (4664 kg ha^{-1}), which was 20 bu ac^{-1} (1372 kg ha^{-1}) greater than the Arkansas state average from 2015, and 11 bu ac^{-1} (767 kg ha^{-1}) greater than the state average from Nebraska, the most productive soybean state in the U.S. in 2015 (USDA-NASS, 2016). Soybean yields in the HY areas of fields ranged from 42 bu ac^{-1} (2822 kg ha^{-1}) in Region 2 to 109 bu ac^{-1} (7324 kg ha^{-1}) in Regions 3 and 6, while the mean yield for all HY areas was 82 bu ac^{-1} (5537 kg ha^{-1}; Table 1; Fig. 1). Regions 2, 3, and 6 of the yield contest are all in the eastern portion of Arkansas (Fig. 1); however, Region 2 has alluvial and loessial soils, while the soils in Region 3 were derived from a mix of alluvial and eolian parent materials (Table 1; USDA-NRCS, 2014b). Region 6 consists of terraces and lower-elevation alluvial sediments and is also further south, and has a slightly warmer climate (Table 2; USDA-NRCS, 2014b).

In 2015, yield increases from each AY to the HY area within a field ranged from 5% in Region 2 to 63% in Region 1 (Table 1). The mean yield increase from the AY to HY areas within fields was 19%. Region 1 of the "Grow for the Green" yield contest is as far north as Region 2 (Fig. 1); and similar to Region 2, the soils of Region 1 were derived from a mix of alluvial and loessial parent materials (USDA-NRCS, 2014b).

Seed K concentration differed ($P < 0.05$; Table 3) between yield areas among growth stages for the 2015 growing season. Seed K concentration was greater ($P < 0.05$; Fig. 2) in HY areas at mid-R5 (1.95%; 19.5 g kg^{-1}) than in all other growth stage/yield area treatment combinations. Seed K concentration was also greater ($P < 0.05$; Fig. 2) in AY areas at mid-R5 (1.76%; 17.6 g kg^{-1}) than in both yield areas at mid-R6 and HM. Seed K concentration did not differ ($P > 0.05$; Fig. 2) between yield areas at mid-R6 and HM. Seed K concentrations at HM measured in this study were well-below those reported previously by Parjev et al. (2015) under low-soil-K fertility conditions across Arkansas, but greater than those reported by Farmaha et al. (2011) in Illinois averaged over soil-K fertility levels.

Across regions and averaged across growth stage, seed C and B concentrations differed ($P < 0.05$) between yield areas (Table 3). Seed B concentration was greater in HY than in AY areas. In contrast, seed C concentration was greater in AY than in HY areas. However, the difference in seed C concentration was negligible, at only 0.7%. Seed N, P, Ca, Mg, S, Na, Fe, Mn, Zn, and Cu concentrations did not differ ($P > 0.05$; Table 3) between yield areas across regions when averaged across growth stages.

For the 2015 soybean growing season, across regions and averaged across yield area, seed N, C, P, Ca, Fe, Mn, Zn, Cu, and B concentrations differed ($P < 0.05$; Table 3) among soybean growth stages. Seed P, Ca, Fe, Mn, Zn, Cu, and B concentrations all decreased (Table 4) from mid-R5 to HM. Furthermore, seed P, Ca, Fe, Mn, Zn, Cu, and B concentrations were all greater ($P < 0.05$) at the mid-R5 growth stage than at the other two growth stages and were, on average, 30% greater at mid-R5 than at HM. Seed Ca concentration was also 10% greater ($P < 0.05$) at mid-R6 than at HM. It is important to remember that this study merely analyzed seed nutrient concentrations and not contents. Similarly, it was assumed that contents of some nutrients did not decrease, but that contents of other nutrients increased, therefore lowering concentrations of these nutrients at later growth stages. Uptake, partitioning, and remobilization of nutrients in soybean was studied from the 1930s to the 1970s (Bender et al., 2015); however, studies of within-seed-tissue macronutrients and micronutrients are limited, as are studies of seed elemental concentrations throughout reproductive growth.

Seed N and C concentrations trended differently compared to numerous aforementioned seed nutrients (i.e., P, Ca, Fe, Mn, Zn, Cu, and B), numerically increasing from mid-R5 to HM (Table 4). Seed N concentration was greatest ($P < 0.05$) at HM (5.76%; 57.6 g kg^{-1}), and was greater ($P < 0.05$) at mid-R6 (5.61%; 56.1 g kg^{-1}) than at mid-R5 (5.47%; 54.7 g kg^{-1}). Similar to seed N, seed C concentration was greatest at HM, which did not differ ($P < 0.05$) than that at mid-R6. Seed C concentration was, on average, 5% greater ($P < 0.05$) at HM and mid-R6 than at mid-R5. Soybean N demand is greater than for other crops due to the high protein content, and this demand is met by accumulation as well as remobilization of N from vegetative tissue (van Roekel et al., 2015). In Illinois on a silty clay loam, Bender et al. (2015) reported one-half of total N accumulation occurred after the beginning of R5, in addition to remobilization from leaf and stem N. In Gainesville, Fla., Salado-Navarro et al. (1985) reported that as rates of N relocated from vegetative tissue to seed increased, rates of senescence of vegetative tissue increased.

Seed Mg and S concentrations numerically decreased from mid-R5 to mid-R6 and subsequently increased to HM (Table 4). Seed Mg concentration was 9% greater ($P < 0.05$) at mid-R5 and HM, which did not differ, than at mid-R6. Similar to seed Mg, seed S concentration at HM (0.21%; 2.1 g kg^{-1}), which did not differ from that at mid-R5 (2.06 g kg^{-1}), was greater than seed S at mid-R6 (0.202%; 2.02 g kg^{-1}), which also did not differ from that at mid-R5. As with yield area, seed Na concentration did not differ among growth stages (Table 3) when averaged across yield areas.

Rotundo and Westgate (2008) reported in a meta-analysis that differences in seed elemental concentration primarily result from differing extents of inhibition of accumulation of individual components. This inhibition is a result of stress, either by drought, high temperatures, or low N fertility. In the meta-analysis by Rotundo and Westgate (2008), water and temperature stresses decreased protein, oil, and residual content, while supplemental N increased protein content, had no effect on oil content, and decreased residual content. While Slaton et al. (2013) reported fertilization and other management practices influenced seed nutrient concentration in Arkansas, Kleese et al. (1968) reported in Minnesota that soybean genotype may be more important than location or year in determination of accumulation of mineral elements. However, the methods for determination of elemental concentration of seeds in Kleese et al. (1968) was different than that used in this study.

Practical Applications

To meet the needs of an increasing global population and ensuing rise in food production efforts, continuous increases in yields are necessary to alleviate crop production expansion onto poorer quality soils, which may decrease land quality and threaten sustainability. By encompassing diverse landscapes and cropping systems, this research is invaluable to soybean producers, whether or not entering areas into yield contests, across all of Arkansas. However, other factors (i.e., genetic, agronomic and/or environmental) should be further studied, which would help advance soybean production across Arkansas and elsewhere. Nevertheless, future research should mimic the approach used in this study by conducting studies on producer fields, despite the logistics being challenging, as was the case in the present study.

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Table 1. Variety planted, planting day of year (PDOY), and final yield for high- (HY) and average-yield (AY) areas for the fields sampled in the seven regions in the "Grow for the Green" yield contest across Arkansas in 2015. Variety, PDOY, and yield from AY areas were reported by growers, while yields from HY areas were reported by growers or verified by Arkansas Soybean Association (ASA, 2015). Values are rounded.

	HY			AY		
Region	Variety	PDOY	Yield (bu/ac)	Variety	PDOY	Yield (bu/ac)
1	Asgrow 4633	107	90	Asgrow 4633	100	55
2	USG 74E88	166	68	USG 74E88	166	60
3	Asgrow 4632	121	109	Pioneer 46T21	120	88
4	Pioneer 47T36	157	78	Pioneer 47T36	156	71
5	Asgrow 4835	98	80	Asgrow 4632	98	73
6	Pioneer 47T36	98	109	Pioneer 45T11	96	98
7	Rev 49R94	156	42	Pioneer 94Y70	155	40

Table 2. Climate and geographical data for the Arkansas counties represented in the 2015 plant sampling. Climate data were obtained from the Southern Region Climate Center (SRCC, 2015) and are 30-year normal values.

				Air Temperature		
Region	County	MLRA†	Annual Precipitation (in)	July (°F)	January (°F)	Annual (°F)
1	Craighead	131A	48.2	80.2	35.8	59.2
2	Cross	131A, 134	48.2	80.4	37.6	60.1
3	Woodruff	131A	49.2	81.9	36.7	60.8
4	Lonoke	131B, 131D	48.6	81.1	41.3	62.4
5	Phillips	131A, 134	50.8	82.6	40.5	62.6
6	Desha	131B	53.7	82.6	42.4	63.0
7	Conway	118A	49.9	80.6	38.1	59.9

† Major Land Resource Area (MLRA): 118A - Arkansas Valley and Ridges, Eastern Part; 131A - Southern Mississippi River Alluvium; 131B - Arkansas River Alluvium; 131D - Southern Mississippi River Terraces; 134 - Southern Mississippi Valley Loess (USDA-NRCS-MLRA, 2014a).

Table 3. Analysis of variance summary of the effects of yield area (i.e., high- and average-yield area), growth stage (i.e., mid-R5, mid-R6, and harvest maturity), and their interaction on seed concentrations measured across Arkansas in 2015.

Seed Concentration[†]	Yield Area	Growth Stage	Yield Area x Growth Stage
	-----------------------------------	*P*	-----------------------------------
C	0.040	< 0.001	NS[‡]
N	NS	< 0.001	NS
P	NS	< 0.001	NS
K	< 0.001	< 0.001	0.024
Ca	NS	< 0.001	NS
Mg	NS	< 0.001	NS
S	NS	0.048	NS
Na	NS	NS	NS
Fe	NS	< 0.001	NS
Mn	NS	0.002	NS
Zn	NS	< 0.001	NS
Cu	NS	< 0.001	NS
B	0.009	< 0.001	NS

[†] Units are as follows: C, N, P, K, Ca, Mg, S, g kg^{-1}; Na, Fe, Mn, Zn, Cu, B, mg kg^{-1}.
[‡] Effects and interactions that are not significant (NS) at the 0.05 level are represented by NS.

Table 4. Soybean seed elemental concentrations, averaged across yield area, measured at the mid-R5 and mid-R6 growth stages (as defined by Fehr et al., 1971) and harvest maturity (HM) of the "Grow for the Green" yield contest across Arkansas in 2015.

	Growth Stage		
Seed Element	**Mid-R5**	**Mid-R6**	**HM**
B (ppm)	36.8 a	28.2 b	25.8 b
C (%)	47.3 a	49.4 b	49.5 b
Ca (%)	0.36 a	0.26 b	0.24 b
Cu (ppm)	9.8 a	8.6 b	8.7 b
Fe (ppm)	55.6 a	50.5 b	48.8 b
Mg (%)	0.18 a	0.17 b	0.18 a
Mn (ppm)	33.6 a	24.9 b	23.2 b
N (%)	5.47 a	5.61 b	5.76 c
P (%)	0.42 a	0.37 b	0.39 b
S (%)	0.21 ab	0.2 a	0.21 b
Zn (ppm)	36.4 a	29.1 b	28.1 b

[†] Means with the same letter within a row are not different at $\alpha = 0.05$.

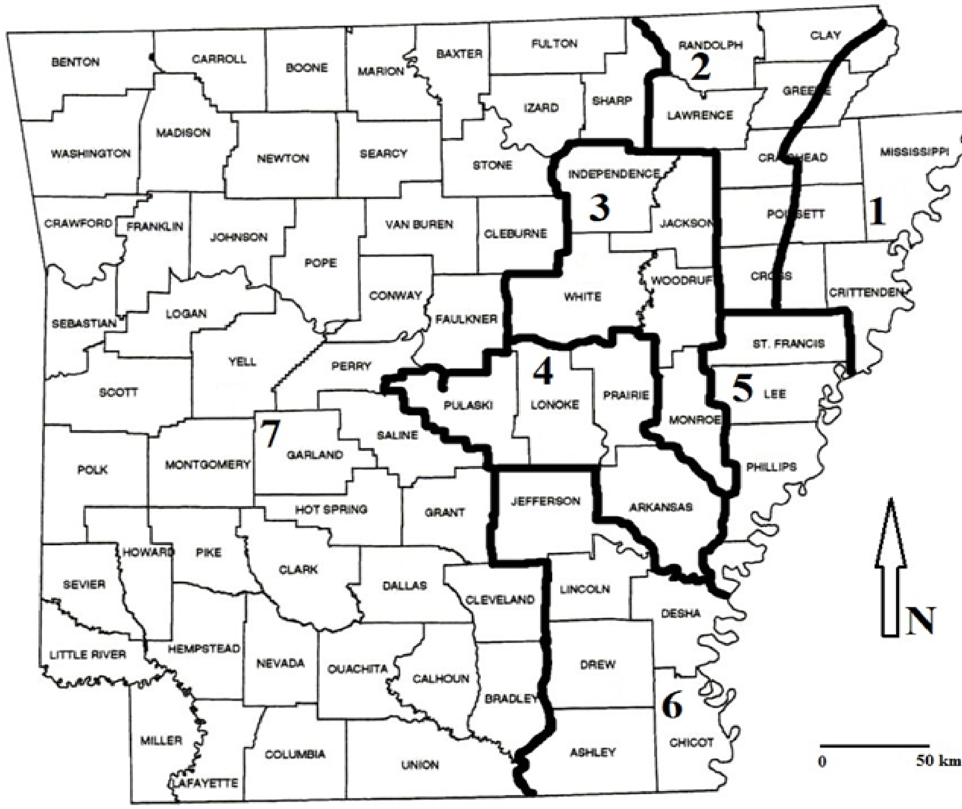

Fig. 1. Seven regions for the "Grow for the Green" yield contest sponsored by the Arkansas Soybean Promotion Board together with the Arkansas Soybean Association. Division 1: Northeast Delta; Division 2: Northeast; Division 3: White River Basin; Division 4: Central and Grand Prairie; Division 5: East Central Delta; Division 6: Southeast Delta; Division 7: Western.

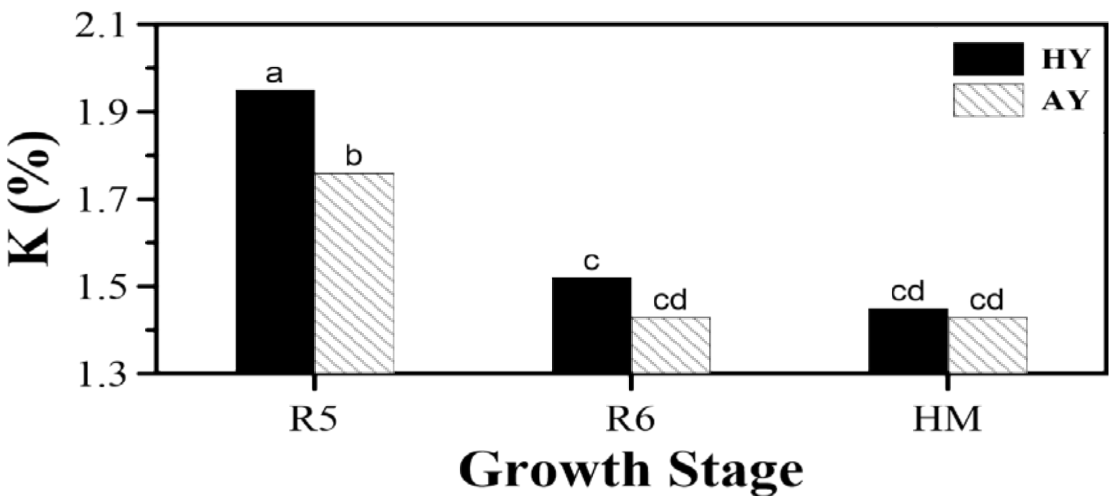

Fig. 2. Seed K concentration measured at the mid-R5 and mid-R6 growth stages (as defined by Fehr et al., 1971) and harvest maturity (HM) across regions in high- (HY) and average-yield (AY) areas of the "Grow for the Green" yield contest across Arkansas in 2015. Means with the same letter within each plant property are not different at α = 0.05.

2016 Soybean Research Verification Program

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Abstract

The 2016 Soybean Research Verification Program (SRVP) was conducted on 15 commercial soybean fields across the state. Counties participating in the program included; Arkansas, Ashley, Chicot, Desha, Drew (2 fields), Jefferson, Lee, Lincoln, Lonoke, Monroe (2 fields), Phillips (2 fields), and Prairie Counties for a total of 675 acres. Grain yield in the 2016 SRVP averaged 58 bu/ac ranging from 29 to 82 bu/ac. The 2016 SRVP average yield was 10 bu/ac greater than the estimated Arkansas state average of 48 bu/ac. The highest yielding field was in Desha County with a grain yield of 82 bu/ac. The lowest yielding field was a non-irrigated field in Phillips County that produced 29 bu/ac.

Introduction

In 1983, the University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) established an interdisciplinary soybean educational program that stresses management intensity and integrated pest management to maximize returns. The purpose of the Soybean Research Verification Program (SRVP) was 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 583 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 be attributed mainly to intensive cultural management and integrated pest management.

Procedures

The SRVP fields and cooperators are selected prior to the beginning of the growing season. Cooperators agree to pay production expenses, provide expense data, and implement CES 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 were made to monitor the growth and development of the crop, determine what cultural practices needed 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 2016, the following counties participated in the program; Arkansas, Ashley, Chicot, Desha, Drew (2 fields), Jefferson, Lee, Lincoln, Lonoke, Monroe (2 fields), Phillips (2 fields), and Prairie counties. The 15 soybean fields totaled 675 acres enrolled in the program. Five Roundup Ready® varieties were planted (Asgrow 4632, Asgrow 4835, Pioneer 47T36R, Pioneer 49T80R, Pioneer 50P40), two Liberty Link® varieties (Stine 42LH22, Stine 51LE20), and three conventional varieties (Hutcheson, UA 5213C, UA 5814HP) in the 15 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 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 58 bu/ac with a range of 29 to 82 bu/ac. The SRVP average yield was 10 bu/ac more than the estimated state yield of 48 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 82 bu/ac and was seeded with Asgrow 4632 in Desha County.

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Planting and Emergence. Planting began with Jefferson County on 23 March and ending with Monroe County 2 planted 9 June. An average of 49 lbs/ac of seed was used for planting. An average of 9 days was required for emergence. Refer to Table 1 for agronomic information.

Fertilization. Fields enrolled in the SRVP were fertilized according to 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 on a weekly basis and CES recommendations were utilized for weed control programs. Refer to Table 3 herbicide rates and timings.

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

Insect Control. Fields were scouted on a weekly basis 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 University of Arkansas Irrigation Scheduler Computer Program. Irrigations were recommended-based information generated from program. Thirteen of the 15 fields in the 2016 SRVP were furrow-irrigated and 2 were dry land.

Practical Applications

Data collected from the 2016 SRVP reflected slightly lower soybean yields, as was the state average, but maintained above average returns in the 2016 growing season. Analysis of this data showed that the average yield was higher in the SRVP compared to the state average and the cost of production was equal to or less than the CES-estimated soybean production costs.

Acknowledgements

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 2016 Soybean Research Verification fields.

County	Variety	Field size (ac)	Previous crop	Production system	Seeding rate (lb/ac)	Stand density (plants/ac)	Planting date	Emergence date	Harvest date	Yield adj. to 13% moisture (bu/ac)
Arkansas	Pioneer 49T80R	48	Corn	FSI	46	90K	4/28	5/9	10/3	72
Ashley	Asgrow 4835	70	Soybean	FSI	42	128K	5/7	5/12	9/20	48
Chicot	Asgrow 4632	45	Soybean	ESI	49	130K	4/10	4/18	9/17	68
Desha	Asgrow 4632	37	Corn	ESI	47	141K	4/6	4/18	9/12	82
Drew – 1	Pioneer 47T36R	22	Soybean	ESNI	50	145K	4/9	4/20	9/11	32
Drew – 2	Asgrow 4632	53	Corn	FSI	61	165K	5/5	5/11	9/27	58
Jefferson	Stine 42LH22	74	Grain Sorghum	ESI	68	100K	3/23	4/3	8/30	71
Lee	UA 5814HP	54	Rice	FSI	48	130K	5/8	5/14	10/15	39
Lincoln	Asgrow 4632	68	Corn	ESI	48	135K	4/9	4/20	9/13	77
Lonoke	Stine 51LE20	84	Soybean	FSI	38	115K	5/14	5/24	10/7	53
Monroe – 1	UA 5213C	24	Corn	FSI	40	130K	5/23	5/30	10/10	51
Monroe – 2	Pioneer 50P40	35	Rice	FSI	55	135K	6/9	6/15	10/12	54
Phillips – 1	Hutcheson	24	Soybean	FSNI	48	90K	5/9	5/16	10/20	29
Phillips – 2	Pioneer 47T36R	23	Soybean	ESI	52	130K	4/10	4/19	9/22	68
Prairie	Asgrow 4632	18	Corn	FSI	47	115K	4/24	5/2	10/6	66
Average		45			49	125K	4/27	5/6	9/27	58

State Avg. 48 bu/ac.

Table 2. Soil tests results, applied fertilizer and soil classification for the 2016 Soybean Research Verification fields.

	Applied Fertilizer P-K (lb/ac)				
County	**pH**	**P**	**K**	**Pre-plant**	**Soil Classification**
Arkansas	6.6	60	410	0-0-0	Immanuel, Tichnor silt loam
Ashley	6.5	38	182	0-50-80	Calloway silt loam
Chicot	6.6	58	200	0-40-60	Sharkey clay
Desha	6.8	70	216	0-0-60	Desha silt loam, Desha clay
Drew – 1	6.0	56	164	0-0-0	Grenada, Henry silt loam
Drew – 2	6.4	70	180	0-30-90	Rilla, Hebert silt loam, Perry clay
Jefferson	5.7	122	252	0-0-60	Coushatta, Roxana silt loam
Lee	6.1	78	344	0-0-0	Alligator clay
Lincoln	6.8	60	188	0-46-100	Herbert, Rilla silt loam, Perry clay
Lonoke	6.3	80	190	0-0-60	Immanuel, Calhoun silt loam
Monroe – 1	6.2	64	182	0-36-72	Foley-Calhoun-Bonn Complex
Monroe – 2	6.3	60	210	0-40-60	Jackport silty clay loam, Dubbs silt loam
Phillips – 1	5.7	54	164	0-0-120	Henry silt loam
Phillips – 2	6.1	38	180	0-45-90	Foley, Memphis silt loam
Prairie	6.5	36	92	0-45-90	Immanuel, Stuttgart silt loam

Table 3. Herbicide rates and timings for 2016 Soybean Research Verification Program fields by county.

County	Burndown/Pre-emergence	Post-emergence
Arkansas	Burndown: 1 qt/ac generic glyphosate plus 2 oz/ac Valor® Pre-emerge: 1 qt/ac generic glyphosate plus 1 pt/ac generic S-metolachlor	1st: 1 qt/ac generic glyphosate plus 2 oz/ac Zidua® 2nd: 1 qt/ac generic glyphosate pluse 1 pt/ac generic S-metolachlor
Ashley	Burndown: 1 qt/ac generic glyphosate plus 1.5 pt/ac 2,4-D Pre-emerge: 22 oz/ac Roundup PowerMax® plus 1.25 pt/ac generic metolachlor	22 oz/ac RoundupPowerMax plus 1.5 pt/ac Flexstar®
Chicot	Burndown: 1 qt/ac generic glyphosate plus 1 qt/ac 2,4-D Pre-emerge: 2 oz/ac Valor	1qt/ac generic glyphosate plus 1.25 pt/ac generic metolachlor
Desha	Burndown: 22 oz/ac Roundup PowerMax plus 1.5 oz/ac Leadoff plus 1 qt/ac 2,4-D plus 6 oz/ac Select Pre-emerge: 1.25 pt/ac generic metolachlor	22 oz/ac Roundup PowerMax plus 2 oz/ac Zidua
Drew – 1	Pre-emerge: 1 qt/ac generic glyphosate plus 3.5 oz/ac Envive	1st: 1 qt/ac generic glyphosate plus 1.25 pt/ac generic metolachlor 2nd: 1 qt/ac generic glyphosate plus 1.25 pt/ac generic metolachlor
Drew – 2	Pre-emerge: 1.25 pt/ac generic metolachlor	1 qt/ac generic glyphosate plus 1.5 pt/ac Flexstar® 1 qt/ac Liberty plus 2 oz/ac Zidua
Jefferson	Pre-emerge: 1 qt/ac generic glyphosate plus 1.25 pt/ac generic metolachlor	Harvest aid: 1 pt/ac generic Gramoxone plus 1% NIS
Lee	Burndown: 1 qt/ac generic glyphosate plus 6 oz/ac generic metribuzin Pre-emerge: 1 qt/ac generic Gramoxone® plus 3 oz/ac generic metribuzin plus 2 oz/ac generic Valor	1st: 8 oz/ac generic Select® plus 1 qt/ac Prefix 2nd: 1.5 pt/ac generic metolachlor
Lincoln	Burndown: 25.6 oz/ac Roundup PowerMax plus 1.5 pt/ac 2,4-D plus 1.5 oz/ac Leadoff® Pre-emerge: 22 oz/ac Roundup PowerMax plus 1.25 pt/ac generic metolachlor	1st: 22 oz/ac Roundup PowerMax plus 1 qt/ac Prefix® plus 6 oz/ac Flexstar 2nd: 22 oz/ac Roundup PowerMax (25 acres)
Lonoke	Pre-emerge: 2 oz/ac generic Valor	1st: 1 qt/ac Liberty plus 1 pt/ac Dual Magnum® 2nd: 1 qt/ac Liberty plus 1 qt/ac Prefix
Monroe – 1	------------------------	1st: 1.5 pt/ac Storm plus 2 oz/ac Zidua 2nd: 1 pt generic Select plus 1 % COC 3rd: 1 qt/ac Prefix
Monroe – 2	Pre-emerge: 36 oz/ac Intimidator plus 1 qt/ac generic glyphosate	1qt/ac generic glyphosate plus 1 pt/ac Select Max plus 1 pt/ac Dual Magnum
Phillips – 1	Burndown: 40 oz/ac Gramoxone Pre-emerge: 1.25 pt/ac generic metolachlor	1.5 pt/ac Flexstar plus 2 oz/ac Zidua
Phillips – 2	Pre-emerge: 3 oz/ac Fierce®	1 qt/ac generic glyphosate plus 1.25 pt/ac generic metolachlor
Prairie	Burndown: 1 qt/ac generic glyphosate plus 1 oz/ac Sharpen® Pre-emerge: 1.5 pt/ac Boundary®	1st: 1 qt/ac generic glyphosate plus 2 oz/ac Zidua 2nd: 1 qt/ac generic glyphosate

Table 4. Fungicide and insecticides applications in 2016 Soybean Research Verification fields by county.

County	Aerial Web Blight	Frogeye	Bollworm/Defoliators	Stink Bug
Arkansas	----------	----------	---------	----------
Ashley	----------	4.5 oz/ac Stratego YLD®	2 oz/ac Belt®	----------
Chicot	----------	----------	----------	5.12 oz/ac Brigade®
Desha	----------	----------	----------	----------
Drew – 1	----------	----------	----------	----------
Drew – 2	----------	----------	2 oz/ac Belt	6.4 oz/ac Brigade plus .5lb/ac generic acephate
Jefferson	----------	----------	---------	----------
Lee	----------	----------	----------	----------
Lincoln	----------	----------	----------	----------
Lonoke	----------	----------	----------	----------
Monroe – 1	----------	----------	----------	3.66 oz/ac Lambda-Cy
Monroe – 2	----------	----------	2 oz/ac Belt	----------
Phillips – 1	---------	----------	----------	----------
Phillips - 2	----------	----------	----------	5.12 oz/ac Brigade
Prairie	----------	----------	----------	----------

Breeding New Soybean Cultivars with High Yield and Disease Resistance

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Abstract

The focus of University of Arkansas System Division of Agriculture's Soybean Breeding and Genetics Program is developing maturity group (MG) 4 and 5 soybean varieties with high yield, pest resistance, and specialty traits. Conventional cultivars developed in our soybean breeding program are well adapted to be grown in Arkansas and other southern states. We select high yielding lines with desirable traits from public breeding programs to design new cross combinations every year. We make new crosses and advance breeding populations in Fayetteville, Ark. After several years, lines are initially tested in preliminary tests in two Arkansas locations and further evaluated in three to five Arkansas locations with three replications. Subsequently, the best lines with high yield and traits of interest are selected and tested in other southern states in the United States Department of Agriculture's (USDA) Uniform Preliminary Test, USDA Uniform Test, or Regional Quality Traits Test. In 2016, we released one conventional high yielding (UA 5115C) and one soy nut type edamame (UA Mulberry) varieties.

Introduction

In the University of Arkansas System Division of Agriculture's Soybean Breeding Program we breed conventional, herbicide tolerant, and specialty type soybeans to meet farmer demands in Arkansas. High yield, pest resistance, stress tolerance, good adaptation, and desirable seed composition are the main traits we focus on when we develop new cultivars. Our experimental lines are tested multiple years in multiple Arkansas locations and other southern states before considering them for release. They are also tested in University of Arkansas System Division of Agriculture's Soybean Variety Performance Testing program as well as other variety testing programs in the southern U.S. The best performing lines across locations with good disease packages and the traits of interest are selected for release. New potential releases are usually checked for soybean cyst nematode (SCN), root knot nematode (RKN), sudden death syndrome (SDS), stem canker (SC), frogeye leaf spot (FLS), and soybean mosaic virus (SMV) in addition to salt tolerance. Our lines have relative maturity of late 4 to late 5. Most of our released cultivars such as Osage (Chen et al., 2007), Ozark (Chen et al., 2004), UA 5612, (Chen et al., 2014), UA 5213C (Chen et al., 2014), UA 5014C (Chen et al., 2016), UA 5814HP (Chen et al., 2017), and UA 5615C have been used in commercial production and cultivar development in other breeding programs. Osage and UA 5612 have been used as yield checks in the United States Department of Agriculture's (USDA) uniform tests and Regional Quality Traits Test.

Procedures

A series of well established procedures of conventional breeding and selection for important agronomic traits were implemented in this project. Our breeding objective is to combine the best traits from different varieties and/or lines. The breeding scheme can be summarized in three steps: 1) selection of parents with desired complementary characteristics and intercrossing them, 2) growing resulting populations for four generations to allow genetic segregation/recombination and then reach genetic homozygosity (true-breeding), and 3) selecting and evaluating pure lines from each cross.

We make 200-250 different crosses for several projects using high yielding lines developed from our breeding program and other southern varieties/lines, or disease resistant germplasm as parents. The plant populations at early generations are advanced using a bulk pod descent method, and 12,000 to 15,000 $F_{4:5}$ families are evaluated for adaptation and agronomic performance. Off-season nursery facilities are used to speed up the breeding process. For the preliminary yield trials, we test 1500 to 2000 new lines each year. Approximately, 150-200 lines are selected and subsequently evaluated in advanced replicated trials in 3-5 Arkansas locations with three replications. The best lines are selected and

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evaluated in the USDA Southern Uniform Test, Regional Quality Traits Test, and the Arkansas Soybean Variety Performance Test. Promising lines are increased for foundation seed in preparation for cultivar release. Selected lines are also included in a cooperative test for SCN, RKN, SDS, SC, SMV, and FLS in other southern state programs.

Results and Discussion

In 2016, we released two varieties: one high-yielding conventional and one soy nut type for edamame. Our conventional release is R09-430 which is MG 5.1 high-yielding cultivar with grey pubescence color, purple flower color, and tan pod wall. It is tolerant to stem canker and frogeye leaf spot and susceptible to soybean cyst nematode (races 2, 3, and 5) and sudden death syndrome. When tested in Southern Uniform Trials in 2012 and 2013, it ranked number 1 both years yielding 1 bushel more than the highest yielding check AG 4632RR2Y. Variety R09-430 was licensed to a private company. Our second release, UA Mulberry is a MG 5.8 specialty soy nut type with purple flower, tawny pubescence, tan pod, all black seed coat and large seed size. It is resistant to sudden death syndrome, frogeye leaf spot and susceptible to soyban cyst nematode, root knot nematode, and reniform nematode. Compared to the previously released edamame type soybean, UA Kirksey (21.1g/100 seed), UA Mulberry has larger seed size 24.5 g/100 seed) and black colored seed coat which is desirable to soy nut type. UA Mulberry is licensed to a private company. In addition to the newly released varieties, we also produced foundation seed for our previous releases: Osage (868 units), UA 5014C (780 units), UA 5213C (698 units), UA 5612 (842 units), UA 4414RR (2685 units), and UA 5715GT (1139 units). For pipeline products in the program to release in the future, we increased seeds using 0.25 ac for each line.

A total of 15 advanced lines were tested in the 2016 USDA Uniform Trials in MG 4 to 6. Three lines (R11-328, R12-226, and R12-712) in MG 4's-Late test yielded 57.4–58 bu/ac and ranked 4-7 in the 20-entry test. In MG 5, two lines, R12-7448RY and R13-13997 yielded 60.7–63.5 bu/ac and ranked 2nd and 5th in the 28-entry test. In MG 6 test, two lines, R11-171 and R12-2517 yielded 57 bu/ac ranking 2nd and 3rd in the 22-entry test.

A total of 19 lines were evaluated in the 2016 USDA Uniform Preliminary Test in MG 4 to 6. In MG 4-Late test, two lines, R10-298 and R13-1724, yielded 57.5–59 bu/ac ranking 3rd and 4th in the 36-entry test. In the MG 5 test, R13-818 and R13-4638RY yielded 62.9–64.6 bu/ac ranking 5th and 6th in the 49-entry test. In the MG 6 test, four lines were top 4 in the 19-entry test yielding 44–45 bu/ac. These high yielding lines will be evaluated in the 2017 USDA Uniform Trials.

In addition, 12 Arkansas released varieties or future releases were evaluated to compare with commercial checks in Arkansas and 10 other southern states. We also tested 26 specialty soybean lines (5 high oil, 6 high protein, 11 modified fatty acids, 4 high sucrose and low stachyose lines) with competitive yields in the 2016 Regional Quality Traits Test (QT) for MG 4-6. In QT 4, high oil line, R13-7797, yielded 96% check yield (AG4835, LD06-7620, LD00-2817P, and LD07-3395bf; 47.7 bu/ac) with 20.9% oil and meeting the protein meal criteria of 48%. In QT 5, one high oil and three high protein lines meet the criteria of oil, protein, and meal protein. High oil line, R09-4010, yielded 99% check yield (Osage, Ellis, UA 5612, and AG5534; 56.1 bu/ac) with 20.9% oil and 48% meal protein. Three high protein lines, R11-8011, R11-8346, and R11-8397, yielded 95-101% check yield with 37.2–38.4% protein and 50.7–51.3% meal protein, which is considered as ultra-high meal protein. Two sugar lines, R13-10658 and R13-10669, yielded 101% and 93% check yield with 9.6% and 8.6% sucrose and 0.4 and 1% stachyose, respectively. In QT 6, two high protein lines, R10-5828 and R12-5723, yielded 98% and 102% check yield (NC-Roy, Dillon, NC-Miller, and AG6534; 48.3 bu/ac) with 38.5% protein, 51% and 52% ultra-high meal protein, respectively.

A total of 2045 lines were evaluated in advanced and preliminary yield trials in Arkansas in 2016; including 97 advanced and 308 preliminary conventional lines; 29 advanced and 126 preliminary RR-1 lines; 33 advanced and 215 preliminary RR-2 lines; 52 advanced and 86 preliminary drought-tolerant lines; and 36 advanced and 155 preliminary disease-resistant lines in addition to 21 advanced and 95 preliminary high protein; 29 advanced and 134 preliminary high oil; 79 advanced and 371 preliminary modified fatty acid (low linolenic, low sat, and/or high oleic); 31 advanced and 148 preliminary high sugar/low phytate lines (Tables 1 and 2). A total of 2760 plant populations and 10684 progeny rows were evaluated for breeding purposes. We also made 285 cross combinations to combine high yield with specialty traits for diverse projects (Table 1). Breeding populations for MG 4 breeding and high oleic and low linolenic breeding were sent to winter nursery in Costa Rica for generation advancement to speed up the breeding process.

Practical Applications

Yield, market price, and production cost are important factors in determining the economics of soybean industry. The Soybean Breeding and Genetics program provides high-yielding cultivars with low seed cost to growers and seeds for the conventional and RR-1 cultivars can be saved and re-used for planting. The continued release of public varieties such as Ozark, UA 4805, Osage, UA 5612, UA 5213C, UA 5014C, UA 5414RR, and UA 5715GT in recent years not only ensured the availability of high-yielding varieties with production premiums and low seed cost for Arkansas growers, but also served as excellent crossing materials for many public and private breeding programs in the United States.

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Table 1. Overview of University of Arkansas System Division of Agriculture's Soybean Breeding and Genetics Program tests in 2015.

Test	No. of entries
Released varieties	2
SDA Uniform/Preliminary Tests	34
AR Variety Testing Program	12
Arkansas advanced lines	159
Arkansas preliminary lines	649
Progeny rows	10684
Breeding populations (F_1 – F_4)	2760
New crosses	285

Table 2. Overview of food-grade and specialty trait tests at the University of Arkansas System Division of Agriculture's Soybean Breeding and Genetics program in 2015.

Specialty type	No. of advanced lines	No. of preliminary lines
Tofu/milk	36	86
Edamame	45	54
High Protein	21	95
High Oil	29	134
High Oleic/low linolenic/low saturated fatty acid	79	371
Sugar	31	148
Flood	37	43
Drought	52	86

Soybean Germplasm Enhancement Using Genetic Diversity

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Abstract

Development and release of high-yielding varieties with enhanced germplasm is one of the main breeding goals of the University of Arkansas System Division of Agriculture's Soybean Breeding Program. Breeding efforts made in 2016 include the advancement of breeding populations for high yield, disease and insect resistance, drought tolerance, modified seed composition, and the development of food-grade type soybeans. Two germplasm lines, R10-5086 and R11-6870, were released because of their high yield (100% and 101% of commercial checks) and exotic germplasm (25%) in the pedigree. Both lines can be used as sources of 'high yield genes' in Arkansas or other southern soybean breeding programs for breeding purposes. Two other high-yielding germplasm lines, R10-2436 and R10-2710, were also released because of their drought tolerance and extended nitrogen fixation under drought. One of the first effects of drought is to reduce the nitrogen fixation, and these two lines have the capacity to continue fixing nitrogen at lower levels of moisture in the soil, mitigating the effect of a moderate drought. A food-grade soybean variety was also released in 2016. UA Mulberry, an edamame-type variety was released because of its black seed coat and large seed size and will be commercialized for roasted soy nut production. After the successful release of the high protein variety UA 5814HP (approximately 6000 acres commercially grown in 2016), we are in the process of releasing another high protein line, R11-7999 with yield advantage over UA 5814HP. Moreover, seed of UARK-288, our most advanced line with high oleic (85.6%) and low linolenic fatty acid (2.8%) and 57.6 bu/ac yield (91% of commodity commercial check) is being increased in preparation for release. Breeding efforts in collaboration with other southern United States breeding programs continue aiming to generate a line with more than 80% oleic, less than 3% linolenic, and 100% check yield.

Introduction

The University of Arkansas System Division of Agriculture's Soybean Breeding Program has been very efficient in the screening, characterization and use of the available germ plasm to release varieties and lines with specific traits of interest. We have been able to generate varieties with specific value-added traits such as altered seed composition: high protein, high oleic and low linolenic fatty acids, high sugar, and low content of anti-nutritious components such as low phytates. Just released are two high-yielding lines with exotic germplasm in the pedigree, which is important given the narrow genetic base among United States (U.S.) soybean varieties (Carter et al., 1993). Two lines with drought tolerance were also released.

Procedures

The scheme of development of advanced lines with value-added traits, starts with an extensive screening of the germplasm available, according to the trait of interest. Once new germplasm has been identified, 100-120 crosses are made between the foreign material and our elite lines. The derived breeding populations are advanced from F_2 to F_4 using a modified single-pod descent method (Fehr, 1987). Subsequently, single rows are grown and lines are selected visually based on overall field appearance. Selected breeding lines are extensively evaluated in Arkansas and other southern U.S. locations for yield, maturity, plant height, lodging, and the value-added trait of interest such as disease resistance, modified seed quality composition, and drought tolerance.

Results and Discussion

Genetic Diversity for Yield Improvement. As a continuous effort to increase the genetic diversity of the parents used in our breeding program, two diverse high-yielding germplasm lines, R10-5086 and R11-6870, have been released (both carrying 25% of exotic parents in the pedigree). The release proposal for this line was approved in February 2017 by the University of Arkansas System Division of Agriculture. Based on 21 environments in Arkansas and other southern states (2012 to 2016), R10-5086 and R11-6870 yielded 61.2 and 61.5 bu/ac, respectively, representing 100.8% and 101.3% of check yield (Table 1). Because of the high yield

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and good agronomic characteristics, both lines can be incorporated in breeding programs as parents that introduce 'yield genes'. In 2016, we advanced 18 F_4, 47 F_3, 30 F_2 and 22 F_1 breeding populations in the genetic diversity project, using a modified single-pod descent method (Fehr, 1987). We also made 16 new cross combinations as part of this project.

Disease Resistance. We continue introducing 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 2016, 36 advanced and 155 preliminary breeding lines derived from parents with disease resistance were evaluated for yield. Among the advanced lines, we identified 7 high-yielding lines (R10-28, R14-22045, R11-1294, R14-14314, R12-8133, R10-197, and R11-982G) from parents with SDS and SCN resistance and 90–95% check yield (AG 4934, AG 4835, AG 5335, AG 5535; 64.9 bu/ac). Resistance to disease will be confirmed in 2017. Among the preliminary lines, they yielded between 85% and 94% of the commercial checks yield (AG 4934, AG 5335, AG 5535, P4930LL, and UA 5612; 61.1 bu/ac). Additionally, 293 new lines derived from populations with resistance to SCN, SDS, SMV, PSD, and salt tolerance were selected to be evaluated in single progeny row test in 2017.

Seed Composition. We have successfully used germplasm to develop value-added varieties with special seed composition traits. The program works on traits such as high protein, high oil, high oleic, low linolenic, modified carbohydrate profile, and varieties for specialty (tofu/soymilk) markets. For the high protein project, using the Maryland germplasm BARC-7 as original source of the high-protein, it was crossed with high-yielding Arkansas lines. As a result, in 2014, we released the high-yielding, high-protein variety UA 5814HP, which was commercially grown in more than 5000 acres in Arkansas and Mississippi during 2016. Another two advanced high-protein lines R11-7999 (38.9% protein, 17.1% oil on 13% moisture basis, and 94% commercial check yield) and R11-8346 (39.3% protein, 16.9% oil and 96% commercial check yield) are potential variety releases (Table 2). In our high oil project, we are in the process of releasing a germplasm line, R02-6268F, originated from the cross KS4895 × Jackson with 23.2% oil (on dry basis) and 97% commercial check yield.

In the high oleic project, we are combining the high oleic alleles of PI 603452 and PI 283327 and the low linolenic alleles of Iowa lines IA2064 and IA2065. We developed a line, UARK-288, with 85.6% oleic, 2.8% linolenic fatty acid, and yield of 57.6 bu/ac (91% commercial check). We are increasing the seed of UARK-288, in preparation for release. Through a backcrossing breeding program, we are combining the high oleic and low linolenic traits in high-yielding Arkansas varieties/lines. We will continue the breeding process in coordination with other southern breeding programs, to generate lines with > 80% oleic, < 3% linolenic and 100% check yield.

In the modified carbohydrate profile project, after the release of UA 5515HS with 8.1% sucrose, 0.4% stachyose, and 1406 ppm of inorganic phosphorus (low phytate), we have identified another outstanding line R13-10658 (9.6% sucrose, 0.4% stachyose, 101% check yield), which has been entered in the 2017 USDA Preliminary MG5E test for yield evaluation in several southern U.S. locations. High sucrose increases the metabolic energy of soybean meal for animal feeding, while low content of stachyose and phytate (anti-nutritional factors) increases the digestibility of the soybean meal, preventing water and soil pollution when manure is applied as fertilizer.

Food-Grade Soybean. The variety UA Mulberry was released in spring 2016 for roasted soy nut and edamame production because of its black large seed. Variety UA Mulberry was derived from two large-seeded lines, R01-3597F (Arkansas) and V96-7198 (Virginia). Another two edamame-type lines R07-589 (R95-1705 × PI 243545) and R14-6450 (R08-4006 × R07-10397) are promising lines for future release. The variety R07-589 is a brown-coated large-seeded line (21.8 g/100 seeds) suitable for the soy nut market and R14-6450 is a yellow large-seeded line (25.0 g/100 seeds) with potential use for edamame production.

Drought Tolerance. In 2016, two drought-tolerant lines: R10-2436 (R01-52F × R02-6268F) and R10-2710 (R01-52F × N97-9658) were proposed for release as germplasm because of their high yield under irrigation and less yield reduction under drought. Under irrigation, R10-2436 and R10-2710 yield 66.2 and 62.9 bu/ac, respectively, compared to 64.1 and 64.5 check mean of MG 4 and MG 5 Asgrow checks (Table 3). Under drought, R10-2436 and R10-2710 yielded 48.6 and 46.0 bu/ac, respectively compared to 39.3 and 46.3 bu/ac of MG 4 and MG 5 checks (Table 3). Both lines were probed to have the extended nitrogen fixation trait under drought, which means that they are able to continue fixing nitrogen even with lower water content in the soil. Both lines were approved for release in February 2017.

Practical Applications

The soybean breeding program has made progress in the development of value-added varieties through the use of the available soybean germplasm. Thanks to the active exchange of soybean germplasm among the U.S. university breeding community, the Arkansas Soybean Breeding Program has been able to integrate the available germplasm in the parental stock and thus, continue the breeding process to develop varieties with improved seed composition, suitable to specialty markets, or tolerant to biotic or abiotic limiting factors such as drought and disease.

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Table 1. Yield and agronomic traits of R10-5086 and R11-6870, six commercial checks, and three diversity germplasm releases evaluated in the USB-Diversity MG 5 Test from 2013 to 2016.

Name	2013	2014	2015	2016	Mean[a]	% CK[b]	Maturity Oct. 1 = 1[c]	Height in.	Lodging (1-5)[d]	Seed Size g/100-seed	Seed Quality (1-5)[e]
	Yield (bu/ac)										
R10-5086	65.4	63.7	65.7	49.9	61.2	100.8	9	30	2.2	14.0	1.9
R11-6870	--[f]	64.0	62.3	55.4	61.5	101.3	8	32	2.0	14.2	1.8
Osage	63.2	65.8	67.8	54.1	62.7		6	28	1.7	13.3	1.7
95Y70	65.3	63.8	--	--	61.7		11	41	2.5	13.9	2.5
5002T/Ellis	59.3	65.4	65.7	52.1	60.6		4	28	1.8	13.9	1.7
AG5332/AG5335	--	62.5	64.3	51.6	60.4		3	36	2.4	14.9	2.2
AG 5606/AG5534	63.3	62.5	63.1	48.3	59.3		7	35	2.1	16.1	2.0
5601T	60.1	62.4	--	--	58.4		--	33	1.9	14.8	1.9
Check Mean	62.2	63.7	65.2	51.5	60.7						
LSD (0.05)	7.9	6.4	3.8	--	--						
No. Locations	5	6	4	6							
R10-5086	65.4	63.7	65.7	49.9	61.2	100.8	9	30	2.2	14.0	1.9

[a] Least Significant Means option of SAS-GLM (adjusted mean for missing values).
[b] Percent of yield with respect to check mean.
[c] Number of days until maturity starting day 1 at Oct. 1.
[d] 1 = all plants erect, 5 = all plants prostrate.
[e] 1 = excellent, 5 = poor.
[f] Missing data.

Table 2. Yield and protein and oil content of advanced high-protein lines grown in three Arkansas locations during 2016.

Name	Pedigree	Yield	% CK[a]	Protein[b]	Oil
		bu/ac	%	%	%
R11-8346	Osage × S00-9980-22	59.6	96	39.3	16.9
R11-7999	5002T × R00-2097	58.4	94	38.9	17.1
AG5535	N/A	64.6		35.0	18.3
AG5335	N/A	63.8		36.3	19.0
AG4934	N/A	61.9		35.6	18.7
AG4835	N/A	58.1		35.0	18.3
Check Mean		62.1			
CV (%)		7.8			
LSD (0.05)		3.9			
Grand mean		53.8			

[a] Percent of yield with respect to check mean
[b] % Protein and oil based on 13% moisture.
N/A = not available

Table 3. Yield of R10-2436 and R10-2710 under irrigation and drought conditions (2012- 2016).

	Irrigation						Drought					
Name	**2012**	**2013**	**2014**	**2015**	**2016**	**Mean**	**2012**	**2013**[a]	**2014**	**2015**	**2016**	**Mean**
	----Yield(bu/ac)----						----Yield (bu/ac)----					
R10-2436	65.5	69.0	78.2	52.4	65.8	66.2	54.6	17.3	56.3	44.5	39.1	48.6
R10-2710	63.1	63.4	75.4	49.8	63.0	62.9	52.4	25.5	54.4	39.3	38.1	46.1
Check Avg. (MG 4)[b]	–[d]	64.2	72.4	58.1	61.7	64.1	–	15.3	39.9	37.5	40.6	39.3
Check Avg. (MG 5)[c]	66.1	63.9	74.4	53.8	64.5	64.5	43.9	13.9	40.6	32.5	40.9	39.5
No. Environments	2	2	1	2	2		1	1	1	1	1	
Check Mean	66.1	64.0	73.7	55.9	63.1		40.3	16.7	40.3	38.6	41.7	
CV (%)	6.9	9.3	4.1	7	6.5		9.7	16.4	9.5	11.8	10	
LSD (0.05)	4.8	6.6	5.0	4.1	4.5		7.2	5.3	7.2	6.7	6.0	
Grand Mean	61.7	61.6	75.0	51.1	60.1		45.4	19.7	46.6	34.4	36.8	

[a] Yields from dryland in 2013 are not included in average because high shattering compromised yield data.
[b] MG 4 checks: AG 4907, AG 4835, AG 4933, AG 4934, and P4930LL.
[c] MG 5 checks: 5002T, AG 5606, AG 5905, AG 5332, AG 5335, AG 5535, and AG 5831.
[d] Missing data.

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 develops new germplasm to broaden the genetic background and improve traits such as yield, seed quality, disease resistance, and stress tolerance in the southern soybean gene pool. We carefully select breeding lines with desired traits, then advance them and maintain the purity for future release to Arkansas farmers, or as non-exclusive licensing to private companies and seed dealers. This report summarizes the effort during the 2016 growing season.

Introduction

Increased demand for conventional varieties has solidified the need for public breeding programs since private companies have focused primarily on varieties with genetically modified traits. However, since the patent for Roundup Ready-1 technology expired in 2015, we worked on developing glyphosate-tolerant varieties as well. These varieties offer a lower seed cost source to farmers, who can then save the seed for planting the following year. We also combine specialty traits in our breeding program by advancing high-yielding varieties with added high protein, high oil, high sugar, or modified fatty acids. These exclusive traits provide the farmers an opportunity for an additional profit on their crop.

Procedures

Twenty-one varieties were in foundation and pre-foundation production in 2016. In Stuttgart, Ark. we grew 25 acres of Osage, 28 acres of UA 5213C, and 63 acres of UA 5414RR; and at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark. we grew 40 acres of UA 5612, 50 acres of UA 5014C, 50 acres of R09-430, 25 acres of UA 5414RR and 60 acres of UA 5715GT. Approximately one acre of each of the following were grown as pre-foundation, to use as seed increase for potential releases or licensing: R09-1589, R10-28, R09-345, R11-7999, R13-5174, R13-1019, UARK-288, R13-5029, and R07-589. Additionally, 9.5 acres of R08-4004, 9 acres of UA Kirksey, 3.5 acres of RM-21464, 2.5 acres of UA 5615C, and one acre each of UA 5814HP and UA 5115HS were grown to fulfill contracts with licensees. Seed increases of these varieties were grown in Stuttgart, Ark. at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center.

Each variety that we produce in foundation, pre-foundation and as breeder seed lots are carefully rogued for off-types multiple times during the growing season. Likewise, they are verified for seed traits such as protein, oil, sugar and fatty acid content in the lab. Each line is also tested for diseases including root-knot, reniform and soybean cyst nematode, stem canker, sudden death syndrome and frogeye leaf spot. Each line has been assessed for their sensitivity to salt and to metribuzin and each cultivar has been evaluated in the USDA and variety testing trials throughout the southern United States and in Kentucky, Kansas and Virginia.

Results and Discussion

In 2016, the Arkansas Soybean Foundation Seed program received orders of 5304 units of conventional soybean in total: 1097 units of Osage, 1344 units of UA 5612, 941 units of UA 5213C, and 1216 units of UA 5014C. We also produced 2425 units of UA 5414RR and 847 units of UA 5715GT which were made available to farmers to purchase in 2016. These cultivars have yields competitive with maturity group (MG) late 4 and early to mid-5 commercial cultivars available in the southern U.S. In addition, we produced 203 units of UA 5814HP, 42 units of UA Kirksey, 667 units of R09-430 and 461units of UA 5515HS per agreements with non-exclusive licensing for private industry (Table 1).

Our program had several specialty and conventional varieties that were considered for release in 2016. Variety R09-345 was proposed as UA Mulberry and it shows great promise in the soy nut and edamame markets. Variety R07-2000 was proposed and released as UA 5515HS, a high-sucrose, low-stachyose, and low-phytate variety. Its intended use is for the soymeal market as a dietary supplement for human and livestock consumption, it will also have a potential production premium. Variety R10-230 has been proposed as UA 5615C, a high-yielding maturity group 5 that has been

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approved as a non-exclusive license to private industry. Variety R09-430 was proposed and is now licensed to a private entity; it is a high-yielding maturity group 5.1 variety. Both R10-230 and R09-430 have been tested in state variety testing programs in Kansas, Arkansas, Missouri, Tennessee and Mississippi and in the USDA trials. Both lines have performed very well in all regional tests and together have ranked in the top of the USDA test for several years. Collectively they are high-yielding cultivars that show great promise to farmers.

Practical Applications

Production of breeder and foundation seed of different varieties (conventional, glyphosate-tolerant, and modified-seed composition) developed in the University of Arkansas System Division of Agriculture's Soybean Breeding program provides high seed quality (purity and percent germination) to local soybean producers, enhancing the competitiveness of Arkansas soybean in both the national and international markets.

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Table 1. 2016 foundation, pre-foundation seed production overview.

Variety	Produced (50 lb bag units)	Adv. Orders	Available	Use
Osage	1097	868	0	Foundation
UA 5612	1344	842	0	Foundation
UA 5213C	941	608	0	Foundation
UA 5014C	1216	780	0	Foundation
UA 5615C	33	580	0	Licensed
R10-430	667	580	0	Licensed
UA 5414RR	2425	2685	0	Foundation
UA 5814HP	203	203	0	Licensed
UA 5715GT	847	1139	0	Foundation
UA 5515HS	461	0	0	To be licensed
UA Kirksey	42	42		Licensed
Total	**9276**	**8327**	**0**	

Development of Flood-Tolerant Soybean Varieties and Breeding Lines

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Abstract

Flooding is an abiotic stress that causes considerable reductions in soybean growth and grain yield. Most of the commercial soybean cultivars in America are generally sensitive to flooding stress. The University of Arkansas System Division of Agriculture's Soybean Breeding Program is committed to developing high-yielding, flood-tolerant varieties and germplasm for the southern United States soybean-producing region. The breeding effort includes germplasm characterization and identification of flood-tolerant sources to develop these germplasm and varieties; assessment of flooding effect on field seed germination; evaluation of the effects of flooding stress on yield and seed composition; and identification of flood Quantitative Trait Loci (QTLs) for marker-assisted selection (MAS). This report highlights the breeding efforts made by the Soybean Breeding Program for the flood tolerance project in 2016.

Introduction

Flooding reduces approximately 16% of worldwide soybean production, causing billions of dollars in losses for farmers (Boyer 1982; Rosenzweig et al., 2002). In the Mississippi delta region, flooding reduces up to 25% of soybean grain yield in soybean-paddy rice rotations (VanToai et al., 2010). Most soybean cultivars are intolerant to flooding (Russell et al., 1990) and yield losses are estimated to be between 17% and 43% when flooding stress occurs during the vegetative stage, and 50% to 56% during the reproductive stage (Oosterhuis et al., 1990). In addition, genetic variability for flood tolerance in soybean exists among different germplasm and cultivars (VanToai et al., 1994). Results from a three-year field study showed that there was a 40% yield reduction in a soybean flood-tolerant group versus an 80% reduction in a flood-susceptible group (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 those germplasm in breeding efforts has become an ongoing goal of the University of Arkansas System Division of Agriculture's Soybean Breeding Program.

Procedures

Yield potential of 35 advanced soybean varieties/lines was evaluated in one advanced test (16FLF) in three Arkansas locations of the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark.; Lon Mann Cotton Research Station, Marianna; and Rohwer Research Station near Rohwer, Ark. with three replications without flooding. Flood tolerance of these 35 varieties/lines was evaluated in a test with two replications at the Rice Research and Extension Center in Stuttgart, Ark. In addition, 43 lines with flood-tolerant pedigrees (Caviness × R08-2496, PI 471931 × PI 471938, PI 471931 × R02-1325, PI 471931 × R08-2416, PI 567682B × R08-2416, R04-342 × 91210-350, R08-2416 × Jake, and RA-452 × R01-581F) were evaluated in a preliminary flood test (16FLP) without flooding in two Arkansas locations (Stuttgart and Marianna) with one replication. In a separate study, a total of 341 new lines derived from flood-tolerant pedigrees (Ozark × Jake, R07-6669 × Jake, R07-6669 × R09-2988, R07-6669 × R10-412 RY, R08-47 × Jake, R08-1178 × Jake, R09-2567 × Jake, R09-430 × Jake, R07-10322 × Jake, R07-6669 × UA 5612, UA 5615C × UA 5612, TN08-100 x R11-262, R11-262 × JTN-5110, R11-262 × R10-5721, and R04-342 × 91210-350) were evaluated in a progeny row test in Stuttgart, Ark.

Additional sets of screening tests with 2 replications each were conducted in the field at Stuttgart, Ark with the purpose of identifying sources of flood tolerance for future crossing. Entries included 34 high-yielding conventional or glyphosate-tolerant lines and 24 drought-tolerant lines from the Soybean Breeding Program, and 142 commercial cultivars from the Arkansas Variety Testing Program. For all tests, 100 seeds of each variety/line were planted in a 10-ft row in June 2016. Once plants reached R1 growth stage (first flower at any node), flooding was imposed for 8 days (irrigating water 4 to 6 inches above the soil surface). Foliar damage score (FDS) and plant survival rate (PSR) were recorded in 3-day intervals for three times immediately after the flood was removed. In our program, FDS is used to evaluate flood tolerance. This score is based on a 1 to 9 scale, where 1 indicated less than 10% and 9 indicated over 85% of the plants showing foliar damage or death, respectively (1 = 0% to 10%; 2 = 11% to 20%; 3 = 21% to 30%; 4 = 31% to 40%; 5 = 41% to 50%; 6 = 51% to 60%; 7 = 61% to 70%; 8 = 71%

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to 85%; 9 = 86% to 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.

In order to evaluate the effect of flooding on soybean seed germination in the field, a separate set of tests were conducted in 2016. Twenty varieties/lines with different responses to flooding (based on a preliminary screening; data not shown), from the Soybean Breeding Program, were selected and included in 3 replication tests at Stuttgart, Ark. Seeds of each genotype were split in two sets: an untreated set and a set treated with fungicide Apron Maxx RTA (active ingredients: Fludioxonil (0.73 %) and Metalaxyl-M and S-isomer (1.10%)) (Syngenta Crop Protection Inc., Greensboro, N.C.). A total of 0.5 oz (14.8 ml) of Apron Maxx RTA were added to every 10 lb (4.540 kg) seeds and mixed even in bucket. Paper envelopes filled with 100 seeds per entry per replication, were prepared for planting. Flooding stress was imposed three days after sowing, with 2–2.8 in. (5–7 cm) of water above the soil surface. Flooding treatments were 6, 12, 24, 36, 48, 72, 96, and 120 hours of flooding. After each flooding treatment, water was drained for seed germination. At the same time, two control tests without flood stress (untreated and treated seed) were conducted in the field. Four weeks after removing the flooding, germination of each entry was recorded by counting the number of emerged seedlings. Concurrently, seed germination data of the two control tests without flood stress were also collected. Seed germination rate (SGR) was calculated by dividing the number of emerged seedlings obtained in each counting per 100 seeds.

A preliminary test was conducted to evaluate the yield performance and seed composition of 20 varieties/lines (9 tolerant, 9 sensitive, and 2 commercial cultivars) under normal irrigation and flooding conditions in Stuttgart, Ark. Plants were flooded for three days at R1 growth stage. Data of yield, plant height, lodging, seed size, seed quality, and seed protein and oil were collected. Results were analyzed and compared between the two treatments. This test will be repeated in 2017 to further confirm findings.

Two $F_{7:9}$ genetic mapping populations: WH-A (5002T × 91210-350) and WH-B (RA-452 × Osage) were screened for flood tolerance in 3 replication tests with the objective of identifying Quantitative Trait Loci (QTL) associated with flood tolerance for marker-assisted selection (MAS). Leaf samples were collected from each recombinant inbred line (RIL) in both populations and DNA was extracted to conduct single nucleotide polymorphism (SNP) marker analysis in 2017. In addition, 300 plant introductions (PIs) from USDA germplasm collection were screened for flood tolerance in a 3 replication tests in Stuttgart and Rohwer, Ark. Flood was imposed at R1 stage for 8 days in Stuttgart and 5 days in Rohwer. Foliar damage score was recorded after flooding was removed. This test will be repeated in 2017 to further confirm our results. Several additional collaborative tests with the University of Missouri were conducted at Stuttgart and Rohwer, Ark. to investigate the environmental effect on the flood-tolerant trait, and also to identify molecular markers associated with flood tolerance.

In addition, 70 flood-tolerant genetic populations were advanced using either modified single-pod or single-plant descent methods. Moreover, parental materials from the Soybean Breeding Program, other U.S. soybean breeding programs, and the USDA World Soybean Collection to combine flood tolerance, were selected and integrated to the program in order to combine the flood-tolerant trait with yield and desired seed quality traits.

Results and Discussion

Among the lines tested in 16FLF, seven varieties/lines (UA 5615C, R11-262, R07-6669, R04-342, R10-4892, R11-6870, and Walters) had flood tolerance (low foliar damage score = 3.3 to 3.8; high plant survival rate = 61.2% to 72.5%). Three of them (UA 5615C, R11-6870, and R11-262) also exhibited high yield (91% to 93% check yield; AG4934, AG5335, AG5535; 63.9 bu/ac) (Table 1). Our release UA 5615C, was the best performing variety (93% grain yield of check yield) with flood tolerance (foliar damage score = 3.3; plant survival rate = 72.5%). Similarly, R11-6870, our most recent diversity germplasm release, showed good flood tolerance (foliar damage score = 3.3; plant survival rate = 67.7 %) with high yield (92% check yield).

In the preliminary flood test, three lines (R15-7817, R15-10832, and R15-7823) yielded 82% to 91% of the check yield (AG 4934 and AG 5533; 60.6 bu/ac) (Table 2). High-yielding lines in this test will be selected for yield and flood tolerance evaluation in 2017. A total of 27 progeny rows were visually selected based on plant uniformity and overall field appearance at maturity. A total of 10 F_4, 13 F_3, 22 F_2, and 25 F_1 breeding populations were advanced. In addition, 18 new crosses for the flood project were designed and made.

In the screening of 34 high-yielding conventional or glyphosate-tolerant lines for the identification of flood-tolerant sources for future crossing, 4 lines (R11-6870, R10-298, R12-226, and R13-1419) showed tolerance to flooding (foliar damage score = 2.5 to 3.0; plant survival rate = 74.8% to 80.3%) (Table 3). The screening of 24 lines developed for drought tolerance showed 3 lines (R11-2836, R10-2710, and R14-13561) with flood tolerance (foliar damage score = 3.5 to 3.8; plant survival rate = 64.3% to 70.2%) (Table 3). The screening of 142 commercial cultivars showed that majority of the commercial cultivars are sensitive to flooding (Table 3).

Results from the test evaluating the effect of flooding stress on soybean seed germination in the field showed that means of seed germination rate of untreated and fungicide-treated seeds significantly decreased over the eight flooding treatment times ($P < 0.0001$) (Fig. 1). Flooding effect on germination between untreated and fungicide-treated seeds was not significantly different ($P = 0.1559$) (Fig. 2); however, means of seed germination rate of untreated and fungicide-treated seeds was significantly different without flooding stress ($P < 0.0001$) (Fig. 3). Mean comparison of the seed germination rates among flood-tolerant, moderately flood-tolerant, and flood-sensitive groups, showed no significant difference between untreated and fungicide-treated seeds ($P = 0.8490$) (Fig. 4). Conclusions from this test include: 1) Longer flooding duration leads to lower seed germination in the field; 2) fungicide treatment increases seed germination under non-flooded conditions but not under flood stress; and 3) seed germination rates of tolerant, moderately tolerant, and sensitive groups were not significantly different under flooding stress.

Results from the preliminary test conducted to evaluate the yield performance and seed composition of 20 varieties/lines under normal irrigation conditions vs. 3-day flooding showed that after 3 days of flooding, yield mean of all genotypes was significantly reduced (63.0%). In addition, yield reduction of flood-tolerant entries was 54.3% which was significantly different from that of flood-sensitive entries (71.7%). Similarly, plant height reduction was larger in flood-sensitive entries compared to that of flood-tolerant entries (32.5% and 25.4%, respectively). Seed size of all genotypes significantly decreased 2.5 gram/100 seeds after flooding treatment. In addition, protein content of all genotypes decreased 1.8% while oil content varied slightly (Table 4).

Combined results from the two $F_{7:9}$ genetic mapping populations (WH-A and WH-B) and the several additional collaborative tests with the University of Missouri will be included in the next research series publications.

Practical Applications

The Soybean Breeding Program 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.

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Table 1. 2016 Arkansas advanced flood test (16FLF) grown in three locations with three replications.

Entry	Name	Pedigree	Yield[a]	% Cks[b]	FDS[c]	PSR[d] (%)
30	AG5535	N/A	66.0	103	6.3	34.6
20	AG5335	N/A	63.0	99	6.3	29.6
10	AG4934	N/A	62.6	98	7.5	20.1
2	UA 5612	R97-1650 × 98601	61.6	97	4.5	51.4
26	R11-7999	5002T × R00-2097	60.5	95	6.0	38.3
7	R09-1589	5002T × R01-4752	60.1	94	6.0	35.8
5	R10-230	5002T × R04-357(UA 5612)	59.3	93	3.3	72.5
21	R11-6870	5002T × R01-3474F	58.8	92	3.3	67.7
6	R09-430	BA 743303 × R00-684	58.7	92	4.8	51.5
9	R11-262	5002T × R04-357	58.1	91	3.8	61.2
1	Osage	Hartz 5545 × KS4895	58.0	91	4.8	50.3
38	UA 5014C	Ozark × Anand	58.0	91	7.3	24.2
24	R10-2622	R01-888F × R05-5559	57.5	90	4.3	53.7
17	R10-197 RY	Ozark BC1F4	56.3	88	4.8	52.0
39	UA 5014C	Ozark × Anand	56.2	88	7.8	16.4
3	UA 5213C	R98-1523 × 98601	56.1	88	5.3	40.9
19	R10-5086	Osage × R99-1613F	56.0	88	5.5	39.8
23	R10-2436	R01-52F × R02-6268F	56.0	88	6.3	34.6
8	R11-245	5002T × R04-357	55.8	87	4.0	58.7
22	R10-4892	5002T × R01-3474F	55.5	87	3.5	66.1
15	UA 5414RR	FST 5 Early	55.3	87	6.4	38.9
16	R07-6614RR	FST 5 Late	54.8	86	6.0	37.0
4	UA 5014C	Ozark × Anand	54.7	86	7.8	14.9
18	R11-89RY	Osage × RR2Y	54.3	85	6.5	31.5
32	R09-1223	R01-4910 × IA2064	53.1	83	4.5	54.1
13	R04-342	R97-1650 × 98601	52.8	83	3.8	63.4
12	R07-6669	Lonoke × R00-33	52.7	83	3.8	61.5
11	R11-1617	R03-263 × UA 4805	52.4	82	6.3	33.7
25	UA 5814HP	R95-1705 × S00-9980-22	51.8	81	4.3	52.1
33	UARK-288	Ole23-3-13	50.9	80	5.3	42.9
36	R13-12638	R01-52F × 91210-350	50.0	78	5.5	40.3
14	Walters	Forrest × Narow	48.9	77	3.3	71.8
29	R07-2000	Ozark × V99-5089	48.2	76	6.0	37.2
35	R13-12535	5002T × 91210-350	46.5	73	6.8	28.6
40	R14-14008	5002T × N97-9658	45.9	72	5.3	46.2
27	R08-4004	R95-1705 × MFL-552	44.2	69	6.3	35.0
37	R13-12552	5002T × 91210-350	43.7	68	5.3	47.1
31	R07-2001	Ozark × V99-5089	43.6	68	4.3	53.7
34	R13-12695	RA 452 × 91210-350	41.8	66	6.0	35.2
28	UA Kirksey	R95-1705 × MFL-552	37.8	59	6.3	36.3
		CHECK MEAN	**63.8**			
		CV (%)	**9.4**			
		GRAND MEAN	**53.9**			
		LSD (0.05)	**4.7**			

[a] Average yield of three locations University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark.; Lon Mann Cotton Research Station, Marianna; and Rohwer Research Station near Rohwer, Ark

[b] Percentage of yield average of three checks (AG 5535, AG 5335, and AG 4934).

[c] Foliar damage score (flood-tolerant, FDS = 3.3–3.8; moderately tolerant, FDS = 4.0–5.5; sensitive, FDS = 6.0–7.8).

[d] Plant survival rate (flood-tolerant, PSR = 61.2–72.5%; moderately tolerant, PSR = 38.3–58.7%; sensitive, PSR = 14.9–38.9%).

Table 2. 2016 Arkansas preliminary flood test (16FLP) grown in two locations with one replication.

Entry	Name	Pedigree	Yield[a]	%Cks[b]
30	AG5535	N/A	63.4	105
10	AG4934	N/A	57.8	95
31	R15-7817	R08-2416 x Jake	55.2	91
9	R15-10832	R04-342 x 91210-350	49.8	82
33	R15-7823	R08-2416 x Jake	49.6	82
14	R15-10957	R04-342 x 91210-350	46.7	77
1	R15-7794	R08-2416 x Jake	46.1	76
24	R1511802	RA-452 x R01-581F	44.7	74
19	R1511710	RA-452 x R01-581F	44.3	73
36	R15-7852	Caviness x R08-2496	44.1	73
8	R15-10829	R04-342 x 91210-350	44.0	73
39	R15-7869	Caviness x R08-2496	43.8	72
29	R15-7810	R08-2416 x Jake	43.7	72
37	R15-7856	Caviness x R08-2496	43.7	72
20	R1511718	RA-452 x R01-581F	43.4	72
22	R1511778	RA-452 x R01-581F	43.4	72
16	R1511648	PI 471931 x PI 471938	43.3	71
2	R15-7797	R08-2416 x Jake	42.4	70
44	R15-7773	PI 471931 x R02-1325	41.9	69
28	R15-7809	R08-2416 x Jake	41.9	69
4	R15-7807	R08-2416 x Jake	41.5	68
26	R15-7792	R08-2416 x Jake	40.5	67
45	R15-7785	PI 471931 x R02-1325	40.4	67
11	R15-10857	R04-342 x 91210-350	40.2	66
42	R15-7764	PI 471931 x R02-1325	40.0	66
41	R15-7762	PI 471931 x R02-1325	39.8	66
34	R15-7848	Caviness x R08-2496	39.2	65
43	R15-7770	PI 471931 x R02-1325	38.8	64
12	R15-10878	R04-342 x 91210-350	38.5	63
35	R15-7849	Caviness x R08-2496	37.8	62
13	R15-10903	R04-342 x 91210-350	37.8	62
5	R15-7821	R08-2416 x Jake	37.6	62
15	R1511633	PI 471931 x PI 471938	37.0	61
38	R15-7867	Caviness x R08-2496	36.1	59
7	R15-7845	PI 471931 x R08-2416	35.8	59
27	R15-7799	R08-2416 x Jake	35.8	59
6	R15-7825	R08-2416 x Jake	35.4	58
18	R1511668	PI 471931 x PI 471938	35.2	58
32	R15-7820	R08-2416 x Jake	35.2	58
23	R1511796	RA-452 x R01-581F	35.0	58
3	R15-7806	R08-2416 x Jake	34.0	56
17	R1511652	PI 471931 x PI 471938	33.9	56
25	R15-7787	R08-2416 x Jake	33.7	56
21	R1511734	RA-452 x R01-581F	29.3	48
40	R15-7891	PI 567682B x R08-2416	27.9	46
		CHECK MEAN	**60.6**	

[a] Average yield of two locations University of Arkansas System Division of Agriculture's Northeast Research and Extension Center, Keiser, Ark. and Lon Mann Cotton Research Station, Marianna, Ark.
[b] Percentage of yield average of two checks (AG 5535 and AG 4934).

Table 3. Response of Arkansas varieties and lines to flood stress in 2016.

Flood tolerance	FDS[a]	PSR[b] (%)	Number of varieties/lines		
			CV[c] + RR1	Drought[d]	Commercial[e]
High	2.5–3.8	61.7–80.3	4	3	8
Moderate	4.3–5.8	38.6–60.8	15	9	43
Sensitive	6.0–7.8	15.7–45.1	15	11	84
Highly sensitive	8.0–8.3	11.1–17.1	0	1	7
Total			34	24	142

[a] FDS = foliar damage score.
[b] PSR = plant survival rate.
[c] Conventional lines.
[d] Drought-resistant lines.
[e] Commercial cultivars

Table 4. 2016 Comparison of yield, agronomic traits, and seed composition of 20 entries under irrigation vs. flooding.

Category	Yield Reduction (%)	Height Reduction (%)	Lodging Reduction	Seed size Reduction (g)	Seed quality Rate (1-5) Increase	Protein Reduction (%)	Oil Reduction (%)
Tolerant	54.3	25.4	1.4	2.4	1.1	1.7	0.5
Sensitive	71.7	32.5	1.0	2.7	1.0	1.8	0.2
Test mean	63.0	29.0	1.2	2.5	1.0	1.8	0.4

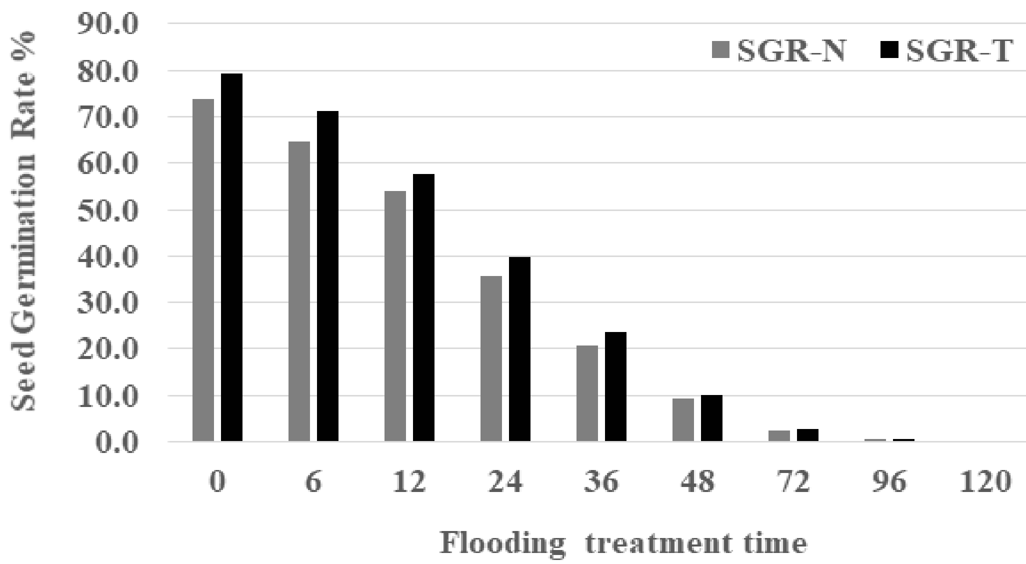


Fig. 1. Seed germination rate (SGR) of untreated and fungicide-treated seed under eight flooding duration times (6 to 120 hours) and without flooding (0 hour).

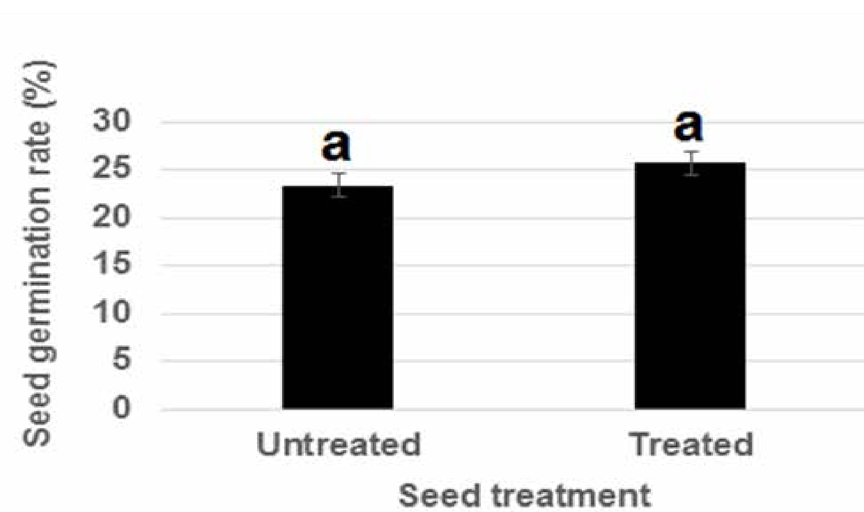


Fig. 2. Seed germination rate of untreated and fungicide-treated seed under flooding.

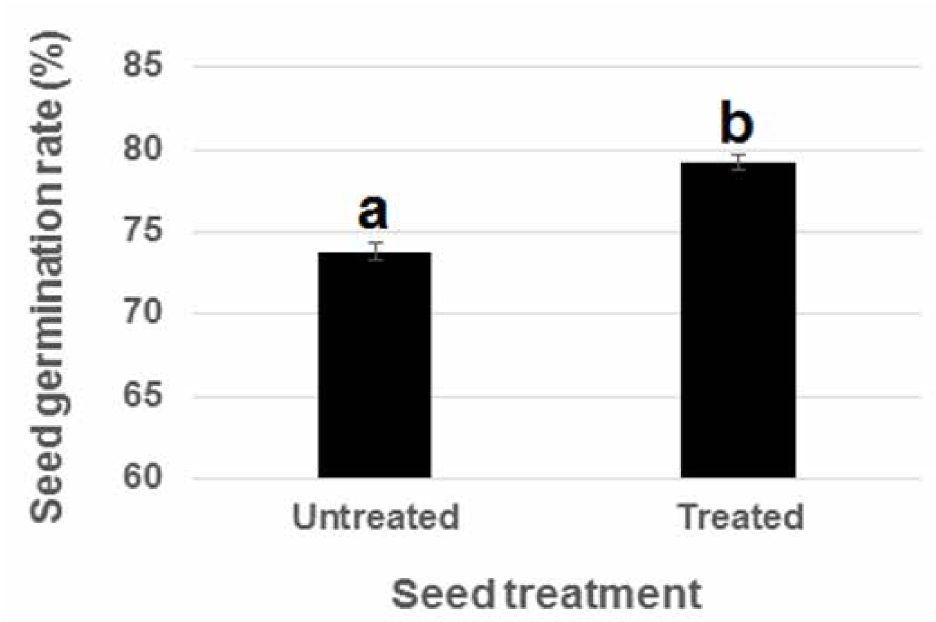
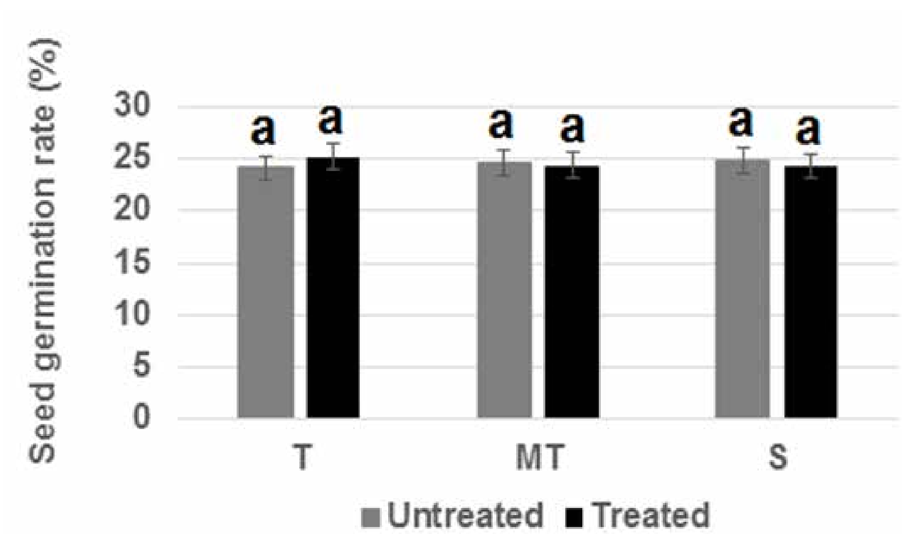


Fig. 3. Seed germination rate of untreated and fungicide-treated seeds without flooding.



T = Tolerant group; MT = Moderately tolerant group; S = Sensitive group.

Fig. 4. Germination rate comparison between untreated and fungicide-treated seeds grouped by their flood response, under flooding conditions.

Salt Stress Alters Insect Growth in Chloride-Includer Varieties of Soybean

J. Najjar[1], L.D. Nelson[1], P. Chen[2] and K.L. Korth[1]*

Abstract

Exposure to salt and the resulting chloride toxicity in soybean, *Glycine max* [(L.) Merr.], continue as problems in Arkansas soybean production. Plants in the field are constantly exposed to combinations of both biotic and abiotic stresses that reduce yields and quality. Exposure to salt in chloride-includer variety of soybean resulted in reduced chlorophyll levels and in less growth of the soybean looper, *Pseudoplusia includens*. This demonstrates that even relatively low levels of salt exposure can impact plants physiological performance and interactions with biotic pests.

Introduction

The soybean looper is a foliar soybean pest that can be found in soybean fields across the globe including the soybean-growing regions of the eastern and southern United States. Larvae cycle through six larval stages in about two to three weeks during which they feed on the leaves and sometimes pods of the soybean plants. Defoliation of soybean plants by the larvae results in decreased photosynthetic capacity and can ultimately lead to a reduction in yield of the damaged plants. Although soybean loopers alone do not typically cause economic damage, loopers often occur in combination with other lepidopteran foliage feeders that together contribute to much higher levels of defoliation (Lorenz et al., 2006). Chemical control of the soybean looper can be difficult due to the species' high level of resistance to a broad range of insecticides including pyrethroids (Lorenz et al., 2006; Smith et al., 1994). As a result, more expensive insecticides are necessary for looper control making the management of any serious soybean looper outbreak more costly for the producer.

Saline soils are common worldwide and limit the yield potential of many agricultural crops. Salt-affected soils are found on every continent and are caused by a high concentration of soluble ions with sodium (Na^+) and chloride (Cl^-) being the most soluble and damaging to plants (Munns and Tester, 2008). Some soil textures in Arkansas, particularly where groundwater irrigation is used or where groundwater carries a high Cl^- concentration, are especially prone to buildup of Cl^- levels. Variation in salt tolerance exists among soybean, with tolerance generally associated with an ability to exclude Cl^- ions from foliar tissues. High salinity conditions may cause reductions in soybean plant height, leaf size, biomass, number of branches, number of pods and weight of seeds (Abel and MacKenzie, 1964; Chang et al, 1994). A major reduction in any one of these categories can severely limit yield potential of the soybean crop and have major effects on financial return.

Because crops are likely to experience both biotic and abiotic stresses under field conditions, it is imperative to understand how these different stressors interact with one another and ultimately how that interaction affects crop productivity. Using measures of chlorophyll content, we indirectly assess the phyotosynthetic capacity of H_2O- and NaCl-treated soybeans. Soybean looper weights were assessed after feeding on either H_2O- or NaCl-treated soybeans.

Procedures

Seed from soybean cultivars Clark (salt-sensitive) and Manokin (salt-tolerant) were planted into 4 by 4- by 3.5 in. square plastic pots containing pasteurized river sand at a density of 1 seed per pot. These lines were selected because they are U.S. varieties and have been previously categorized as Cl^--includer and -excluder, respectively. Plants were treated with a salt solution once the first trifoliate was fully emerged (V1 stage). For chlorophyll measurements, treatments consisted of partial flooding with 100 mM NaCl or deionized H_2O for two hours daily. For insect growth measurements, treatments were the same except that salt levels were reduced to 50 mM NaCl. Soybean looper eggs were obtained from Dr. Clint Allen. Eggs typically hatched at seven to ten days, and were fed on a soybean looper-specific diet from Southland Products, Inc. (Lake Village, Ark.).

After the twelfth day of salt treatment, first instar larvae were caged individually onto soybean leaves using a Petri dish that had been altered to allow gas exchange. Three larvae were caged individually on each of three leaves and six plants of each cultivar were used in each treatment. Larvae were allowed to feed for 72 hours after which they were collected and weighed individually.

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Twenty additional plants of each cultivar (Clark and Manokin) were grown and treated with NaCl or H_2O in the same manner as described above. These plants were treated daily for fourteen days after which chlorophyll content was assessed using a SPAD-502 Chlorophyll Meter (Konica Minolta; Tokyo, Japan). This instrument detects the absorbance of chlorophyll in both the red and near-infrared regions from which the meter calculates a SPAD value which is proportional to the amount of chlorophyll present in the leaf. One leaf of each plant was assessed for chlorophyll content by placing the leaf inside the measuring head of the meter while avoiding the thick mid-vein. Means were compared using a one-way analysis of variance (ANOVA) with Tukey's post hoc test and a significance level of $P < 0.05$.

Results and Discussion

Sodium chloride treated Clark plants showed a significant reduction in chlorophyll content relative to H_2O-treated Clark plants (Fig. 1). The chlorophyll content of the salt-tolerant Manokin plants did not differ significantly between treatments. Under the salt treatment, chlorophyll content of salt-sensitive Clark was significantly reduced compared to chlorophyll content of salt-tolerant Manokin. More specifically, NaCl-treated Clark plants suffered a 38.6% reduction in chlorophyll content relative to H_2O-treated Clark plants, while NaCl-treated Manokin plants were not significantly different in chlorophyll content relative to H_2O-treated plants. These treatments were at a relatively high level of NaCl, demonstrating that Manokin is considerably more tolerant of salt than cultivar Clark. A similar trend was observed by Ren et al. (2012) in which salt-sensitive Union soybean experienced more severe reductions in chlorophyll content relative to salt-tolerant WF-7 soybean under salt stress. Clear differences in biomass production between the cultivars as measured by fresh weight and root dry weight (Korth Lab, data not shown) indicate that the salt-tolerant Manokin plants are able to continue active photosynthesis at higher levels than salt-sensitive Clark plants under NaCl stress, which would translate presumably to higher yields.

Loopers that fed on NaCl-treated Clark plants weighed significantly less than loopers that fed on H_2O-treated plants of the same cultivar (Fig. 2). Looper weight was not affected by salt treatment in the salt-tolerant Manokin plants, in which no significant difference was detected between the H_2O- and NaCl-treated plants. More specifically, insects feeding on salt-treated Clark plants displayed a 40.6% reduction in average weight compared to insects on H_2O-treated Clark plants. This enhanced performance of insects occurred even at a relatively low level, 50 mM, of NaCl treatment. Thus, even at levels of salt exposure that don't cause severe leaf curling or browning, secondary effects of salt stress can be seen in the form of altered insect growth. This decrease in insect weights most likely reflects a lower nutritive value of the salt-stressed leaves of cultivar Clark.

Together the data show that 1) salt-sensitive Clark plants are photosynthetically less productive under saline conditions than their salt-tolerant counterparts, and 2) reductions in insect weight due to salt treatment of soybean is more severe in salt-sensitive Clark plants. Given that reduced chlorophyll content can lead to decreases in photosynthesis-derived food on which these leaf-feeding insects depend, limited weight gain by insects on plants suffering from salt stress is perhaps not surprising. Furthermore, plants that are tolerant to saline conditions and are able to maintain normal chlorophyll levels appear to have more nutritionally beneficial foliage to offer foliar feeders.

Practical Applications

Interestingly, these results suggest that under saline field conditions, loopers may perform better when feeding on salt-tolerant soybean cultivar Manokin. Although additional experiments are necessary to determine the effect on saline conditions on fecundity of these insects in soybean production, the results of these experiments suggest that a better understanding of how biotic and abiotic stresses interact to affect plant productivity in the field is necessary in order for farmers to make informed management decisions.

Acknowledgements

We thank Dr. Clint Allen for providing soybean looper colonies. This work was supported by generous funding from the Arkansas Soybean Promotion Board. Additional support comes from the USDA National Institute of Food and Agriculture, Hatch project #1011326, and University of Arkansas System Division of Agriculture.

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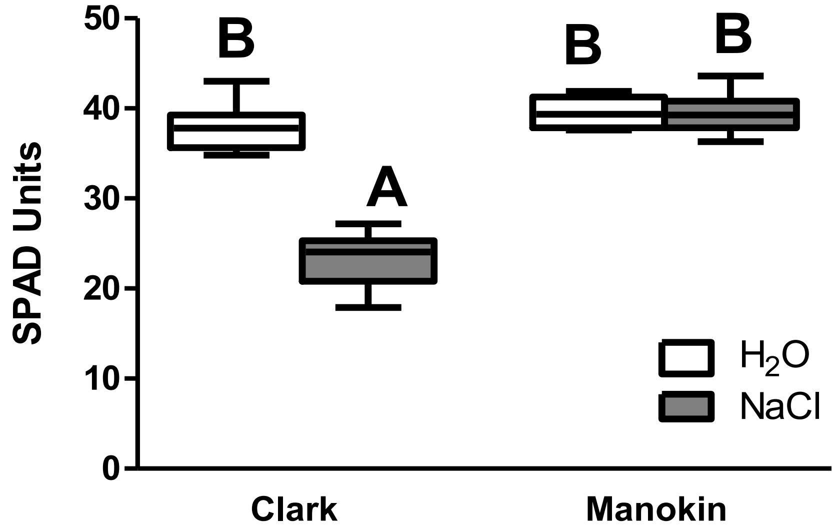

Fig. 1. The average chlorophyll content (in SPAD units) was significantly reduced in NaCl-sensitive cultivar Clark following 14 days of 100 mM NaCl treatment while chlorophyll content of Manokin was unaffected by the NaCl treatment. Bars that share a letter are not significantly different from one another according to one-way analysis of variance (ANOVA); n = 10; $P < 0.05$; +SEM.

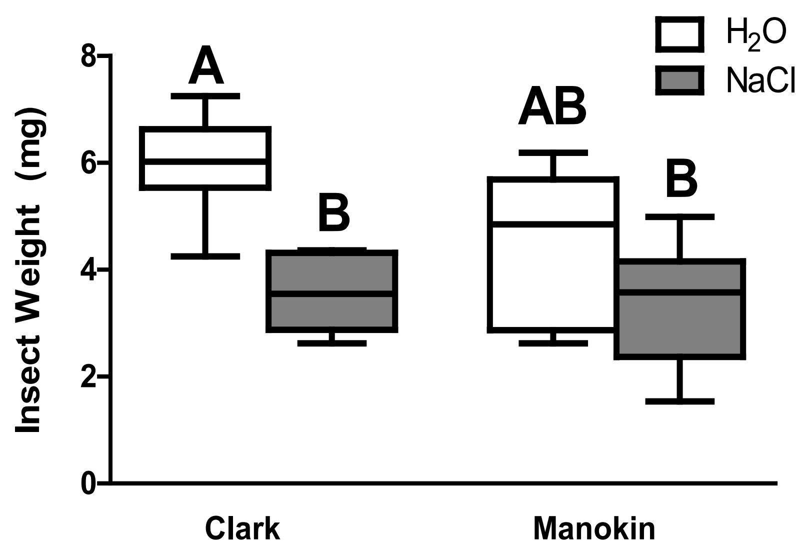

Fig. 2. The average insect weight (in milligrams) was significantly reduced in NaCl-sensitive cultivar Clark while insect weight in Manokin plants was not significantly different between treatments. Bars that share a letter are not significantly different from one another according to one-way analysis of variance (ANOVA); n = 6; $P < 0.05$; +SEM.

Field Performance of Several Glyphosate-Resistant Maturity Group 4 and 5 Soybean Cultivars in a Root-Knot Nematode Infested Field

M. Emerson[1], K. Brown[1], T.R. Faske[1] and T.L. Kirkpatrick[2]

Abstract

The southern root-knot nematode *(Meloidogyne incognita)* is one of the most important yield-limiting pathogens of soybean in Arkansas. Using host-plant resistance is an effective management tool; however, many of the commercially available cultivars are susceptible or there is limited information on their susceptibility to the southern root-knot nematode. The objective of this study was to evaluate several commonly grown maturity group (MG) 4 and 5 soybean cultivars that have limited information on their susceptibility to root-knot nematode. Soybean cultivars were planted in a field with a high population density (342 J2/100 cm^3 of soil, fall sample) of southern root-knot nematode and the root systems were rated for galling (0-5 with 0 = none and 5 = >80% of root system galled) at R7 growth stage. Of the 16 MG 4 cultivars, 4 cultivars: Delta Grow DG 4995 GLY, Delta Grow DG 4940, Pioneer P47T59R, and Terral REV48A46 were rated as moderately resistant. These cultivars had an average gall rating of 2.1 and yield of 42 bu/ac, whereas the remaining were rated susceptible with an average gall rating of 4.9 and yield of 18 bu/ac. Seven of the MG 5 cultivars: Agventure 52M7R, Armor 53D31, NK S53-G5, Pioneer 52T86R, Pioneer 53T73SR, Stine 51D02, and Terral REV52A94 were rated moderately resistant. These cultivars had an average gall rating of 2.0 and an average yield of 46 bu/ac, whereas the remaining were rated susceptible with an average gall rating of 4.6 and yield of 22 bu/ac. Though the majority of these soybean cultivars were susceptible, a few were rated as moderately resistant, which would be a better option in fields with a damaging population density of root-knot nematode.

Introduction

The southern root-knot nematodes (RKN), *Meloidogyne incognita*, are one of the most common important nematode 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 samples collected in soybean fields across Arkansas were infested with RKN (Kirkpatrick, 2017), which is a dramatic increase over the last survey conducted some 30 years ago (Robbins, et al., 1987). Factors that contributed to this increase include a decrease in cotton production acres that are replaced by soybean, increase in monoculture soybean or soybean-corn cropping systems, and 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 RKN 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 Official Variety Testing Program (OVT). 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 OVT.

Procedures

Twenty-nine soybean cultivars were evaluated in a field that was naturally infested with *Meloidogyne incognita* near Kerr, Ark. Selected cultivars were among the most popular MG 4 and 5 grown in the state (Table 1) and experiments were divided between MG. Fertility, irrigation, and weed management followed recommendations by the CES. Plots consisted of 4 rows, 25-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 20 April 2016 at a seeding rate of 150,000 seeds/ac. The experimental design was a randomized complete block design with four replications per cultivar. The population density of RKN at planting averaged 140 second stage juveniles/100 cm^3 of soil with a final population density of 340 J2/100 cm^3 of soil. Nematode

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infection was based on root galling using a 6-point scale (0 = no galls, 1 = 0.1–10%, 2 = 10.1–30%, 3 = 30.1–50%, 4 = 50.1–80%, and 5 = >80% galling per root system) from 10 arbitrarily sampled roots/plot at R7 growth stage (150 d after planting). Based on gall ratings, a cultivar's susceptibility was determined where 0–1= resistant, 1.1–2.9 = moderately resistant, 3.0–3.5 = moderately susceptible, and 3.5–5.0 = susceptible (Rowe et al., 2015). The two center rows of each plot were harvested on 11 Oct. 2016 using a K Gleaner equipped with a Harvest Master weigh system (Harvest Master, Logan, Utah).

Data from gall ratings were transformed using a log transformation [log (x +1)] to normalize for analysis. 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 honestly significant difference (HSD) test at $P = 0.10$.

Results and Discussion

None of the cultivars evaluated were resistant to root-knot nematode, and there was a wide range in susceptibility with gall ratings from 1.6 to 5.0 among the MG 4 cultivars. Four cultivars, Terral REV 48A46, Pioneer 47T59RR, Delta Grow DG 4940, Delta Grow DG 4995 GLY were rated as moderately resistant and all had a lower ($P = 0.10$) gall rating than Armor 4744, one of the most susceptible cultivars (Table 1). The average grain yield of these moderately resistant cultivars was 42 bu/ac, which was 26 bu/ac greater than the average yield (16 bu/ac) of the susceptible cultivars.

Of the maturity group 5 cultivars, no cultivar was considered resistant to RKN, and there was a wide range in susceptibility with gall ratings ranging from 1.3 to 4.9. Seven cultivars, Terral REV 52A94, Agventure 52M7R, Pioneer P53T73SR, Armor 53D31, NK S53-G5, Pioneer P52T86R, and Stine 51RD02 were rated as moderately resistant and all had a lower ($P = 0.10$) gall rating than Morsoy 50X64, one of the most susceptible cultivars (Table 2). These moderately resistant cultivars had an average yield of 46 bu/ac, which was 24 bu/ac greater than the average yield (22 bu/ac) of the susceptible cultivars.

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 moderately resistant cultivars can have a dramatic impact on yield in a root-knot nematode infested field.

Acknowledgements

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Table 1. Root gall ratings and yield from 16 maturity group 4 soybean cultivars grown in a root-knot nematode infested field.

Cultivar	Root Galling †	Susceptibility‡	Yield (bu/ac)§
Terral REV48A46	1.62 c	MR	46.82 a
Pioneer P46T59R	2.04 bc	MR	46.53 a
Delta Grow DG 4940	2.10 bc	MR	38.09 a
Delta Grow DG 4995 GLY	2.52 b	MR	37.24 a
Asgrow AG4633	4.58 a	S	24.77 b
Armor 47-70	4.73 a	S	10.66 d
Pioneer P47T36RR	4.81 a	S	20.77 bcd
Armor 49-D90	4.86 a	S	16.06 bcd
Asgrow AG4730	4.86 a	S	14.10 cd
Delta Grow DG 4790 GENRR2Y	4.86 a	S	14.51 bcd
Stine 4782-2	4.89 a	S	21.83 bc
Asgrow AG4632	4.92 a	S	19.52 bcd
Delta Grow DG 4880 GLY	4.92 a	S	10.97 d
Stine 47RC32	4.95 a	S	11.92 cd
Armor 4744	5.00 a	S	16.44 bcd
Delta Grow DG 4825 GENRR2Y/STS	5.00 a	S	12.23 cd

† Root gall rating based on a 6-point scale where 0 = no galling and 6 = >80% of root system galled.
‡ Susceptibility based on root gall ratings where 0–1 = resistant, 1.1–2.9 = moderately resistant, 3.0–3.5 = moderately susceptible, and 3.5–5.0 = susceptible.
§ Adjusted to 13% moisture.
¶ Numbers within the same columns followed by the same letter are not significantly different (*P* = 0.10) according to Tukey's Honestly Significant Difference test.

Table 2. Root gall ratings and yield from 16 maturity group 5 soybean cultivars grown in a root-knot nematode infested field.

Cultivar	Root Galling †	Susceptibility‡	Yield (bu/ac)§
Terral REV52A94	1.33 e	MR	48.97 ab
Agventure 52M7R	1.38 de	MR	47.54 ab
Pioneer P53T73SR	1.65 de	MR	43.56 ab
Stine 51RD02	1.99 cd	MR	45.54 ab
Armor 53D31	2.36 bc	MR	49.71 a
Pioneer P52T86R	2.71 bc	MR	42.62 b
NK S53-G5	2.85 b	MR	42.48 b
Progeny P5333 RY	4.21 a	S	27.95 c
Delta Grow DG 5170	4.42 a	S	17.38 d
Delta Grow DG 5230	4.65 a	S	29.50 c
Progeny P5213 RY	4.79 a	S	20.09 d
Progeny P5226 RY	4.81 a	S	16.85 d
Morsoy 50X64	4.84 a	S	17.23 d

† Root gall rating severity was based on a 6 point scale where 0= no galling and 6= >80 % galling.
‡ Susceptibility based on root gall ratings where 0–1 = resistant, 1.1–2.9 = moderately resistant, 3.0–3.5 = moderately susceptible, and 3.5–5.0 = susceptible.
§ Adjusted to 13% moisture.
¶ Numbers within the same columns followed by the same letter are not significantly different (*P* = 0.10) according to Tukey's Honestly Significant Difference test.

Comprehensive Disease Screening of Soybean Varieties in Arkansas

T.L. Kirkpatrick[1], K. Rowe[1], T.R. Faske[2], and M. Emerson[2]

Abstract

Since 1990, thanks to the ongoing support of the Soybean Promotion Board, Arkansas has maintained the most comprehensive soybean disease screening program in the southern United States. A combination of field nurseries and greenhouse tests are used to evaluate all cultivars that are entered into the official University of Arkansas System Division of Agriculture's Official Variety Testing Program (OVT) each year for resistance to major diseases of concern in Arkansas. Each year, our results form the basis for our annual Soybean Update and the SOYVA cultivar selection program to inform growers of the strengths and weaknesses of new soybean cultivars relative to disease resistance. Results are also reported in full on the Arkansas Variety Testing website.

Introduction

The disease screening program has historically been conducted at various locations throughout the state. Currently, we have field disease nurseries established at the University of Arkansas System Division of Agriculture's Newport Extension Center for evaluating stem canker and frogeye leaf spot. Fields that are used for the screens are equipped with overhead irrigation that, in combination with supplemental inoculation with appropriate pathogens allow us to develop consistent and severe disease pressure for our evaluations. We also conduct root-knot and reniform nematode screenings in greenhouses at the Southwest Research and Extension Center near Hope and the Cralley Warren Laboratory at the Division's Experiment Station in Fayetteville.

Procedures

In 2016, 263 cultivars were screened for root-knot, reniform, stem canker, and frogeye leaf spot.

Root-knot. The screening was conducted in the greenhouse at the Southwest Research and Extension Center by Kim Rowe from early to late summer. All entries were planted and inoculated with 5000 eggs of *Meloidogyne incognita*, replicated 4 times, and allowed to grow for 40 days. After 40 days of reproduction, each root system was given a visual gall rating of 0–5. Ratings were averaged by cultivar to establish a designation on level of susceptibility.

Reniform. The screening was conducted in Fayetteville at the Cralley Warren Laboratory greenhouse by Bob Robbins. It consisted of 142 new cultivars for 2016. Each cultivar was planted and replicated 5 times and was inoculated with 2000 *Rotylenchulus reniformis* nematodes. After a reproduction period of approximately 50 days, each pot was extracted, nematodes quantified and compared to a susceptible standard to determine level of susceptibility.

Stem Canker. The screening was conducted at the Newport Extension Center by Kim Rowe and Michael Emerson on 263 cultivars. Each cultivar was planted and replicated three times. In each replication, the stems of 10 plants were inoculated with toothpicks infested with *Diaporthe phaseolorum var. meridionalis* fungus at stage V5. After approximately 80 days, each inoculated plant was given a rating based on presence and length of canker and ratings were averaged to determine level of susceptibility.

Frogeye Leaf Spot. This screening was also conducted at the Newport Extension Center by Michael Emerson and Kim Rowe on 263 cultivars. Each cultivar was planted and replicated three times. *Cercospora sojina* spores in a water suspension were applied using a sprayer twice, once 6 weeks post planting, and then again several weeks later. Visual ratings were taken approximately 12 weeks post planting as percentage of leaf area affected.

Results and Discussion

The results of the 2016 disease screenings were comparable with previous years' results. On average, the nematode screenings showed that greater than 70% of entries were susceptible to reniform and root-knot (Figs. 1 and 2.) An increase in the number of moderately resistant varieties was noted in the root-knot screen when compared to previous years. Steps are being taken to ensure the virility of inoculum for subsequent screens. The stem canker screening results showed that 90% of entries were resistant to the disease, 2% were moderately resistant, 2% were moderately susceptible, and 6% were susceptible (Fig. 3). Although the majority of cultivars were resistant, this indicates that an evaluation of new soybean cultivars for stem canker resistance is still necessary to avoid unpleasant and costly surprises in grower fields. The frogeye leaf spot screening showed the most variation between levels of susceptibility, and like stem canker, the 9% of varieties in the susceptible category could mean trouble for growers (Fig. 4). A copy of all data from the 2016 disease screenings in a Microsoft® Excel spreadsheet form is available at: www.arkansasvarietytesting.com.

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Practical Applications

Most growers select cultivars based primarily on yield performance. Unfortunately, while yield potential is an important factor in cultivar selection, the yield of a cultivar may be drastically reduced by soybean diseases, so yield performance results may not tell the complete story. In Arkansas, resistance to a number of soybean pathogens is as important as yield potential in selecting an appropriate cultivar. Soybeans are grown on about 3.3 million acres in the state each year, with a value of $1,840,616,000 in 2013 (USDA-NASS, 2013). Diseases result in yield losses of 10% annually some estimate. By this figure, last year nearly $200 million was lost to soybean diseases in Arkansas. (Faske et al., 2014). Each year, well over 200 new soybean cultivars become available to Arkansas growers. Many of these cultivars are accompanied by little or no information on their resistance to diseases or nematodes. Since only one variety will be grown in a particular field, choosing the best variety can be a difficult decision. This program provides comprehensive information on the disease package that each new cultivar contains prior to widespread planting of the cultivars in the state, lowering the risk of severe disease losses due to incorrect cultivar selection.

Acknowledgements

Many thanks to the Arkansas Soybean Promotion Board for their continued support and funding of this project. Support also provided by the University of Arkansas System Division of Agriculture.

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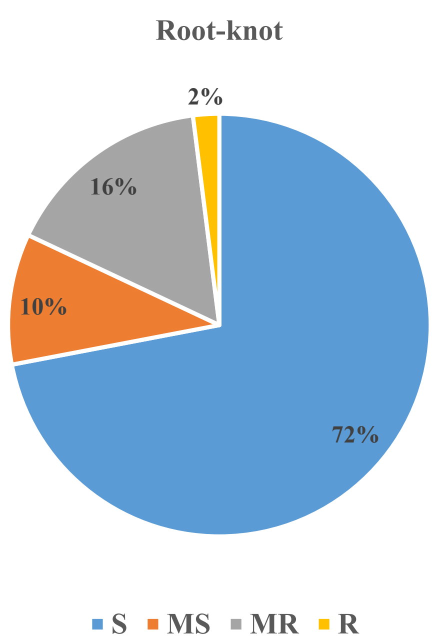

Fig. 1. Percent of soybean cultivars screened that were susceptible (S), moderately susceptible (MS), moderately resistant (MR), or resistant (R) to root-knot nematodes.

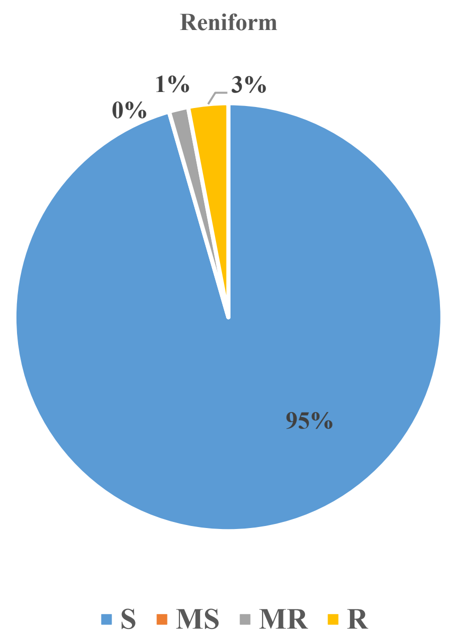

Fig. 2. Percent of soybean cultivars screened that were susceptible (S), moderately susceptible (MS), moderately resistant (MR), or resistant (R) to reniform nematodes.

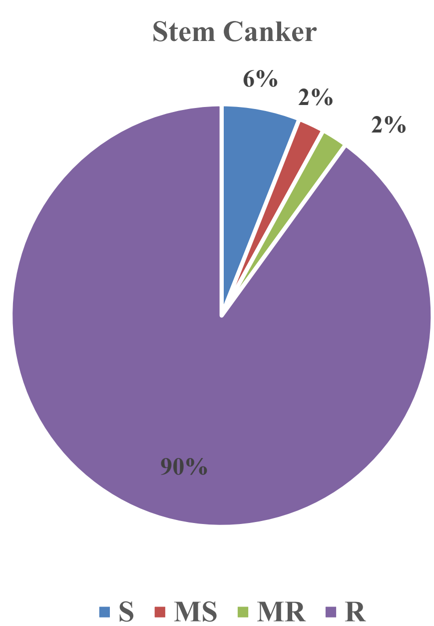

Fig. 3. Percent of soybean cultivars screened that were susceptible (S), moderately susceptible (MS), moderately resistant (MR), or resistant (R) to stem canker.

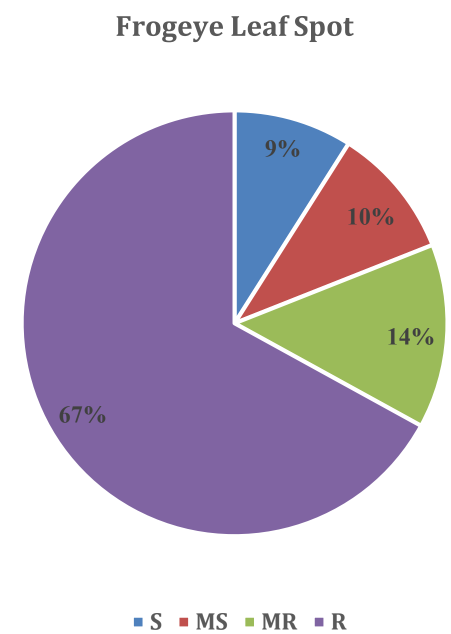

Fig. 4. Percent of soybean cultivars screened that were susceptible (S), moderately susceptible (MS), moderately resistant (MR), or resistant (R) to frogeye leaf spot.

Incidence, Population Density, and Distribution of Soybean Nematodes in Arkansas

T. Kirkpatrick[1] *and K. Sullivan*[1]

Abstract

The recent increase in soybean production in Arkansas is likely a result of declining cotton prices that resulted in a more diverse agricultural cropping system. Many formerly monocultured cotton fields are now regularly rotated into soybean and corn. With the increase of soybean production, there has also been an increase in incidence of the types of nematodes that could be of economic importance. The third and final year of the three-year survey funded by the Arkansas Soybean Promotion Board was completed in 2016. Results indicate that the soybean cyst, root-knot, lesion, and reniform nematodes were present in 25%, 36%, 33%, and 2%, respectively, of the 1,444 fields that were sampled by county agents, crop consultants, and growers. Race assays indicate that a majority of the soybean cyst nematode population in the state are races 2, 5, or 6 with races 1 and 9 found infrequently.

Introduction

The agricultural landscape is changing in Arkansas. Historical acreage of agronomic crops has changed significantly in the last few years. For example, cotton acreage in the state has decreased 80% since 2005, while in the same period of time corn acreage has almost tripled, grain sorghum acreage has increased 2-fold, and soybean acreage has increased about 10% per year since 2009. Soybeans are now grown on approximately 3.5 million acres in the state (Anonymous, 2014). Nematodes account for a significant loss in yield in Arkansas soybeans each year (Wrather and Koenning, 2012), both as primary pests and in complexes and interactions with fungal pathogens. Those in Arkansas that are considered to be economic pests of soybean include the soybean cyst nematode, *Heterodera glycines* (SCN), the southern root-knot nematode, *Meloidogyne incognita*, the reniform nematode, *Rotylenchulus reniformis*, and lesion nematodes, *Pratylenchus spp*.

Historically, SCN was widely distributed and of major concern statewide—present in about 66% of Arkansas soybean fields surveyed from 1979 to 1986 (Robbins, et al., 1987). The root-knot nematode was present at low incidence, and the reniform nematode was not reported. Both root-knot and reniform nematodes have been detected at increased frequency in recent years, however, particularly in regions that were historically cotton production areas (Bateman and Kirkpatrick, 2011). Major yield loss has been associated with root-knot nematodes in soybean, but there is little information regarding the impact of either reniform or lesion nematodes on soybean yield in the mid-South.

The biotype (race) of soybean cyst nematodes has a major impact on the damage potential to specific soybean cultivars. There has not been an attempt made to determine the nematodes that are associated with soybean or the soybean cyst nematode races that are associated with the Arkansas soybean crop in about 30 years. Given the changes in cropping system dynamics recently, it is vital that we learn what nematodes are associated with the soybean crop.

Procedures

The third year of a three-year survey, sponsored by the Arkansas Soybean Promotion Board was conducted statewide during the 2016 season. Because nematode samples must be collected and handled properly prior to assay, an on-line course describing proper sampling and handling techniques as well as how to submit samples to the Arkansas Nematode Diagnostic Laboratory (ANDL) was developed for potential surveyors. This course is accessible via the University of Arkansas System Division of Agriculture Cooperative Extension Services' website at: http://courses.uaex.edu/login/index.php. To date, there have been 154 people participating in the Nematode Sampling short course online on the course module. County agents, consultants, and in some cases growers themselves sampled fields that were planted to soybean in 2016. Procedures were as follows. Sampling occurred from 1 September through 1 December. Fields of 40 acres or less were sampled as a unit by collecting a minimum of 20 soil cores (1 inch diameter) randomly from the rows after harvest. Larger fields were subdivided into blocks of 40 acres or less and each block was sampled as above. Soil cores were bulked and mixed, then approximately 1 pint was placed into a plastic bag, labeled and sealed. Samples were mailed (priority mail) or sent by courier to the ANDL. Each sample was thoroughly mixed in the laboratory, and a 100 cm^3 subsample was assayed by a semi-automatic elutriator and centrifugal flotation. Nematodes were identified to genus and counted. Where soybean cyst nematodes were detected, the remaining soil was extracted and the cysts that were collected were placed into clay pots in the greenhouse to be increased on soybean, Lee 74. Once populations were ncreased sufficiently, (ca. 45 days), they were inoculated on three plants each of Lee 74, Pickett, PI 88788, PI 90763, and Peking—the differentials used to identify races of the nematode—and grown for 30 days in the greenhouse to determine the race. Results from the race tests are pending.

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Results and Discussion

County agents, crop consultants, and growers collected and submitted 1444 samples for assay during the September-December period (Fig. 1). Root-knot nematodes were the most frequently detected nematode, present in 36% of the samples that were submitted (Fig. 2). Lesion nematodes, *Pratylenchus spp*. were the second most frequently encountered nematode with 33% of fields having detectable populations, while one-fourth of the fields contained SCN. Reniform nematodes were recovered from 2% of the fields. It is interesting to note the increase in root-knot nematode and drop in soybean cyst nematode relative to the 1979-1988 survey.

Although these results are based on a relatively limited number of samples, it appears that SCN incidence has declined from the 66% of fields reported in the 1978-1986 survey of the state's soybean acreage (Robbins, et al., 1987). Twenty-five percent incidence is still, however, a significant and troubling presence in the state's soybean fields. In contrast with soybean cyst nematodes, the southern root-knot nematode was not a commonly encountered inhabitant of the soybean fields in Arkansas in 1978-1986. However, this nematode was found in nearly half of the samples that were collected for our survey this year. The relatively high incidence of this nematode is troubling since root-knot can be severely damaging to soybean. The high incidence of root-knot is likely due in part to two factors: 1) An increased number of fields have recently been converted from cotton monoculture to soybean or soybean-corn cropping systems, and 2) The popularity of the early soybean production system that utilizes earlier maturity soybeans, most of which are highly susceptible to root-knot. Root-knot nematodes are most damaging in lighter-textured sandy soils and are rapidly becoming a major yield-limiting factor in soybean in many parts of the state.

The reniform nematode was not found in the 1978-1986 soybean nematode survey, but was detected in 2% of the fields sampled in 2016. As with root-knot, it is likely that many of the fields in this survey with reniform nematodes were historically in cotton, the preferred host for these nematodes. It is unclear at this time what impact reniform nematodes will have on soybean production in Arkansas. Several species of the lesion nematode were associated with soybean in the earlier survey, and 33% of the 2016 fields had lesion nematodes. Identification to species has not been done for the *Pratylenchus* found in the survey, and there is no data on the impact of lesion nematodes on the soybean crop. Studies are currently underway to identify the species of lesion nematodes recovered in 2016.

Soybean cyst nematode races are currently being identified through bioassay. The majority of populations assayed to date have been races 2 or 5. The prevalence of these races in Arkansas is somewhat reflective of the race structure of Tennessee soybean fields that was reported in a 1990 survey (Young, 1990) where races 2, 5, and 6 predominated. In the Tennessee survey, races 3, 4, 9, and 14 were also detected. A few race 9 and 1 populations have been detected in the 2016 Arkansas survey.

Practical Applications

The relative population densities of plant-parasitic nematodes in soybean fields change in response to crop history, and the overall incidence of nematode species is an indication of the potential for nematode-induced crop loss within an area. Since the last nematode survey of soybeans in the state was conducted about 30 years ago, prior to this survey effort, we have no idea which nematodes are present, how high their populations are, or if there is cause for concern. Because nematodes are microscopic and soilborne, the only way to know if they are a potential threat to soybean production in any particular field is through a nematode assay.

The Arkansas Soybean Promotion Board in partnership with the Arkansas Nematode Diagnostic Laboratory is providing growers and crop advisors an opportunity to “know for sure” if nematodes are a potential threat in their fields. This knowledge will in turn allow development of effective nematode management strategies on a field-by-field basis.

Acknowledgements

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Table 1. Counties represented in the 2016 SPB-sponsored soybean survey, and the number of fields that were sampled.

County	Number of Samples
Arkansas	6
Ashley	421
Clay	3
Craighead	46
Crittenden	56
Cross	57
Desha	452
Faulkner	4
Greene	2
Jackson	18
Jefferson	32
Johnson	10
Lafayette	14
Lawrence	14
Lee	49
Lincoln	76
Lonoke	3
Miller	2
Mississippi	24
Monroe	3
Phillips	14
Poinsett	12
Pope	1
Prairie	4
Pulaski	71
Randolph	5
St. Francis	10
White	10
Woodruff	22

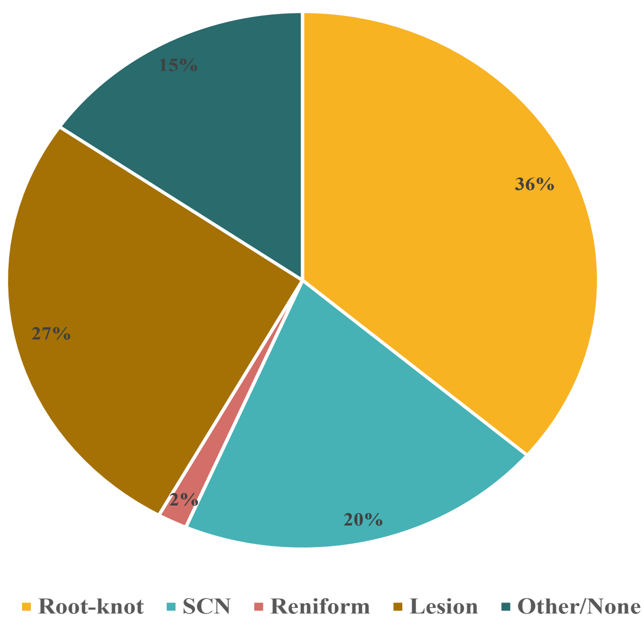

Fig. 2. Percent of Arkansas soybean fields with soybean cyst (SCN), root-knot, lesion, and reniform nematodes, 2016.

Impact of Five Premium Fungicide Combinations to Control Strobilurin-Resistant Frogeye Leaf Spot of Soybean in Arkansas

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

Abstract

Frogeye leaf spot, caused by *Cercospora sojina*, is one of the most important and common foliar diseases of soybean in Arkansas. Strobilurin-resistant frogeye leaf spot was identified in 2012 and since then, it has been detected in all major soybean-producing counties in the state. Few studies have investigated the effect of premium fungicides on disease control. The objective of this study was to evaluate the efficacy of five premium fungicide premix and tank-mix combinations to control frogeye leaf spot. Fungicides consisted of Stratego® YLD, Domark® + Quadris®, Quadris Top® SBX, Priaxor® + Tilt®, Aproach Prima® + Topsin® M and Quadris Top® SB as the standard control. Fungicides were applied in 2015 with a disease severity of 0.1%, while in 2016 they were applied at growth stage R 5.5 with a disease severity of 8%. Disease control in each year was similar among these fungicides. Overall, a lower disease severity was observed with Priaxor + Tilt, Quadris Top SB, and Aproach Prima + Topsin M than the non-fungicide control. Of these fungicides, only Quadris Top SB contributed to a greater yield protection than the non-fungicide control. All fungicides contributed to a greater crop value per acre than the non-fungicide control; however, the highest priced fungicide did not result in the highest crop value. Overall, frogeye leaf spot control and yield protection were similar among these premium fungicides.

Introduction

Frogeye leaf spot (FLS) of soybean, caused by *Cercospora sojina*, is one of the most important foliar diseases in the mid-South (Faske et al., 2014). Generally, yield losses range from 12% to 15%, but can reach as high as 30% on susceptible soybean cultivars (Phillips, 1999). Yield losses to frogeye leaf spot in 2015 were estimated at 7.6 million bushels in the mid-South (Allen et al., 2016). Management of frogeye leaf spot consists of utilizing resistant cultivars, crop rotation, and foliar fungicides.

Fungicide groups marketed for use to control FLS include, quinone outside inhibitors (QoI; also known as strobilurin) demethylation inhibitors (DMI; also known as triazole), and methyl benzimidazole carbamates (MBC; or benzimidazole) (Faske, 2017). However, the recent detection of fungicide resistance in frogeye leaf spot has limited the use of one of these groups. Isolates of *C. sojina*, collected in 2010 from Lauderdale Co., Tenn. were confirmed to be resistant to strobilurin fungicides (Zhang, et al., 2012a; Zhang, et al., 2012b). As a result, strobilurin fungicides like Quadris® and Headline® are ineffective on these resistant strains. The first isolates of strobilurin-resistant *C. sojina* were identified in 2012 in Arkansas. Since then, such isolates have been detected in 27 counties, which accounts for over 90% of the soybean acreage annually. Since the widespread detection of strobilurin-resistance in FLS, chemical companies have marketed several pre-mix and tank-mix options for disease control. A few studies have reported on the efficacy of premix fungicides (Price et al., 2014; Emerson et al., 2016a, 2016b; Price et al., 2016); however, few have evaluated the premium or "Cadillac" pre-mix and tank-mix combinations. The objective of this study is to evaluate five premium fungicide combinations to control strobilurin-resistant FLS.

Procedures

The efficacy of these premium fungicides was evaluated in 2015 and 2016 at the Newport Extension Center near Newport, Ark.. The soybean cultivar Armor DK 4744 was planted on 4 June in 2015 and on 8 June in 2016 at a seeding rate of 150,000 seed/ac. Weeds were controlled in 2015 using Gramoxone® + Valor® + NIS (48.0 fl oz/ac + 2.0 oz/ac + 0.25 % v/v) applied pre-plant on 4 June followed by Roundup® + Dual II Magnum® (1 qt/ac + 1 pt/ac) applied post-plant on 26 June. The weed control program in 2016 was similar with the exception of Boundary® (2.0 oz/ac) replacing Valor on 8 June and Prefix® (37oz/ac) replacing Dual II Magnum applied post-plant on 29 June. Plots consisted of four, 27-ft long rows spaced 30 in. apart. The experimental design was a randomized complete block design with 4 replications separated by a 3 ft fallow alley. Plots were artificially inoculated with several isolates of strobilurin-resistant *C. sojina* at the R1-R2 growth stage and watered with overhead irrigation to promote disease development. Fungicides were broadcast through flat-fan nozzles (Tee-Jet 110015VS) spaced 30 in. apart over the two center rows per plot using an air pressurized multi-boom plot sprayer. The sprayer was calibrated to deliver 15 gal/ac at 32 psi. Fungicides consisted of Stratego® YLD (trifloxystrobin + prothioconazole), Domark® + Quadris® (tetraconazole + azoxystrobin; at 1:1 ratio), Quadris Top® SBX (azoxystrobin + difenoconazole; at 1:1 ratio), Priaxor® + Tilt® (pyraclostrobin + fluxapyroxad + propiconazole), Aproach Prima® + Topsin M® (picoxystrobin + cyproconazole, + thiophanate-methyl) Quadris Top® SB (azoxystrobin + difenoconazole) as the standard premix, and a non-fungicide treatment as a negative control (Table 1). Fungicides were applied at the R4 growth stage on 10 Aug. 2015 with a severity of frogeye leaf spot that ranged

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from trace to 0.1%, while in 2016 fungicides were applied at the R5.5 growth stage on 25 Aug. with a severity rating of 6% to 8% (Fig. 1). Frogeye leaf spot severity was assessed at 16 days after treatment based on percent severity in the upper one-third of the plant canopy. Plots were harvested on 19 Oct in 2015 and 11 Oct in 2016 using a modified K Gleaner combine equipped with a Master Scales Weigh System (HarvestMaster Logan, Utah).

Profitability of these treatments was determined by calculating the difference in crop value per acre (yield × cash value) compared to the non-fungicide control. Soybean value was based on cash price in mid-October, which was \$8.91 in 2015 and \$9.63 in 2016. Fungicide cost was based on 2017 retail price from local retailers. A fungicide application fee of \$7.00 was added for aerial application to the total cost per acre. Quadris Top SB has not been commercially available since 2015, so its cost per acre was based on Quadris Top SBX, a similar premix fungicide.

Data were analyzed according to general linear mixed models with years and treatment repetitions modeled as a random variable using SPSS 19.0 (SPSS Inc. Chicago, Ill.). Mean separation ($P = 0.05$) was established by Tukey's Honest Significant Difference test.

Results and Discussion

There was no ($P > 0.30$) interaction between years and treatments for disease severity or yield, thus only the main effects are reported. A trace amount of FLS was detected each year near the R3 growth stage. However, a greater ($P = 0.02$) severity of FLS was observed in 2016 (8.2%) than 2015 (2.7%) due to a delay in fungicide application because of persistent rainfall during the first two weeks of August.

Of the fungicides evaluated, a lower ($P \leq 0.05$) severity of FLS was observed with Priaxor + Tilt, Quadris Top SB, and Aproach Prima + Topsin M compared to the non-fungicide control (Table. 1). Topsin M (thiophanate methyl) is a benzimidazole fungicide, which is considered high risk for fungicide resistance; therefore, these fungicides should never be applied as a solo treatment, but rather in combination with another mode of action. No phytotoxicity was observed for any treatment. Of these fungicides that provided the best disease control, only Quadris Top SB had a greater ($P \leq 0.05$) impact on yield protection compared to the non-fungicide control (Table 1). Soybean yield was similar ($P = 0.07$) between years with an average of 55.8 bu/ac in 2015 and 52.0 bu/ac in 2016.

Fungicide premix and tank-mix combinations ranged in price from \$23 to \$31/ac with an average of \$27/ac (Table 1). Fungicides did contribute to a positive impact on the crop value per acre; however, using a higher priced fungicide combination did not result in a higher crop value. For example, Domark + Quadris cost was the most expensive treatment at \$31/ac, but contributed to the lowest crop value per acre at \$495.00. Overall, premium fungicides were similar in disease control and yield protection, which contributed to a greater crop value over the non-fungicide control.

Practical Applications

Fungicides are often used to control frogeye leaf spot on susceptible soybean cultivars in the mid-South. In this study, there was little difference among premium fungicides in frogeye leaf spot control and yield protection. However, the more expensive fungicide combinations did not always contribute to the greatest profit. Thus, the cost of premium premix and tank-mix options should be considered when fungicides are used to manage frogeye leaf spot.

Acknowledgements

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

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Table 1. Impact of five premium fungicide combinations to manage frogeye leaf spot in Arkansas.

Treatment, rate	FLS Severity†	Yield‡	Fungicide Cost/ac§	Crop Value/ac¶	Value Difference#
Non-fungicide treated control	7.8 b††	48.9 a	$0.0	$453	
Stratego YLD 4.18 SC, 4.65 fl oz/ac	6.4 ab	53.9 ab	$23	$500	$47
Domark 230 ME, 5 fl oz/ac + Quadris 2.08 SC, 6.3 fl oz/ac	5.9 ab	53.5 ab	$31	$495	$43
Quadris Top SBX 3.76 SC, 7 fl oz/ac	5.0 ab	54.7 ab	$24	$507	$54
Priaxor 4.17 SC, 4 fl oz/ac + Tilt 3.6 EC, 6 fl oz/ac	4.8 a	54.2 ab	$27	$502	$49
Quadris Top SB 2.72 SC, 8 fl oz/ac	4.7 a	56.6 b	$26	$523	$71
Aproach Prima 2.34 SC, 5 fl oz/ac + Topsin M 70 WP 1 lb/ac	3.6 a	55.6 ab	$29	$515	$62

† Frogeye leaf spot severity as percent severity in upper 1/3 canopy.
‡ Average for 2015 and 2016 cropping season. Adjusted to 13% moisture.
§ Fungicide cost based on retail price at local distributors plus a $7.00 application fee.
¶ Crop value was calculated on cash price for soybean in mid-October multiplied by yield.
# Value difference is crop value per acre per treatment minus the non-fungicide treated check. This value does not include fungicide or other variable cost.
†† Numbers within columns followed by the same letter are not significantly different at α = 0.05 according to Tukey's Honest Significant Difference test.
SC = soluble concentrate; ME = micro encapsulated: EC = emulsifiable concentrate; WP = wettable powder

Fig. 1. Soybean leaflet with approximately 10% frogeye leaf spot.

Potential for the Integration of Brassica Winter Cover Crops into Soybean Production Systems for the Suppression of Nematodes

C.S. Rothrock[1] and T.L. Kirkpatrick[2]

Abstract

Plant parasitic nematodes are an increasing problem on soybean in Arkansas. Recent research has suggested the value of brassica cover crops for suppression of plant pathogens. A field at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station near Marianna, Ark. and a producers' field were identified for trials where nematodes were limiting soybean yields. Locations included sites with root-knot nematodes or soybean cyst nematodes. The brassica crops planted were the Indian mustard 'Fumus', Tillage Radish, and rapeseed 'Coahoma'. These brassicas cover crops were compared to wheat, the legume cover crop hairy vetch, and winter fallow. No significant differences were found in the value of winter cover crops for management of the soybean cyst nematode. A reliable assessment of cover crop impact on root-knot nematode was not obtained as a result of no suitable trials. The data also indicated that choice of brassica cover crop is important for consistent biomass production, with the Indian mustard cultivar 'Fumus' consistently producing good biomass. In summary, winter cover crops had little influence on plant parasitic nematodes on soybean.

Introduction

Plant parasitic nematodes are an increasing problem on soybean in Arkansas. The soybean cyst nematode *(Heterodera glycines)* has historically been the most important nematode, but the root-knot nematode *(Meloidogyne incognita)* is increasing in importance in part as a result of soybean being planted in fields historically used for cotton production. Options for economical control of nematodes are limited, with the most effective treatment being the use of preplant fumigants, such as Telone® II (1,3-dichloropropene). Winter cover crops have historically been examined for minimizing soil erosion and nutrient management. However, more recent research has focused on selected cover crops to suppress plant pathogens. Winter cover crops fit well in production systems in the southeastern United States because of moderate winter temperatures and adequate rainfall allowing the production of a subsequent cash crop. Recent work on winter cover crops has examined the value of brassica crops, which include canola and mustard crops. Many brassicas contain high quantities of glucosinolates which break down into toxic compounds when the plant tissue is destroyed at crop termination (Kjaer, 1976; Sarwar et al., 1998). The process of incorporating plant material into the soil to control pathogens or pests through the release of toxic decomposition chemicals is termed biofumigation. Brassica residues have been used to reduce diseases on a number of crops, including soybean *(Glycine max)* (Lodha et al., 2003). Research conducted in Arkansas on cotton has demonstrated the value of Indian mustard *(Brassica juncea)* cultivar 'Fumus' to suppress nematodes and diseases on cotton *(Gossypium hirsutim)* (Bates and Rothrock, 2006).

The goals of this research are to establish a sustainable soybean production system for nematode infested fields by growing a high-glucosinolate brassica winter cover crop and to quantify the impact of incorporating brassica cover crops on soilborne pathogens.

Procedures

A field at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station near Marianna, Ark. and a producer field were identified for trials in 2016 to examine the value of cover crops for limiting damage from soybean cyst nematode or root-knot nematodes, respectively. Winter cover crops were established in the fall by broadcasting seed and compared the brassica crops Indian mustard 'Fumus', Tillage Radish, or rapeseed 'Coahoma' to wheat, hairy vetch, and winter fallow (Table 1).

The replicated field trial near the University of Arkansas System Division of Agriculture's Rohwer Research Station was established on a field with a history of root-knot nematode with the treatments winter fallow and the winter cover crops Indian mustard, rapeseed, and wheat. At the Division's Lon Mann Cotton Research Station near Marianna, Ark. a trial was established on a field with a history of soybean cyst nematode. Treatments included the winter cover crops rapeseed, Tillage Radish, Indian mustard, hairy vetch, and wheat and winter fallow.

The cover crops were desiccated using herbicides prior to incorporation, at least four weeks prior to planting soybean. Cover crop biomass was measured prior to destruction by harvesting 10.8 ft^2. Soybeans were managed using the Division's Cooperative Extension Service production practices.

Soil samples were collected from plots at planting of the soybean crop, mid-season and at harvest. Nematode population densities were evaluated for each of the above-mentioned sampling dates.

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Results and Discussion

In 2016, at the Lon Mann Cotton Research Station, Marianna, Ark. above-ground biomass for tillage radish, Indian mustard, and hairy vetch were 17,799, 8,857, and 11,689 lbs/ac., respectively (Table 1). Rapeseed and wheat were poorly established. In the winter of 2016, tillage radish performed poorly, while rapeseed biomass was similar to Indian mustard. Of the brassica crops, Indian mustard was the most consistent in producing biomass. Cover crops did not establish well at Rohwer in the fall of 2015.

No differences in soybean cyst nematode eggs among treatments were found early-season, late-season, or postharvest for the Marianna location in 2016 (Table 2).The early-season sample ($P = 0.1463$) indicated some trends in the treatment responses early. Soybean cyst egg numbers were lower for Indian mustard and tillage radish, the brassica crops with substantial cover crop biomass in 2016, but numerically egg counts were still similar to the non-brassica crops hairy vetch and wheat. This trend did not continue throughout the soybean crop. All trials for the root-knot nematode, including the 2016 trial, had low cover crop biomass and no good assessment of the benefits of brassica cover crops on root-knot nematode on soybean were obtained.

At Marianna, winter cover crop biomass treatment did not affect soybean yield (Table 2). These results for soybean yield were similar in 2015.

Practical Application

Brassica cover crops have been demonstrated to be effective in other crops at suppressing plant parasitic nematodes, including the root-knot and reniform nematodes on cotton in Arkansas. However, for this project, these brassica cover crops were not shown to have efficacy in suppressing soybean cyst nematode populations at Marianna where substantial cover crop biomass was produced over a two year period. This research suggests that for soybean cyst nematode, which is known to be more resistant to the influence of soil environment, cover crop choice will not impact losses from this nematode. A reliable assessment of cover crop impact on root-knot nematode was not obtained as a result of no suitable trials. The data also indicated that choice of brassica cover crop is important for consistent biomass production, with the Indian mustard cultivar ‘Fumus’ consistently producing good biomass, while tillage radish had winter kill in some years. In summary, winter cover crops had little influence on plant parasitic nematodes on soybean.

Acknowledgements

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Table 1. Cover crop above-ground biomass prior to planting soybean.

Cover crop	Marianna 2016	Marianna 2017	Rohwer 2016
Tillage Radish	17,799 a[†]	2,041 d	
Indian mustard	8,857 c	6,567 bc	1,193 a
Rapeseed	1,410 d	6,406 c	461 b
Hairy vetch	11,689 b	19,544 a	
Wheat	2,180 d	9,760 b	387 b
Fallow (winter weeds)	1,604 d	485 d	414 b

[†] Means in a column followed by the same letter are not significantly different; Fisher’s protected least significant difference (LSD), $P < 0.05$.

Table 2. Winter cover crop effects on soybean cyst nematode populations and soybean yield at Marianna in 2016.

Cover crop	Soybean cyst nematode eggs 12 May	2 Sept.	19 Oct.	Soybean yield (bu/ac)
Tillage Radish	374 a†	966 a	421 a	35.4 a
Indian mustard	432 a	1090 a	389 a	35.5 a
Rapeseed	1100 a	592 a	377 a	37.1 a
Hairy vetch	502 a	704 a	195 a	36.1 a
Wheat	543 a	1019 a	549 a	35.1 a
Fallow (winter weeds)	743 a	779 a	321 a	36.2 a

† Means in a column followed by the same letter are not significantly different; Fisher's protected least significant difference (LSD), $P < 0.05$.

Frogeye Leaf Spot Trial Summaries 2014-2016

T.N. Spurlock[1], A.C. Tolbert[1], B. Boney[1]

Abstract

Over three seasons, fourteen field trials planted in six different cultivars representing maturity groups 3, 4, and 5 were conducted to determine the best timings and chemistries for foliar fungicides to manage frogeye leaf spot *(Cercospora sojina)* on soybean. Chemistries included strobilurins, triazoles, carboximides, and mixed modes of action to combat populations of strobilurin resistant fungi. Triazole fungicides and products containing a strobilurin and triazole were effective for frogeye leaf spot control. These studies also show that under low disease pressure, or when a variety is planted that is not susceptible to frogeye leaf spot, a fungicide application will not increase yield.

Introduction

Cercospora sojina, a fungal pathogen on soybean, causes a foliar disease called frogeye leaf spot (FLS), and can be found anywhere soybeans are grown. Frogeye leaf spot can cause yield reductions of up to 30% in susceptible cultivars (Phillips, 2008). Symptoms first appear on leaves as purple water-soaked spots, developing into circular to angular brown lesions surrounded by dark reddish-brown or purple margins. On the lower surface of the leaves, spots are darker in color and have light to dark grey "fuzzy" centers (sporulation). The fungus survives the winter on infected seeds and infested soybean residue (Phillips, 2008). Due to the increasing acreage of soybean in Arkansas, and more fields planted to soybean in successive years, disease pressure from FLS is likely to be high each year if weather is favorable for disease development. Therefore, making the best management choices such as resistant cultivars, high quality seed selection, deep tillage of residues, crop rotation, and foliar fungicides are essential to proper control and limiting yield loss. Using foliar fungicides to control FLS has been complicated by a population of *C. sojina* that is resistant to strobilurin fungicides and evidence suggests strobilurin fungicides do not provide adequate control (Emerson et. al., 2014 and Spurlock et. al., 2015). Further, fungicides are most often effective when applied at the proper timing. The objective of this work is to determine chemistries most effective against the current population of *C. sojina* in Arkansas as well as to determine if growth stage can be used to indicate proper timing for fungicide application.

Procedures

Most trials were conducted at the University of Arkansas System Division of Agriculture's Rohwer Research Station in a randomized complete block design on 38-in. row-spacing divided into 4-row plots, 20 ft. in length (FLS threshold plots were 10 ft. in length and arranged in a completely random design) at a seeding rate of 140,000 seed/ac. Trials in 2014-2015 had 5 replications in 2 maturity groups (MGs), 4 and 5. Trials in 2016 had 4 replications in 3 MGs, 3, 4, and 5. All treatments were compared to an untreated check. Fungicide efficacy trials within years and among all MGs contained the same treatments. The timing trials contained the same fungicides in all years. The center two rows of each plot were sprayed at specified timings for the timing trials, and efficacy trials were sprayed when disease levels warranted an application or when soybeans reached beginning seed (R5) growth stage (whichever came sooner). Plots were sprayed using a sprayer with a compressed air driven custom multi boom with 19-in. nozzle spacing. Fungicides were applied at 10 GPA using Teejet 11002VS. Disease assessments were based on percentage of disease coverage in the upper one-third of the canopy and were taken at applications and at 1–2 week intervals following. The center 2 rows were harvested with a plot combine, yield data collected, and standardized to 13% moisture content (MC). All data were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Fisher's protected least significant difference.

2016 Fungicide Efficacy Trials. Trials were planted 9 May, and fungicides were applied at R5 on 14 Jul, 26 Jul, and 2 Aug for MGs 3, 4, and 5, respectively. Disease ratings for MG 3 were taken weekly with the final assessments taken 9 Aug, MG 4 assessments were taken 8 days post application (DPA), and MG 5, 14 DPA. Total foliar disease severity was assessed 29 DPA in MG 5. Diseases included FLS, Septoria brown spot *(Septoria glycines)*, and Cercospora leaf blight *(Cercospora kikuchii)*. Plots were harvested 1 Sept. in MG 3, 22 Sept. for MG 4 and 20 Sept. for MG 5.

2016 Frogeye Leaf Spot Threshold Trials. Trials were planted 9 May. Maturity group 3 was planted in AgVenture 38H4R-DU23, MG 4 in Armor DK4744, and MG 5 in AgVenture 52B2RRR-DU23. An untreated check was compared with plots sprayed once with Quilt Xcel® 27 fl oz/ac, each on a different week starting at R1 (MG 5) - R2 (beginning bloom–full bloom) and ending at R7 (beginning maturity). Disease severity assessments were taken each week,

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growth stage recorded, and 10 leaflets from the untreated check and the current week's treatment digitized and subjected to digital image analysis to quantify disease. Maturity group 3 was harvested on 1 Aug, and MGs 4 and 5 on 20 Sept.

2015 Fungicide Efficacy Trials. Trials were planted 9 June, and fungicide treatments and were applied at beginning seed (R5). Disease assessments were taken 22 DPA on 17 Sept. Plots were harvested on 26 Sept. and on 21 Oct. for MG 4 and MG 5 trials, respectively.

2015 Fungicide Timing Trials. Trials were planted 9 Jun, and fungicides were applied at multiple timings. Disease severity was assessed weekly through 17 Sept. Plots were harvested on 26 Sept. and on 22 Oct. for MG 4 and MG 5 trials, respectively.

2014 Fungicide Efficacy Trials. The MG 4 test was planted 20 May and the MG 5 test 23 June. Plots were sprayed at beginning pod (R3). Disease assessments were taken 12 and 21 DPA. Plots were harvested on 26 Sept. and on 22 Oct. for MG 4 and MG 5 tests, respectively.

2014 Fungicide Timing Trials. The MG 4 test was planted 20 May and MG 5 23 June. Plots were sprayed at multiple timings. Disease assessments were taken at weekly intervals post-application. Plots were harvested on 22 Oct.

Results and Discussion

2016 Fungicide Efficacy Trials. Frogeye leaf spot *(Cercospora sojina)* was absent at application in MG 3 soybeans. Fortix© was the only treatment exhibiting phytotoxicity 11 DPA. Statistical differences were seen in the 9 Aug. rating as shown in Fig. 1; however, FLS severity never exceeded 1%. Plots were harvested at average MC of 17%. Statistical differences were not observed in yields. Disease severity assessments for FLS at application averaged 3% in MG 4 soybeans. Eight DPA, FLS severity remained less than 4%. Plots were harvested at an average MC of 11%. Topguard®, Fortix®, and Aproach® treatments yielded significantly higher than the untreated check as shown in Fig. 2. Fungicide treatments in MG 5 were applied at an average of 0.5% FLS severity. Frogeye leaf spot severity was rated at 1%, 14 DPA. Total foliar disease severity was assessed 29 DPA. Diseases assessed included Septoria brown spot (*Septoria glycines*) and Cercospora leaf blight (*Cercospora kikuchii*) and averaged of 12%, 29 DPA. Plots were harvested at an average MC of 9%. Statistical differences were not observed in yields.

2016 Frogeye Leaf Spot Threshold Trials. In the MG 3 threshold trial, statistical differences were observed in FLS severity at R5 and R7 growth stages, with a maximum FLS severity assessment of 1.5%. The trial was harvested at an average MC of 12% and an average yield of 73 bu/ac. In the MG 4 threshold trial, statistical differences were observed in FLS severity at R2, R4 (full pod), and R7 growth stages, with a maximum FLS severity rating of 9%. The trial was harvested at an average MC of 7% and an average yield of 56 bu/ac. In the MG 5 threshold trial, statistical differences were not observed in FLS severity, with a maximum FLS severity rating of 2.3%. The trial was harvested at an average MC of 10% and an average yield of 64 bu/ac. In all FLS threshold trials, statistical differences were not observed in yields, and FLS severity remained below 9%.While a threshold could not be established from only these data, we have concluded that this method is satisfactory for establishing a FLS threshold and plan to expand locations in 2017.

2015 Fungicide Efficacy Trials. Phytotoxicity was not observed in either trial, nor did FLS exceed 1%, and was rated 1% for all plots at the 17 Sept. rating in MG 4. Statistical differences were absent among treatments in MG 4, nor were any differences in yield observed. Statistical differences were seen in the 9 Sept. rating for MG 5, however no differences in yield were observed (Table 1).

2015 Fungicide Timing Trials. For the MG 4 trial, FLS never exceeded 1%, and was rated 1% for all plots at the final 17 Sept. rating. Phytotoxicity was not observed in either MG at any time. For the MG 5 trial, FLS averaged 2.4% at the 25 Aug rating and 8.3% on 17 Sept. Statistical differences were absent among treatments, nor were any differences in yield observed in both MGs.

2014 Fungicide Efficacy Trials. For the MG 4 trial, FLS was absent at application, and FLS was rated at an average of 1% 15 DPA. By 22 DPA, FLS ranged from 2.0 to 2.5%, and differences were observed among treatments (Table 2). By 36 DPA, no significant differences were observed among any treatments, nor were any differences in yield observed. In the MG 5 trial, FLS was 2% at application. At 12 DPA, all treatments except Approach© and Stratego YLD© reduced FLS severity compared to the untreated check. At 21 DPA, all treatments were significantly different than the check; however, none of the treatments had any effect on yield (Table 3).

2014 Fungicide Timing Trials. For the MG 4 trial, average severity of FLS at the R1, R3, and R5 timings was 0.0%, 1.0%, and 3.1%, respectively. Differences in fungicide efficacy were only observed on ratings taken 30 Jul. All treatments had been applied by 30 Jul, except the R5 sprays. On 30 Jul (Table 4), with the exception of the R1 treatment alone, Headline© (strobilurin) did not provide as much control as Domark© (triazole) or Quilt Xcel© (strobilurin + triazole). For the MG 5 trial, average severity of FLS at the V4, R3, and R5 timings was 0%, 2%, and 5.8%, respectively. Table 5 shows the ratings taken from 3 Sept. to 29 Sept. and yield data. Data prior to 3 Sept. (not shown) lacked significant differences. All treatments had been applied by 22 Sept. Although some timings × fungicide did improve disease control over the untreated check, no statistical significances were shown in yield.

Practical Applications

Over 3 seasons, 14 field trials on 6 different cultivars representing maturity groups 3, 4, and 5 were conducted to determine the best timings and chemistries for foliar fungicides to manage FLS. Overall, triazole fungicides and products containing a strobilurin and triazole were effective controls for frogeye leaf spot. These studies also show that under low disease pressure, or when a variety is planted that is not susceptible to frogeye leaf spot, a fungicide application will not increase yield. These results support the practice of sound integrated pest management practices (IPM) where scouting and spraying is likely more effective than applying a fungicide at a given growth stage "automatically". Additionally, in the soybean production area of Arkansas, the population of *C. sojina* is largely resistant to strobilurin fungicides due to repeated applications selecting out the tolerant population of fungal isolates. Due to this resistance issue, products with mixed modes of action have been used. In many cases, these fungicides are more expensive than a fungicide with a single chemistry and cause the farmer to incur even greater expense and profit loss when disease is absent or at lower levels. These data support findings from other studies and indicate that regardless of product used and timing, fungicides do not increase yield significantly. When disease is active on a susceptible cultivar, a well-timed fungicide application with a chemistry effective on the disease will likely keep the yield that would have been lost had the disease not been controlled.

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Table 1. 2015 fungicide efficacy average frogeye leaf spot severity percentages and yield on MG 5, AgVenture 52B2RR, soybeans at the University of Arkansas System Division of Agriculture's Rohwer Research Station.

Treatment and rate/ac	% FLS 9/17†	Yield (bu/ac)‡
Alto® 4 fl oz	9.0 abc	46.6
Aproach® 6 fl oz	9.8 ab	44.2
Domark® 4 fl oz	7.0 d	43.9
Equation® 4 fl oz	7.8 cd	42.1
Fortix® 5 fl oz	9.8 ab	46.5
Priaxor® 4 fl oz	10.2 ab	47.6
Proline® 2.5 fl oz	10.2 ab	42.6
Stratego® YLD 4 fl oz	9.0 abc	43.8
Topguard® 7 fl oz	8.6 bcd	44.2
Topsin® XTR 20 fl oz	10.6 a	40.7
Quilt Xcel® 10.5 fl oz	9.0 abc	41.2
Untreated Check	9.8 ab	46.1
LSD (0.10)	1.85	NS
P(F)	0.0749	0.4085

†Frogeye leaf spot; Columns followed by the same letter are not statistically significant using Fisher's protected Least Significant Difference ($P = 0.10$).

‡Yields standardized to 13% moisture content.

Table 2. 2014 fungicide efficacy average frogeye leaf spot severity percentages and yield on MG 4, Armor DK 4744, soybeans at the University of Arkansas System Division of Agriculture's Rohwer Research Station.

Treatment and rate/ac	% Frogeye leaf spot 22 DPA†	% Frogeye leaf spot 36 DPA	Yield (bu/ac) ‡
Alto® 4 fl oz	2.0 c	4.5	52.5
Aproach® 6 fl oz	2.1 c	4.2	53.9
Domark® 4 fl oz	2.1 c	4.0	55.5
Equation® 6 fl oz	2.0 c	4.3	52.8
Fortix® 5 fl oz	2.4 ab	4.7	51.9
Muscle® 4 fl oz	2.2 bc	4.7	50.2
Priaxor® 4 fl oz	2.2 bc	4.5	53.6
Prolin®e 2.5 fl oz	2.0 c	4.4	56.8
Stratego YLD® 4 fl oz	2.4 ab	4.7	51.8
Topguard® 7 fl oz	2.1 c	4.4	53.5
Quilt Xcel® 10.5 fl oz	2.1 c	4.5	53.8
Untreated Check	2.5 a	4.9	51.7
LSD (0.05)	0.248	NS	3.929
P(F)	0.0006	0.5477	0.1100

†Days post application; Columns followed by the same letter are not statistically significant using Fisher's protected Least Significant Difference (*P* = 0.05).

‡Yields standardized to 13% moisture content.

Table 3. 2014 fungicide efficacy average frogeye leaf spot severity percentages and yield on MG 5, AgVenture 52B2RR, soybeans at the University of Arkansas System Division of Agriculture's Rohwer Research Station.

Treatment and rate/ac	% Frogeye leaf spot 12 DPA†	% Frogeye leaf spot 21 DPA	Yield (bu/ac) ‡
Alto® 4 fl oz	3.0 bc	4.4 bcd	49.5
Aproach® 6 fl oz	3.4 ab	4.6 bcd	47.4
Domark® 4 fl oz	2.9 bc	4.4 bcd	51.0
Equation® 6 fl oz	3.0 bc	5.4 b	50.2
Fortix® 5 fl oz	2.4 bc	2.8 d	52.4
Priaxor® 4 fl oz	3.1 bc	4.4 bcd	48.5
Proline® 2.5 fl oz	2.2 c	4.0 bcd	50.3
Stratego YLD® 4 fl oz	3.4 ab	5.2 bc	49.0
Topguard® 7 fl oz	2.5 bc	3.6 bcd	53.0
Topsin® XTR 20 fl oz	2.1 c	3.4 cd	49.9
Quilt Xcel® 10.5 fl oz	2.7 bc	5.0 bc	49.9
Untreated Check	4.5 a*	7.6 a	48.2
LSD (0.05)	1.107	1.86	NS
P(F)	0.0068	0.0014	0.4151

†Days post application; Columns followed by the same letter are not statistically significant using Fisher's protected Least Significant Difference (*P* = 0.05).

‡Yields standardized to 13% moisture content.

Table 4. 2014 fungicide timing trial average frogeye leaf spot severity percentages and yield on MG 4, AgVenture 49C9RR, soybeans at the University of Arkansas System Division of Agriculture's Rohwer Research Station.

		% Frogeye leaf spot		
Treatment and rate/ac	**Timing**	**30 Jul**	**25 Aug**	**Yield (bu/ac)‡**
Untreated Check	N/A	2.1 cd†	39.0	51.9
Headline® 6 fl oz	R1	2.1 cd	32.2	48.7
Domark® 4 fl oz	R1	2.1 cd	39.0	49.5
Quilt Excel® 14 fl oz	R1	2.5 ab	42.2	49.2
Headline® 6 fl oz	R1+R3	2.5 ab	38.0	49.3
Domark® 4 fl oz	R1+R3	2.1 cd	31.0	54.0
Quilt Excel® 14 fl oz	R1+R3	2.0 d	32.0	50.3
Headline® 6 fl oz	R3	2.6 a	45.0	48.0
Domark® 4 fl oz	R3	2.2 cd	37.0	50.2
Quilt Excel® 14 fl oz	R3	2.1 cd	37.0	49.5
Headline® 6 fl oz	R3+R5	2.6 a	39.0	50.8
Domark® 4 fl oz	R3+R5	2.2 cd	30.0	49.4
Quilt Excel® 14 fl oz	R3+R5	2.3 cd	36.0	52.6
Headline® 6 fl oz	R5	2.3 bc	38.0	52.3
Domark® 4 fl oz	R5	2.2 cd	42.0	50.8
Quilt Excel® 14 fl oz	R5	2.2 cd	38.0	52.1
LSD (0.05)		0.275	NS	NS
P(F)		0.0001	0.5146	0.4811

†Columns followed by the same letter are not statistically significant using Fisher's protected Least Significant Difference (P = 0.05).
‡Yields standardized to 13% moisture content.

Table 5. 2014 fungicide timing trial average frogeye leaf spot severity percentages and yield on MG 5, AgVenture 52B2RR, soybeans at the University of Arkansas System Division of Agriculture's Rohwer Research Station.

		% Frogeye leaf spot				
Treatment and rate/ac	**Timing**	**3 Sept.**	**12 Sept.**	**22 Sept.**	**29 Sept.**	**Yield (bu/ac)‡**
Untreated Check	N/A	4.6 abc†	7.8 a	8.4 a-e	8.6 ab	52.3
Headline® 6 fl oz	V4	5.4 ab	7.4 a	9.3 a	9.2 a	54.1
Domark® 4 fl oz	V4	5.6 a	7.6 a	9.0 ab	8.9 ab	51.4
Quilt Excel® 14 fl oz	V4	5.0 ab	7.4 a	8.5 a-d	9.1 a	50.6
Headline® 6 fl oz	R1+R3	4.1 b-e	5.2 bcd	6.6 d-g	5.9 cde	52.7
Domark® 4 fl oz	R1+R3	2.4 f	4.0 de	5.2 g	5.2 de	54.5
Quilt Excel® 14 fl oz	R1+R3	2.5 f	4.0 de	5.2 g	5.0 e	54.0
Headline® 6 fl oz	R3	4.2 bcd	5.0 cde	6.9 b-g	7.5 abc	52.1
Domark® 4 fl oz	R3	2.9 def	4.2 de	6.31 efg	5.2 de	55.7
Quilt Excel® 14 fl oz	R3	3.0 def	4.0 de	6.8 c-g	5.8 cde	54.2
Headline® 6 fl oz	R3+R5	5.4 ab	6.8 ab	8.8 abc	7.1 bcd	52.6
Domark® 4 fl oz	R3+R5	3.6 c-f	4.6 cde	6.6 d-g	5.5 de	50.3
Quilt Excel 14 fl oz	R3+R5	2.8 ef	3.4 e	6.0 fg	4.9 e	55.7
Headline® 6 fl oz	R5	5.0 ab	7.2 a	8.0 a-f	8.7 ab	50.9
Domark® 4 fl oz	R5	5.2 ab	7.2 a	8.4 a-e	9.4 a	55.4
Quilt Excel® 14 fl oz	R5	4.4 abc	6.2 abc	7.4 a-f	7.9 ab	52.2
LSD (0.05)		1.334	1.63	2.185	1.950	NS
P(F)		0.0001	0.0001	0.0017	0.0001	0.6748

†Columns followed by the same letter are not statistically significant using Fisher's protected Least Significant Difference (P = 0.05).
‡Yields standardized to 13% moisture content.

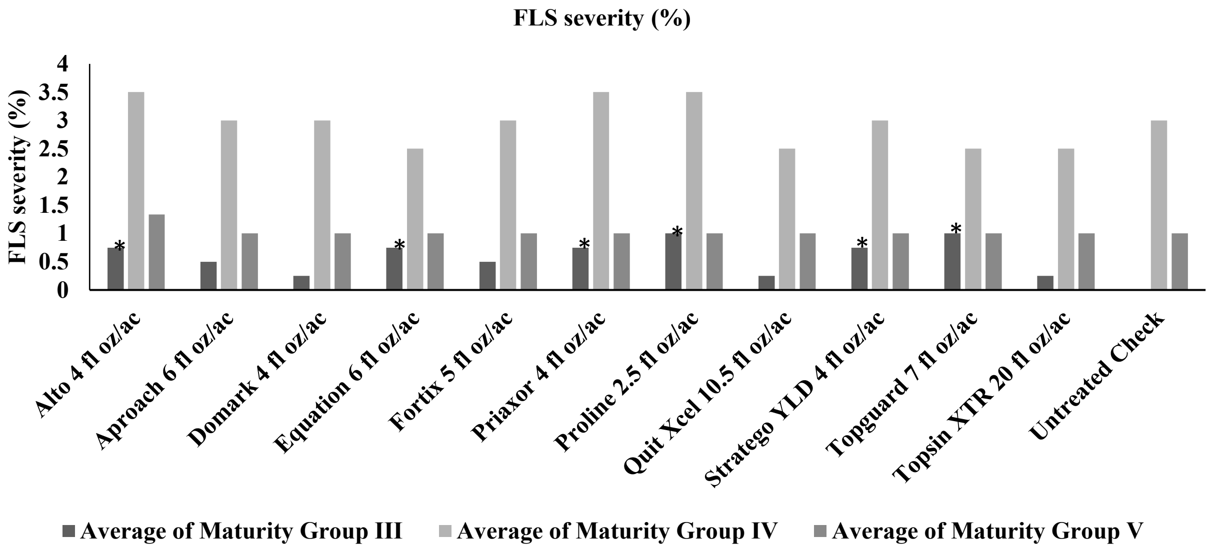

Fig. 1. 2016 Fungicide efficacy trial average frogeye leaf spot (FLS) severity percentages by treatment and maturity group (MG) at final ratings. Final rating dates are as follows: MG 3 (AgVenture 38H4R-DU23) at R7 on 9 Aug., MG 4 (Armor DK4744) at R5.5 on 3 Aug., and MG 5 (UA 5414RR) at R5 on 16 Aug. Columns marked with an asterisk within the same color are statistically significant from the untreated check at *P* = 0.10 using Fisher's protected least significant difference.

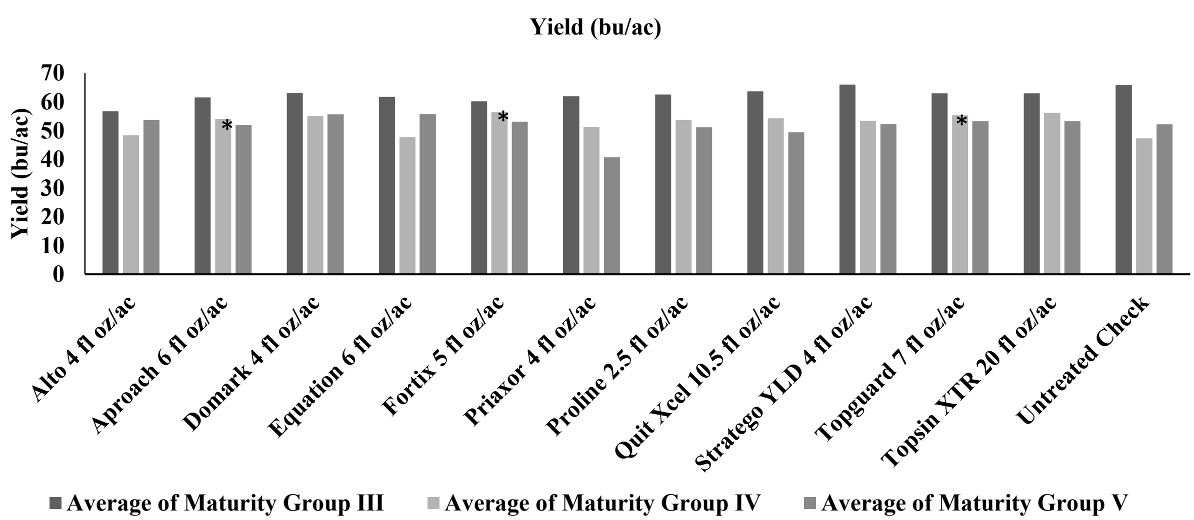

Fig. 2. 2016 fungicide efficacy trial average yields in bu/ac by treatment and maturity group. Maturity groups 3, 4, and 5 were planted with AgVenture 38H4R-DU23, Armor DK4744, and UA 5414RR, respectively. Columns marked with an asterisk within the same color are statistically significant from the untreated check at *P* = 0.10 using Fisher's protected least significant difference.

Effect of Soybean Seed Treatment and Planting Date on Stand and Yield at Three Arkansas Locations in 2016

J. Rupe[1], R. Holland[1], S. Winters[1], and C. Rothrock[1]

Abstract

Nineteen soybean seed treatments were compared at three locations and three planting dates in 2016. The locations were the the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), the Lon Mann Cotton Research Station (LMCRS) and the Rice Research and Extension Center (RREC). Seed treatments resulted in significantly greater stand than the untreated control in April, May, and June at LMCRS, in May and June at RREC and in June at NEREC. There was one seed treatment that had significantly greater stands than the control in six of the nine tests (Albaugh N-Compass Premium 800); two that were significantly greater than the control in three tests, five in two tests, and six in one test. Seed treatments resulted in significantly greater yields than the control in the June planting at RREC with the greatest yield from Albaugh N-Compass Premium 800 treatment. Yields were not significantly different from the control at the other planting dates and locations. Overall, seedling pathogens that were controlled by at least one of the seed treatments accounted for 6% to 16% of the stand loss in any given test. Factors, such as environment, seed quality, or pathogens and pests not controlled by the seed treatments, reduced stands 10% to 47%.

Introduction

Arkansas soybean producers can choose from a large number of seed treatment products to protect their seed. These products include one or more fungicides, or may also include an insecticide or a nematicide. Many growers think that seed treatments are only needed for early plantings, but past research has shown a benefit of seed treatments at any planting date. Seed treatments help protect against poor stands which may necessitate replanting, may increase weed competition, and can result in low yields. With so many choices, a standardized evaluation of the most common seed treatments was needed that included multiple locations and was representative of the wide range of planting dates common in Arkansas.

Procedures

Nineteen seed treatments were selected for testing based on MP-154 Arkansas Plant Disease Control Products Guide 2015 (Faske et al., 2016) and on discussions with extension pathologists. Armor 49R56 seeds were treated with the recommended rates of each fungicide (Table 1). Besides containing one or more fungicides, 12 of the 19 seed treatments also contained an insecticide and four contained a nematicide. The control was treated with water alone. Tests were planted at 69,000 to 87,000 seed/ac at the the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC), Keiser, Ark., on 15 April, 6 May and 8 June; the Lon Mann Cotton Research Station (LMCRS), Marianna, Ark., on 25 April, 18 May and 15 June; and at the Rice Research and Extension Center (RREC), Stuttgart, Ark. on 29 April, 25 May, and 22 June. Stands were counted at two and four weeks after planting (only the four week results will be presented) and yields were taken at the end of the season. Results were statistically analyzed with PROC MIXED (SAS version 9.4, SAS Institute Inc. Cary, N.C., USA). The plots were observed for other diseases during the season.

Results and Discussion

At least one seed treatment significantly increased stands in six of the nine tests in 2016 (Tables 1 and 2). With the seed treatments that resulted in significant stand increases, stand increased from 12% to 29% over the control. Seedling pathogens affected plants at all planting dates. Stands were improved by seed treatments in one of three tests in April, two of three tests in May, and all three tests in June. There was no clear relationship between either test location or planting date and seed treatment. The seed treatments that resulted in significantly higher stands than the control in the nine tests in 2016 were: NCP800 in six tests; NCPS and AM in three tests; ACB500, CMV, EEG, EE, and T2000 in two tests; and AMD, ACB500M, CMVC,EEPV, M, and IS in one test. While 12 of the 19 seed treatments contained an insecticide, it was not clear if the insecticide improved stands. However, an insecticide was added to three fungicide-only treatments: thiomethoxam (Cruiser®) was added to AM; clothianidin (Poncho®) was added to EE; and imidacloprid (Gaucho®) was added to EE and to T2000. In most of the nine tests in 2016, adding an insecticide did not result in stands significantly greater than that fungicide seed treatment alone, except in one case. In the June planting at RREC, stands of EEG were significantly greater than stands of EE. However, there were tests where adding an insecticide resulted in significantly lower stands than the fungicide alone:

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EE vs EEG at LMCRS in May; EE vs EEPV or EEPVI at LMCRS in June; and T2000 vs T2000G at LMCRS in May and at NEREC in June. It is not clear why adding an insecticide lead to lower stands, but our results do not support the inclusion of an insecticide to most soybean seed treatments.

Soybean stands were not only affected by seedling pathogens, the environment was very important. To separate the effect of seedling pathogens from other factors, the total stand loss was calculated by subtracting the total number of seed planted from the stand of the untreated control (Fig. 1). To determine the stand loss due to biotic factors (that is, seedling diseases controlled by seed treatments), the stand of the best seed treatment was subtracted from the stand of the untreated control. The abiotic stand loss (that is the loss of stand due to environment, seed quality, or pathogens and pests not controlled by seed treatments) was determined by subtracting the total number of seed planted from the stand of the seed treatment with the greatest stand. These numbers were converted to percentages of the number of seed planted. In seven of the nine tests, abiotic stand loss was greater than biotic stand loss. This was especially true in the April planting at RREC, the April and May plantings at LMCRS, and the May planting at NEREC. At RREC and NEREC, and to a lesser extent LMCRS, these losses were associated with rainfall shortly after planting. At RREC, 4.1 in. of rain fell four days after planting in April, at NEREC 6.1 in. fell three to five days after planting in May, at LMCRS, 2.5 in. fell five days after planting in April, and 2.6 in. fell 7-9 days after planting in May. The amount of biotic stand loss varied from 6% to 16% across all tests. However, the abiotic stand loss ranged from 10% to 47%. Soybean seedlings are very sensitive to flooding before emergence so timing planting to avoid heavy showers in the first week after planting and planting on raised beds are important for good stand establishment.

The only significant effect of seed treatment on yield was NCP800 in the June planting at RREC. That treatment yield was 12.7 bu/ac more than the control a 23% yield increase (Tables 2 and 3). Planting date affected yield. Average yields across all treatments were 59.9, 73.3, and 49.5 bu/ac at NEREC; 45.4, 42.9, and 24.2 bu/ac at LMCRS; and 46.0, 65.5, and 49.3 bu/ac at RREC for the April, May and June plantings, respectively. There were no other diseases that significantly impacted these tests.

Practical Applications

This research demonstrates the importance of seed treatments in establishing a soybean crop no matter when planted. Late-planted fields are just as likely to benefit by a seed treatment as early-planted fields. In this study, adding an insecticide to a seed treatment usually did not improve the performance of the seed treatment, but efficacy of an insecticide may depend on the field and the field's history of stand problems. As important as the biotic factors affecting emergence, environment often plays an important role. If possible, avoid planting if heavy rainfall is predicted shortly after planting, plant on raised beds, and make sure fields drain well. These measures should help avoid stand loss from wet soils.

Acknowledgements

This research was funded by the Arkansas Soybean Promotion Board. The authors want to acknowledge the University of Arkansas System Division of Agriculture; to thank: Fred Bourland and Shawn Lancaster at the Northeast Research and Extension Center; Claude Kennedy, Clayton Treat, and Jake Norris, at the Lon Mann Cotton Branch Station; and Charles Wilson and Johnathan McCoy at the Rice Research and Extension Center for their help in managing the plots. This research was supported in part by the United States Department of Agriculture HATCH project numbered ARK02396.

Literature Cited

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Table 1. Fungicide treatments, active ingredients and rates (fl oz/cwt) for seed treatment tests in 2016.

Fungicide	Abbrev.	Active ingredients	Rate
N-Compass Plus South®	NCPS	Imidacloprid (40.51%)†, Thiabendazole (5.06%), Metalaxyl (12.66%), Azoxystrobin (7.59%), Thiophante Methyl (3.64%)	4.7
N-Compass Premium 800®	NCP800	Imidacloprid (40.91%)†, Thiabendazole (14.55%), Metalaxyl (14.55%), Azoxystrobin (3.64%), Heads Up (7.09%)	4.4
ApronMaxxRTA®	AM	Fludioxonil (0.73%) Mefenoxam (1.1%)	5
ApronMaxxRTA® + Dynasty®	AMD	Fludioxonil (0.73%) Mefenoxam (1.1%) Azoxystrobin (9.6%)	5 + 0.153
ApronMaxxRTA® + Dynasty® + Cruiser® 5FS	AMDC	Fludioxonil(0.73%) Mefenoxam(1.1%) Azoxystrobin (9.6%) Thiamethoxam (47.6%) †	5 + 0.153 + 1.3
CruiserMaxxVibrance®	CMV	Mefanoxam (3.13%) fludioxonil (1.04%) Sedaxane (1.04%) Thiomethoxam (20.8%)	3.22
CruiserMaxxVibrance® + Clariva® PN	CMVC	Mefanoxam (3.13%) fludioxonil (1.04%) sedaxane (1.04%) *Pasteuria nishizawae*-PN1‡ Thiomethoxam (20.8%)†	3.22 + 2
Avicta Complete Beans® 500	ACB500	Abamectin (22.02%) ‡, Thiamethoxam (11.01%) †, mefenoxam (1.67%), fludioxonil (0..55%)	6.2
Avicta Complete Beans® 500 + Mertect®	ACB500M	Abamectin (22.02%) ‡, Thiamethoxam (11.01%) †, mefenoxam (1.67%), fludioxonil (0..55%), Thiobendazole (42.3%)	6.2+0.075
Integro Suite®	IS	Clothianidin (20.96%) Ethaboxam (2.97%), Ipconazole (0.99%), Metalaxyl (0.79%)	3.37
EvergolEnergy®	EE	Metalaxyl (6.74%) Penflufen (3.59%) Prothioconazole (7.18%)	1
EvergolEnergy® + Gaucho®	EEG	Metalaxyl (6.74%) Penflufen (3.59%) Prothioconazole (7.18%) Imidacloprid (48.7%)†	1 +1.6
EvergolEnergy® + PonchoVotivo® + Ilevo®	EEPVI	Metalaxyl (6.74%) Penflufen (3.59%) Prothioconazole (7.18%) Clothianidin (40.3%) *Bacillus firmus* (8.1%) ‡ fluopyram (48.4%)	1 + 2 + 2.38
EvergolEnergy+PonchoVotivo	EEPV	Metalaxyl (6.74%) Penflufen (3.59%) Prothioconazole (7.18%) Clothianidin (40.3%) † *Bacillus firmus* (8.1%)‡	1 + 2
Allegiance® FL	A	Metalaxyl (28.35%)	1.5
Maxim®	M	Fludioxonil (21%) metalaxyl (8.4%)	0.08
Trilex2000®	T2000	Trifloxystrobin (7/12%) metalaxyl (5.62%)	1
Trilex2000® + Gaucho®	T200G	Trifloxystrobin (7/12%) metalaxyl (5.62%) Imidacloprid (48.7%) †	1 + 1.6
Vibrance®	V	Sedaxane (43.7%)	1

† = insecticides

‡= nematicides

Table 2. Effect of seed treatments on stands (plants/a) and yields (bu/a) of the soybean cultivar Armor 49R56 planted at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) and the Lon Mann Cotton Research Station (LMCRS) in April, May and June†, 2016.

Seed	Northeast Research and Extension Center						Lon Mann Cotton Research Station					
	------April-----		-----May----		-------June-------		----April----		-----May-----		-----June-----	
Treatment	Stand	Yield	Stand	Yield	Stand	Yield	Stand	Yield	Stand	Yield	Stand	Yield
N-Compass Plus South®	56728a‡	59.9	50195	71.1	56315a-d	48.5	52808ab	46.3	52808a	45.7	45451a-d	21.0
N-Compass Premium 800®	56728cde	65.0	50402	73.7	60235a	50.1	55765a	46.0	52121ab	41.0	52671a	23.7
Allegiance® FL	44904cde	54.2	52052	71.7	53152bcd	49.0	49645b-e	44.6	47995b-e	40.5	40638d	22.6
ApronMaxxRTA® + Dynasty® + Cruiser® 5FS	47376bcd	59.1	51914	74.3	53496bcd	50.1	50127b-e	44.2	50608a-e	42.4	52602a	28.8
ApronMaxxRTA® + Dynasty®	47239bcd	59.0	46276	74.4	56315a-d	48.7	48408cde	44.1	50127a-e	42.4	48476abc	24.0
ApronMaxxRTA®	46414b-e	59.0	46689	74.5	54252bcd	50.8	46551e	45.8	52121ab	42.6	51777a	27.0
Avicta Complete Beans® 500 + Mertect®	46276b-e	56.8	49095	70.0	51639d	50.7	50058b-e	45.8	50952a-e	44.5	49577ab	23.9
Avicta Complete Beans® 500	48408bcd	57.7	50952	74.8	53015bcd	52.3	49577b-e	49.2	52052ab	45.8	42700bcd	23.8
CruiserMaxxVibrance®	46345b-e	60.1	46482	73.0	57072abc	52.3	52052abc	44.9	49577a-e	43.0	49026ab	23.6
CruiserMaxxVibrance® + Clariva® PN	46964bcd	65.5	47239	74.9	52121cd	48.8	48476cde	46.5	50264a-e	43.0	47789a-d	25.7
EvergolEnergy® + Gaucho®	47858bcd	57.5	44970	75.8	56865abc	52.0	51983abc	45.3	46826ef	40.3	45863a-d	27.3
EvergolEnergy+PonchoVotivo	46001cde	62.9	46345	74.1	50746d	47.3	48064cde	48.6	51227a-d	44.0	41532cd	21.0
EvergolEnergy® + PonchoVotivo® + Ilevo®	48270bcd	65.9	49989	75.7	55009bcd	49.6	48408cde	43.0	47720cde	43.2	44763bcd	22.3
EvergolEnergy®	48545bcd	60.3	48270	75.3	54734bcd	48.8	50677bcd	47.3	51502abc	41.1	49714a	22.4
Maxim®	40569e	57.5	45657	67.0	50402d	48.1	48064de	44.8	48408b-e	44.4	42357bcd	24.1
Trilex2000®	47651bcd	65.1	46276	76.1	57965ab	47.4	47514de	42.7	49577a-e	40.5	48889abc	25.1
Trilex2000® + Gaucho®	42769de	61.8	49508	70.4	52533cd	53.3	46895de	44.2	41600f	41.6	46689a-d	25.1
Integro Suite®	45588cde	60.9	49026	71.9	55490abcd	48.3	52671ab	48.2	51296a-d	44.6	46345a-d	28.3
Vibrance®	48958bc	53.6	45313	76.2	53633bcd	48.9	47032de	44.0	48408b-e	45.3	44557bcd	23.8
Water	52327ab	55.9	48064	71.8	49577d	45.1	47583de	42.9	47101def	43.0	43182bcd	21.4

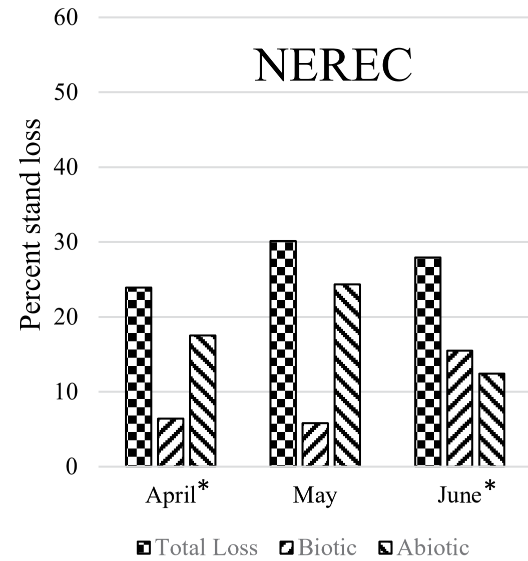
† Planting dates were 15 April, 6 May and 8 June at NEREC and 25 April, 18 May and 15 June at LMCRS in 2016. Planting rates were 69,000 seed/ac.

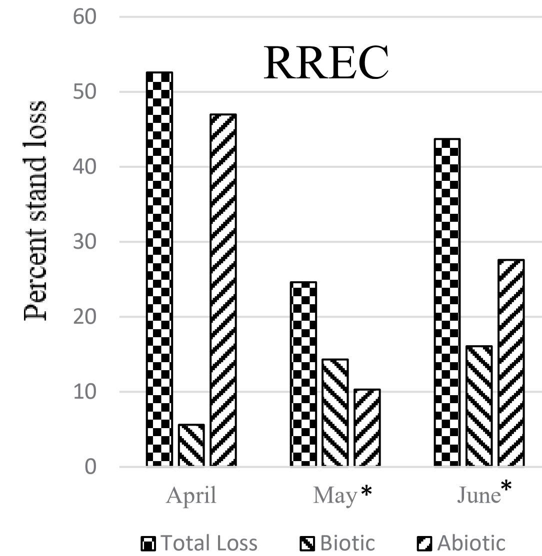
‡ Numbers followed by the same letter were not significantly different ($P = 0.05$). Columns without letters indicate that the differences were not statistically significant.

Table 3. Effect of seed treatments on stands (plants/ac) and yields (bu/ac) of the soybean cultivar Armor 49R56 planted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center (RREC) in April, May and June†, 2016.

	------------April----------		--------May--------		---------June--------	
	Stand	**Yield**	**Stand**	**Yield**	**Stand**	**Yield**
N-Compass Plus South®	36242	43.7abc‡	78147a	66.4abc	52359c-f	40.3d
N-Compass Premium 800®	37462	40.5c	74488a	66.4ab	63075a	56.9a
Allegiance® FL	42340	48.3abc	68215b	66.2abc	50704ef	48.6abc
ApronMaxxRTA® + Dynasty® +Cruiser® 5FS	46174	41.1c	64120bc	65.2bcd	59242ab	51.5ab
ApronMaxxRTA® + Dynasty®	45477	50.6abc	63510c	64.3bcd	53927b-f	52.9ab
ApronMaxxRTA®	40249	39.4c	65950bc	66.6ab	57848abc	49.6abc
Avicta Complete Beans® 500 + Mertect®	39030	46.6abc	64643bc	66.4ab	60200ab	48.2bcd
Avicta Complete Beans® 500	42340	52.9abc	65427bc	64.9bcd	60113ab	51.3ab
CruiserMaxxVibrance®	39378	47.5abc	64382bc	65.9a-d	57586a-d	51.6ab
CruiserMaxxVibrance® + Clariva® PN	45128	46.2abc	62552c	63.4cd	61942a	50.6abc
EvergolEnergy® + Gaucho®	36416	42.6abc	62988c	65.5a-d	58454abc	52.2ab
EvergolEnergy+PonchoVotivo	35371	45.8abc	61332c	64.5bcd	53317b-f	49.2abc
EvergolEnergy® + PonchoVotivo® + Ilevo®	37636	37.3c	62639c	63.9bcd	53927b-f	49.2abc
EvergolEnergy®	44605	61.0a	65688bc	65.5a-d	50791def	43.0cd
Maxim®	45477	46.3abc	67170bc	65.4a-d	56367a-e	52.0ab
Trilex2000®	36765	46.5abc	65166bc	65.7a-d	53230abc	50.3abc
Trilex2000® + Gaucho®	39030	41.9bc	65427bc	68.3a	53230b-f	49.4abc
Integro Suite®	39901	36.9c	67954b	66.4ab	54798a-f	46.7bcd
Vibrance®	41992	59.9ab	62726c	63.2d	50617ef	45.6bcd
Water	41295	44.5abc	65688bc	65.6a-d	49049f	46.2bcd

† Planting dates were 29 April, 25 May and 22 June at NEREC and 25 April 2016. Planting rates were 87,000 seed/ac.
‡ Numbers followed by the same letter were not significantly different (P=0.05). Columns without letters indicate that the differences were not statistically significant.





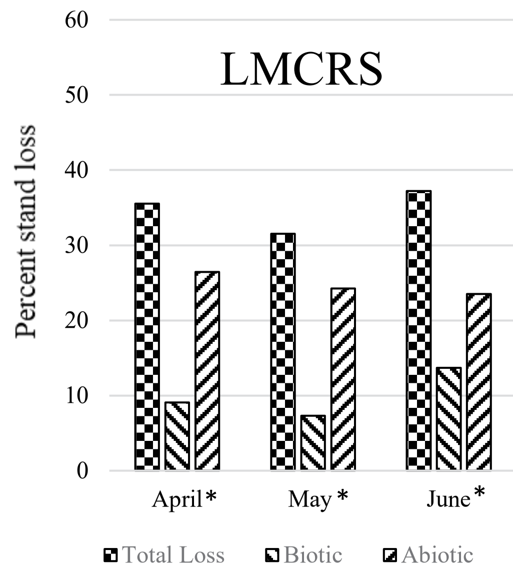


Fig. 1. Total percent stand loss, stand loss due to seedling disease (biotic), stand loss due to environmental factors (abiotic). Total stand loss based on the total number of seed planted minus the stand of the untreated seed. Stand loss due to seedling disease based on the treatment with the greatest stand minus stand of the untreated seed. Stand loss due to environmental factors based on the total stand loss minus stand loss of the treatment with the greatest stand. NEREC, RREC, and LMCRS = University of Arkansas System Division of Agriculture's Northeast Research and Extension Center, Keiser; Rice Research and Extension Center, Stuttgart; and Lon Mann Cotton Research Center, Marianna, respectively.

PEST MANAGEMENT: INSECT CONTROL

Demonstration of Kudzu Bug Management Practices to Consultants and Growers in Arkansas

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Abstract

The kudzu bug, *Megacopta cribraria*, is an invasive pest of soybeans that first arrived in the United States in fall of 2009 and has since spread throughout much of the Southeast (Gardner et al., 2013). The kudzu bug feeds readily on soybean in addition to kudzu, and can reduce yields substantially under heavy feeding pressure (Seiter et al., 2013). Although several insecticides are effective for control of kudzu bugs (Seiter et al., 2015), adults often re-enter fields quickly after a successful application, resulting in repeated, often unnecessary applications where adults are targeted for control. Current University of Arkansas System Division of Agriculture Cooperative Extension Service (CES) recommendations are to target the immatures for control, at a threshold of 25 nymphs in 25 sweeps (Studebaker, 2017). The kudzu bug was first found in Arkansas in 2014 and has since been found at low densities throughout the major crop production areas of the state, and pest managers in Arkansas have little to no experience managing this pest. An in-field demonstration was conducted to train stakeholders and county CES personnel to identify and properly manage kudzu bugs. As part of this demonstration, an insecticide efficacy trial was initiated to verify that materials used in the southeastern U.S. were effective in Arkansas.

Procedures

A soybean field near Helena, Ark. was identified on 29 June 2016 that had approximately 200 adult kudzu bugs in 25 sweeps. A small group of input dealer representatives from the area were hosted at the field on 30 June 2016 and instructed on kudzu bug management, specifically the importance of targeting immatures rather than adults and the economic threshold of 25 nymphs per 25 sweeps. On 6 July 2016, a group of county agriculture agents were brought to the site for an in-field educational meeting, where kudzu bug biology and management were stressed and proper scouting techniques and identification of adults, nymphs, egg masses, and damage were demonstrated. On 25 July 2016 (almost a month after the initial infestation), the economic threshold of 25 nymphs per 25 sweeps was reached, and a field efficacy trial was established (see methods below). A follow-up training was conducted on 29 July 2016 with University of Arkansas System Division of Agriculture Cooperative Extension Service (CES) county agriculture agents.

Field Efficacy Trial. A field experiment was established as a randomized complete block design with 4 replicate blocks and 10 treatments (9 insecticide-rate combinations plus an untreated check). Soybean plots were approximately 40 feet long by 4 rows wide. Foliar treatment applications were applied on 25 July 2016 (soybeans growth stage R4) at a spray volume of 10 gallons of water per acre using a self-propelled, 25-foot multi-boom broadcast sprayer. Kudzu bug adults and nymphs were sampled on 29 July, 5 August, and 23 August 2016 using a mesh 15-inch diameter sweep net (20 sweeps were taken per plot). All data analyses were conducted using ARM 2016 (Gylling Data Management, Brookings, S.D.) software. Adults and nymphs of kudzu bugs per 20 sweeps were analyzed separately for 29 July and 5 August using two-way analyses of variance (ANOVA), with replicate block and treatment considered as fixed effects. Data for adults and nymphs on 29 July and for nymphs on 5 August were transformed by taking the logarithm of x + 1 to meet the assumptions of ANOVA.

Results and Discussion

All life stages of kudzu bugs were affected by the insecticide treatment factor on 29 July and 5 August (Table 1). Discipline®, Karate®, and Discipline® in combination with Belay® or Orthene® provided excellent initial control (4 days post-application) of kudzu bug adults and nymphs (Table 2). Endigo®, Orthene®, and Besiege® provided adequate initial control. By 11 days post-application, adults were able to re-enter treated plots, and appeared to preferentially enter plots

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[4]Area Agriculture Natural Resources Specialist, Department of Agricutlture and Natural Resources, Little Rock.
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where densities of kudzu bugs had been reduced by an insecticide application (Table 2). However, densities of nymphs were still reduced at 11 days post-application in plots that received a successful insecticide application (Table 2). These results are similar to observations made in areas of the U.S. that have previously been infested with kudzu bugs (Seiter et al., 2015). By 23 August, kudzu bug populations throughout the field were dramatically reduced. Infection of the insects by *Beauveria bassiana* was prevalent. This pathogen has been credited with reducing kudzu bug populations dramatically in the southeastern U.S.

Practical Applications

This demonstration was a critical step in educating consultants, agents, and other stakeholders on best management practices for an invasive pest of soybeans. The data we collected showed that effective chemical control of the kudzu bug was not difficult to achieve. The hands-on educational sessions we conducted allowed us to show first-hand the high densities of kudzu bug nymphs that it takes before an insecticide is needed. In states that have been invaded by kudzu bug in the past, the uncertainty associated with this new insect often resulted in multiple applications that were largely unnecessary. Using demonstrations such as this one, we hope to encourage insecticide applications in Arkansas only in those situations where they are likely to provide an economic return on investment.

Acknowledgements

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Table 1. Analysis of variance (ANOVA) statistics for each dependent variable analyzed. Each ANOVA had 39 total degrees of freedom (Replicate = 3 df, treatment = 9 df, error = 27 df).

		Replicate		Treatment	
Date	Dependent variable	*F*	*P*	*F*	*P*
29 July	Adults per 20 sweeps	1.86	0.160	9.76	< 0.001 †
	Nymphs per 20 sweeps	0.53	0.667	5.63	< 0.001 †
5 August	Adults per 20 sweeps	1.79	0.173	3.10	0.011 †
	Nymphs per 20 sweeps	3.95	0.019	16.98	< 0.001 †

† Effect was significant at $\alpha = 0.05$.

Table 2. Densities of kudzu bug adults and nymphs (untransformed means ± standard error) sampled by taking 20 sweeps per plot using a sweep net.

	29 July (4 days post-application)		5 August (11 days post-application)	
Treatment	Adults	Nymphs	Adults	Nymphs
Untreated	5.0 ± 2.7 b†	36.3 ± 13.9 a	0.8 ± 0.5 d	9.5 ± 3.0 a
Discipline (6.4 oz/ac)	0.0 ± 0.0 d	0.8 ± 0.5 c	9.5 ± 1.5 abc	0.3 ± 0.3 bc
Endigo (4.5 oz/ac)	0.5 ± 0.5 d	8.3 ± 7.6 bc	11.5 ± 2.8 abc	0.5 ± 0.5 bc
Karate Z (1.8 oz/ac)	0.3 ± 0.3 d	0.0 ± 0.0 c	14.5 ± 3.7 ab	0.0 ± 0.0 c
Orthene 97 (1 lb/ac)	1.5 ± 1.2 cd	2.0 ± 0.7 bc	6.8 ± 2.1 bcd	0.0 ± 0.0 c
Belay (6 oz/ac)	1.8 ± 0.3 bc	15.3 ± 11.3 ab	9.8 ± 0.6 abc	1.8 ± 1.4 b
Besiege (7 oz/ac)	0.5 ± 0.3 cd	3.5 ± 2.9 bc	15.8 ± 6.1 a	0.3 ± 0.3 bc
Belt (2 oz/ac)	10.3 ± 2.4 a	18.8 ± 5.5 a	4.8 ± 1.9 cd	10.0 ± 4.2 a
Belay (4 oz/ac) + Discipline (5 oz/ac)	0.5 ± 0.3 cd	1.5 ± 1.0 c	13.3 ± 2.6 ab	0.3 ± 0.3 bc
Orthene 97 (0.75 lb/ac) + Discipline (5 oz/ac)	0.5 ± 0.3 cd	1.3 ± 0.9 c	13.8 ± 1.7 ab	0.0 ± 0.0 c

† Means followed by the same letter within a column are not different based on Fisher's method of least significant difference ($\alpha = 0.05$).

Occurrence of Dicamba-like Symptoms on Soybean Offspring

G.T. Jones[1], J.K. Norsworthy[1], L.T. Barber[2], and R.C. Scott[2]

Abstract

Dicamba-resistant soybean and cotton now have a labeled dicamba herbicide for use over-the-top. The likelihood of off-target movement could be increased as use of dicamba will rise and extend into mid-summer months. In 2014 and 2015, sixteen dicamba drift experiments were established at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center in Keiser, Ark. using commercial applicator techniques. Seed from these trials were saved and planted at the University of Arkansas System Division of Agriculture's Arkansas Agricultural Research and Extension Center in Fayetteville, Ark. in 2015 and 2016. Data were subjected to multivariate analysis to determine pairwise correlations between parent and offspring variables. Dicamba-like symptomology appeared as early as the unifoliate stage and lasted in some cases to the third trifoliate stage. Offspring resulting from late reproductive drift events had the highest occurrence of dicamba-like symptoms. Parent mature pod malformation appears to be the best predictor of negative offspring effects. This warrants great concern for non-dicamba seed production fields as drift events could cause offspring to display dicamba-like symptomology.

Introduction

New, technologically advanced formulations are now available for growers to use in dicamba-resistant (DR) crops; however, these technologies do nothing in terms of limiting the possibility for primary (physical) drift. Responsibility must be taken by the applicator to realize situations that would result in off-target movement. Improper boom height, poor nozzle selection, applying when temperature inversions are present, and high winds can lead to substantial off-target movement (Wolf et al., 1992). However, specific guidelines have been listed on approved dicamba product labels that encourage application to DR crops when wind speeds are between 3 and 10 mph and deny application when wind exceeds 15 mph (Anonymous, 2016).

Off-target movement of dicamba to soybean can be highly injurious and direct low-rate exposure has been documented to have deleterious effects (Auch and Arnold, 1978). Exposure of soybean to dicamba during early flowering stages has been documented to cause the greatest amount of yield reduction (Auch and Arnold, 1978; Wax et al., 1969). Furthermore, dicamba exposure in late reproductive stages can cause dicamba-like symptoms to occur in offspring (Thompson and Egli, 1973; Wax et al., 1969). The previous research regarding effects of dicamba on soybean offspring was conducted by making direct applications to parent soybean, rather than attempting to recreate an actual drift event. Furthermore, observations past the V3 stage of soybean have not been made. Therefore, a research experiment was designed to examine the effect actual drift events using commercial applicator guidelines have upon soybean offspring when planted in the field the following season.

Procedures

Drift experiments were conducted in the field in 2014 and 2015 at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NREC) in Keiser, Ark. Sixteen drift trials over the two years were completed at R1, R2, R3, R5, and R6 soybean growth stages (Table 1). A single pass measuring 100 ft by 28 ft. was made using a Bowman Mudmaster (Bowman Manufacturing, Newport, Ark.) traveling at 9.5 mph. Diglycolamine dicamba (Clarity®, BASF, Research Triangle Park, N.C.) was applied at 0.5 lb ae/ac acre^{-1} using AIXR 11003 nozzles (TeeJet Technologies, Springfield, Ill.) delivering 10 gal/ac at 40 psi. At 14 days after application (DAA), fields were grid sampled into 12.6 ft by 20 ft plots that encompassed four rows. Plots extended downwind until no injury was observed. Data collected on parent plants included injury (0 to 100 with 100 being plant death), height (28 DAA and maturity), percent of pods malformed (0 to 100), and yield adjusted to 13% moisture.

Offspring were planted in 2015 and 2016 at the University of Arkansas System Division of Agriculture's Arkansas Agricultural Research and Extension Center (AAREC) in Fayetteville, Ark. Seed were planted in 20-ft plots at 7.5 seed/ft on 36-in. spacing. Initial planting dates were 26 April 2015 and 19 May 2016. In 2015, PRE applied flumioxazin (Valor® SX, Valent Corporation, Walnut Creek, Calif.) resulted in

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unacceptable injury throughout the field which required the trial to be replanted on 25 June. To avoid herbicide injury, no PRE applications were made hereafter and weed control was provided by an application of glufosinate (Liberty®, Bayer CropScience, Research Triangle Park, N.C.) at 0.53 lb ai/ac plus S-metolachlor (Dual Magnum®, Syngenta Corporation, Greensboro, N.C.) at 0.95 lb ai/ac at 21 days after planting and a subsequent application of glufosinate at 0.53 lb ai/ac 14 days later. In 2016, stand loss occurred due to soil crusting and pigeon (*Columba livia*) feeding to the extent that the trial was replanted on 9 June. Measurements on offspring included percent emergence, vigor (1-5), injury at 21 DAP (0 to 100 with 100 being plant death), number of plants malformed (converted to percent of plants emerged that showed malformation), and yield (converted to 13% moisture). Soybean vigor was rated using the following criteria: 1 = extremely low vigor (delayed and/or >60% reduced emergence); 2 = poor vigor (slow growth and 30-60% reduction in emergence); 3 = moderately low vigor (slight reduction in emergence, slowed growth); 4 = moderately high vigor (slight reduction in emergence, normal growth); and 5 = extremely high vigor (quick emergence, rapid growth).

Yield for both parents and offspring was converted to a percent relative to the untreated plots. The untreated within a trial was considered to be the average of five parent plots that observed no injury at 28 DAA. Data were then subjected to multivariate analysis using JMP 12 PRO (SAS Institute, Cary, N.C.) to highlight pairwise correlations between parent and offspring data. Correlations were only considered significant below a *P*-value of 0.01.

Results and Discussion

Regardless of drift event timing, injured offspring were observed. Dicamba-like symptomology occurred in offspring as early as the unifoliate stage and lasted until the second and third trifoliate in some instances. Dicamba-like symptoms in offspring were primarily seen as leaf cupping; however, stunting and malformed growth were also observed.

Dicamba is a phloem-mobile herbicide, meaning that when applied it moves to new areas of growth. Consequently when dicamba drift events occurred during seed fill (R5 and R6), the occurrence of dicamba-like symptomology on offspring was greatest. It is expected that dicamba will move to the seed at the highest concentrations at these times. However, events occurring in early reproductive stages still resulted in some offspring to be malformed; therefore, some dicamba or a metabolite of dicamba must have remained in these plants until seed fill began for dicamba-like symptomology to be observed in the offspring.

Parent and offspring relationships resulting from R5 drift events displayed the highest correlation coefficients (Table 2). Parent percent of pods malformed best predicted offspring emergence, injury, percent of plants injured, and vigor. Therefore, it is likely that a high number of mature pods malformed after an actual drift event will convey possible damage to soybean offspring. If such fields are in soybean seed production, this research suggests that offspring should be grown out to examine possible emergence or vigor issues before distributing to growers the following year.

When drift events were established at R6, 28 DAA measurements were not made due to the crop already reaching maturity. Significant correlations with offspring variables only existed with parent yield (Table 3). Likely because this was the only factor with the capacity to be affected so late in the season as seed fill was terminated when ample dicamba exposure occurred. At R6, plants were very near mature height and only reduced by 11% after drift exposure (data not shown). Furthermore, pod formation was completed in all but the uppermost node as percent of malformed pods ranged from 0 to 1% (data not shown). It is possible that dicamba drift to R6 soybean would go unnoticed as visual symptoms are not evident. Therefore, if such fields are under seed production, seed could be distributed to growers the following year where damage to offspring would be realized. In extreme circumstances, the damage could be mistaken for soil carryover or recent dicamba drift, tempting growers to place blame on neighbors.

Practical Applications

With supplemental labeling of dicamba in DR soybean, use will likely rise. Previously, dicamba use was primarily centered on early spring applications to corn or as a burndown. In 2017, growers will be able to make applications as late as R1 growth stage in DR crops. Application of dicamba to DR crops will now occur when neighboring non-DR soybean is in reproductive stages. This research demonstrates that actual drift events to non-DR soybean during reproductive stages can result in offspring that is malformed and reduced in vigor or emergence. The use of dicamba in DR crops will undoubtedly aid in control of glyphosate resistant weeds such as giant ragweed (*Ambrosia trifida* L.) and horseweed (*Conyza canadensis* L. Cronq.); however, precautions must be taken to limit off-target movement.

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Table 1. Year, trial, variety, growth stage at time of drift event, and number of observations in parent drift trials.

Year	Trial	Variety	Growth stage	Observations
2014	14-1	Progeny 4819	R1	88
2014	14-2	Halo 494	R1	84
2014	14-3	Halo 494	R1	76
2014	14-4	Halo 494	R1	104
2014	14-5	HBK 4850	R1	54
2014	14-6	HBK 4850	R1	65
2014	14-7	Progeny 4819	R3	65
2014	14-8	Progeny 4819	R3	57
2015	15-1	Delta Grow 4767	R3	63
2015	15-2	Delta Grow 4767	R3	50
2015	15-3	Credenz 4950	R2	188
2015	15-4	Credenz 4950	R2	132
2015	15-5	Progeny 4814	R5	52
2015	15-6	Credenz 4950	R6	15
2015	15-7	Credenz 4950	R6	15
2015	15-8	Progeny 4814	R6	21

Table 2. Correlation coefficients between parent and offspring variables at growth stage R5.

	Offspring variables				
Parent variables	Emergence	Vigor	Injury	Plants Injured	Relative Yield
	-------%------		---------------------------%---------------------------------		
Injury (%)	-0.2305	-0.4096*	0.7409*	0.7225*	-0.2197
Relative height at 28 DAA[a] (%)	-0.2717	-0.2635	0.3925*	0.3800*	-0.0791
Relative mature height (%)	0.1073	0.0490	-0.0899	-0.0913	-0.0933
Mature pods malformed (% of total)	-0.3698*	-0.5673*	0.9282*	0.9187*	-0.3393
Relative yield (%)	0.0062	-0.0878	0.1266	0.1274	0.0246

* Indicates significance to α = 0.01.

[a] Days after application.

Table 3. Correlation coefficients between parent and offspring variables at growth stage R6.

	Offspring variables				
Parent variables	Emergence	Vigor	Injury	Plants Injured	Relative Yield
	-----%-----		------------------------%--------------------------		
Injury (%)	-	-	-	-	-
Relative height at 28 DAA[a] (%)	-	-	-	-	-
Relative mature height (%)	0.1753	0.1834	-0.2281	-0.2094	0.3093
Mature pods malformed (% of total)	0.1778	-0.3523	0.3345	0.3150	0.0299
Relative yield (%)	0.1455	0.4096*	-0.4302*	-0.4929*	0.0923

* Indicates significance to α = 0.01.

[a] Days after application.

Residual Activity of Thiencarbazone-Methyl Compared to Common Residual Herbicides in Soybean

Z.D. Lancaster[1], J.K. Norsworthy[1], L.T. Barber[2], and R.C. Scott[2]

Abstract

With the spread of herbicide resistance across the mid-South, growers are increasingly relying on residual herbicides to achieve season long weed control. New options are needed to effectively rotate herbicide mode of action, and slow the development of additional herbicide resistance. Bayer CropScience (Research Triangle Park, N.C.) is currently evaluating thiencarbazone-methyl (TCM), an acetolactate synthase-inhibiting (ALS) herbicide, which could provide pre-emergence and post-emergence activity on many troublesome mid-South weeds in soybean. A field experiment was conducted at the University of Arkansas System Division of Agriculture's Agricultural Research and Extension Center in Fayetteville, Arkansas to determine the residual activity of TCM compared to several common residual herbicides. The experiment was set up as a two-factor factorial, randomized complete block design, with the factor-A being TCM rate and factor-B being tank-mix partner. The TCM rates evaluated were 0, 0.03, and 0.06 lb ai/ac alone and tank mixed with labeled rates of Dual Magnum®, Valor®, Zidua®, Tricor®, and Balance®. Data were collected on visual control of Palmer amaranth *(Amaranthus palmeri)*, entireleaf morningglory *(Ipomoea hederacea)*, and broadleaf signalgrass *(Urochloa platyphylla)*. Overall, TCM provided excellent control of broadleaf signalgrass with 94% and 97% respectively for 0.03 and 0.06 lb ai/ac at 42 days after treatment (DAT). Control of the native ALS-resistant Palmer amaranth population was only 69% with 0.06 lb ai/ac of TCM at 42 DAT. However, the addition of TCM to the labeled rate of Tricor and Balance resulted in a significant increase in Palmer amaranth control. Likewise, the addition of TCM to Dual Magnum, Zidua, Tricor, and Balance increased entireleaf morningglory control compared to those residual herbicides alone. This research shows that TCM alone provides excellent residual weed control of broadleaf signalgrass and entireleaf morningglory, with some added Palmer amaranth control (48%–69%). Furthermore, the addition of TCM increases the spectrum of activity and length of residual control for many common residual herbicides.

Introduction

Soybean is one of the most important crops grown in Arkansas, with 3.1 million acres harvested in 2016 (USDA-NASS, 2016). One of the main problems faced by producers today is weed control, especially the control of herbicide-resistant weeds (Norsworthy et al., 2012). Use of overlapping residual herbicides is an integral management practice to lower selection pressure on post-emergence herbicides and to reduce the risk of herbicide resistance. However, additional residual herbicides are needed to allow for proper rotation of herbicide mode of action. Bayer CropScience (Research Triangle Park, N.C.) is currently evaluating Thiencarbazone-methyl for both post-emergence and pre-emergence applications in soybean. Thiencarbazone-methyl (TCM) is an acetolactate synthase-inhibiting (ALS) herbicide from the Triazolinone family. Research has shown TCM to have activity on both annual and perennial grasses and broadleaf weeds, along with a half-life of 17–44.5 days for prolonged residual weed control (Anonymous, 2010). Thiencarbazone-methyl is currently labeled for use in corn and is applied as part of a premix herbicide (Corvus™) with usage rates up to 0.032 lb ai/ac (Anonymous, 2016). Currently, research is being conducted to evaluate the effectiveness of both pre-emergence and post-emergence applications of TCM in Arkansas soybean production systems. The objective of this experiment was to determine the residual activity of pre-emergence applications of TCM compared to common residual herbicides used in soybean production.

Procedures

An experiment was conducted in 2015 at the University of Arkansas System Division of Agriculture's Agricultural Research and Extension Center in Fayetteville, Ark. to determine the activity of TCM with, and without, other residual herbicides common to soybean production. The experiment was set up as a two-factor factorial, randomized complete block design with factor-A being rate of TCM and factor-B being tank-mix partner (Table 1). Tank mix partners were applied at labeled rates (Scott et al., 2016). The experiment was conducted as a bare ground experiment with a natural population of weeds. Plots 7 ft. by 20 ft. were established on a freshly tilled leaf silt loam soil. Herbicide treatments were applied pre-emergence using a CO_2 backpack sprayer calibrated to deliver a constant carrier volume of 15 gal/ac at 40 PSI. Visual weed control rating were taken on Palmer amaranth (*Amaranthus palmeri*), entireleaf morningglory (*Ipomoea hederacea*), and broadleaf signalgrass (*Urochloa platyphylla*) at 14, 28, 42, and 56 days after treatment (DAT).

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Data were analyzed using JMP Pro v. 12.1 (SAS Institute, Inc., Cary N.C.) using PROC MIXED procedure. For data that met the assumptions of analysis of variance (ANOVA), means were separated using Fisher's protected least significant difference LSD (α = 0.05).

Results and Discussion

Alone, TCM only provides low levels of Palmer amaranth control with 0.03 and 0.06 lb ai/ac (48%–70%, respectively; Table 2) at 42 DAT. However, the addition of TCM increased Palmer amaranth control for Tricor and Balance herbicides to >95% for either rate of TCM. These results were similar to previous research which showed a premix of TCM and isoxaflutole (Balance®) to control Palmer amaranth >90% 28 DAT (Stephenson and Bond, 2012). Thiencarbazone-methyl produced effective entireleaf morningglory control at both rates alone (>90%; Table 2). Likewise, the addition of TCM increased entireleaf morningglory control for Dual Magnum®, Zidua®, Tricor®, and Balance® from <78% to >95%, regardless of TCM rate. For broadleaf signalgrass, TCM provides excellent residual control (>93%), and the addition of TCM increased broadleaf signalgrass control for Valor®, Tricor, and Balance to >95% (Table 2).

Practical Applications

Overall, the addition of TCM improved the spectrum and length of control for many residual herbicides evaluated. Alone, TCM provides excellent control of broadleaf signalgrass and entireleaf morningglory (> 95%), even at a late rating timing of 42 DAT. On a historically ALS-resistant Palmer amaranth population, TCM alone cannot be relied upon for effective residual control. However, the addition of TCM increased control of Palmer amaranth, entireleaf morningglory, and broadleaf signalgrass for many residual herbicides. This supports that TCM appears to have value as a tank-mix partner for multiple common residual herbicides utilized in soybean production in Arkansas. Further research is needed determine the fit and safety of TCM for Arkansas soybean production; however, results from this experiment as well as others are promising.

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Table 1. Rate of TCM[a] and residual herbicide tank-mix partner applied at the University of Arkansas System Division of Agriculture's Agricultural Research and Extension Center Fayetteville, Ark

TCM Rate	Tank-Mix Partner	Tank-Mix Partner Rate
lb ai/ac		lb ai/ac
0	No herbicide	0
0.03	Dual Magnum® (S-metolachlor)	0.95
0.06	Zidua® (pyroxasulfone)	0.13
	Valor® (flumioxazin)	0.06
	Tricor® (metribuzin)	0.38
	Balance® (isoxaflutole)	0.09

[a] TCM = thiencarbazone-methyl

Table 2. Effect of TCM[a] rate and tank-mix partner on control of Palmer amaranth, entireleaf morningglory, and broadleaf signalgrass at 42 DAT

TCM Rate	Tank-Mix Partner	AMAPA	IPOHE	BRAPP
lb ai/ac		--------------% Control--------------		
0	None	0	0	0
	Dual Magnum®	96 ab	75 c	96 a
	Zidua®	89 bc	78 c	97 a
	Valor®	93 abc	90 ab	50 b
	Tricor®	84 c	73 c	53 b
	Balance®	69 d	75 c	51 b
0.03	None	48 e	90 ab	94 a
	Dual Magnum	93 abc	94 ab	100 a
	Zidua	100 a	97 ab	100 a
	Valor	98 a	100 a	98 a
	Tricor	95 ab	97 ab	96 a
	Balance	98 a	98 a	99 a
0.06	None	69 d	95 ab	97 a
	Dual Magnum	97 ab	100 a	99 a
	Zidua	100 a	100 a	99 a
	Valor	99 a	100 a	98 a
	Tricor	96 ab	99 a	96 a
	Balance	97 ab	100 a	98 a

[a] TCM = thiencarbazone-methyl, DAT = days after treatment, AMAPA = Palmer amaranth, IPOHE = entireleaf morningglory, BRAPP = broadleaf signalgrass.

Overcoming Antagonism in Tank-mixtures of Glufosinate + Glyphosate and Glufosinate + Clethodim on Grasses

C.J. Meyer[1] and J.K. Norsworthy[1]

Abstract

Proper management of glufosinate and the LibertyLink® and emerging technologies such as the Enlist™ system is needed to mitigate the likelihood of resistance evolution. An experiment was conducted at the University of Arkansas System Division of Agriculture's Agricultural Experiment Station Fayetteville, Ark. in 2015 and 2016 to evaluate tank-mixtures of glufosinate + clethodim and glufosinate + glyphosate for antagonism using Colby's method. When a low rate of glyphosate (Roundup PowerMax® at 22 fl oz/ac) was applied with glufosinate (Liberty® at 22 fl oz/ac), antagonism was identified for control of barnyardgrass. Increasing the rate of glyphosate to 44 fl oz/ac in mixture mitigated the antagonism for barnyardgrass control. Antagonism was present for all tank-mixtures (glufosinate + clethodim and glufosinate + glyphosate) for control of large crabgrass. Therefore, antagonism was identified for both glufosinate + glyphosate mixtures and glufosinate + clethodim mixtures; however, the instances of antagonism were both dependent upon the rates used and the grass weed species in question. Overall, the least instances of antagonism and highest control of all species occurred when the highest rates of both herbicides in a given mixture was used.

Introduction

Glufosinate can be applied post-emergence in crops with a glufosinate-resistance trait, including LibertyLink® soybean (*Glycine max* [L.] Merr.) and the soon-to-be commercialized Enlist® soybean. Glufosinate will control a broad spectrum of grass and broadleaf weeds; although single-applications of glufosinate are not always enough to control emerged grasses. A detailed investigation on the performance of glufosinate in tank-mixtures on common, hard-to-control grass weeds in the mid-South is needed.

Specific tank-mixtures containing glufosinate have been reported as antagonistic, meaning the benefit of applying two effective sites of action may not provide the control that would be expected. Tank-mix interactions (i.e., antagonism) are often evaluated using Colby's method (Colby, 1967). Prior research has identified antagonism between glufosinate and clethodim (Gardner et al., 2006) and glufosinate and glyphosate (Bethke et al., 2013). However, identification of antagonism may be dependent upon the species and specific mixtures evaluated (Eytcheson and Reynolds, 2015). Herbicide recommendations resulting in antagonism between two herbicides are not an effective resistance management strategy (Norsworthy et al., 2012).

As the interactions between glufosinate, glyphosate and clethodim are not well-documented on barnyardgrass and other common grass weeds in the mid-South, a more thorough investigation is needed to determine if antagonism is occurring with these applications. The objectives of these experiments were to: 1) identify interactions between glufosinate, glyphosate and clethodim for mitigating antagonism on annual grasses common to the mid-South; 2) determine if increasing the rate of herbicides in mixture mitigates antagonism; and 3) determine if instances of antagonism vary by the grass species evaluated.

Procedures

An experiment was conducted at the University of Arkansas System Division of Agriculture's Agricultural Experiment Station in Fayetteville, Ark. on a Leaf silt loam. Plot sizes were 8 ft by 30 ft and the entire experimental area was disked and field cultivated prior to planting. At the time of trial establishment, johnsongrass, barnyardgrass, broadleaf signalgrass, and large crabgrass seed were sown across the trial area. Planting occurred 24 June 2015 and 9 June 2016.

Various rates of glufosinate (Liberty® herbicide, Bayer CropScience, Research Triangle Park, N.C.) were applied alone and in combination with various rates of clethodim (Select Max® herbicide, Syngenta Crop Protection LLC., Greensboro, N.C.) or glyphosate (Roundup PowerMax II® herbicide, Monsanto Company, St. Louis, Mo.). A nontreated check was included for comparison. For a complete list of treatments, refer to Table 1. Treatments containing clethodim included 1.0% volume-to-volume (v/v) of Agridex® (Helena Chemical Company, Collierville, Tenn.), a crop oil concentrate (COC). Following application of the herbicide treatments, all plots received an application of S-metolachlor within 24 h. Treatments were applied at 9:00 A.M. on 24 July 2015, and 8:00 A.M. on 7 July 2016.

Weed control ratings and biomass were collected 4 weeks after treatment (WAT) for all treatments. Weed control was visually evaluated on a scale of 0 (no control) to 100% (complete death of all plants) relative to the nontreated check. Weed biomass was collected by species within 3 days (d) of the final assessment, dried at 40 °C for 7 d and weighed

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to determine dry biomass relative to the non-treated check. All data were subject to an analysis of variance (ANOVA) using JMP 12 (SAS Institute Inc., Cary, N.C.), and means were separated using Fisher's protected least significant difference (LSD) test ($\alpha = 0.05$).

Tank-mix interactions were identified using Colby's method (Colby 1967), where an Expected value (E) is calculated using Eq. 1.

$$E = (X + Y) - (XY)/100 \qquad \textbf{Eq. 1}$$

Where E is the expected level of control of a given species when two herbicides are applied in a tank-mix, and variables X and Y represent the level of control of a given weed species provided by each herbicide applied individually. The observed and expected values were compared using a two-sided t-test ($\alpha = 0.05$). If E was significantly greater than the observed value for a given tank-mix, the tank-mix was determined to be antagonistic.

Results and Discussion

Barnyardgrass Control. Antagonism was identified for glufosinate + glyphosate (22 + 22 fl oz/ac) for control 4 WAT, and for barnyardgrass biomass (Table 1). No differences in control were observed for all mixtures of glufosinate + clethodim and glufosinate + glyphosate at 4 WAT, or for biomass reduction. Even though almost all treatments of glufosinate + clethodim provided >90% control 4 WAT, the results from Colby's method demonstrates that the mixture of these two herbicides is not performing as well as it should.

Broadleaf Signalgrass Control. Antagonism was not identified for any tank-mixtures of glufosinate + clethodim for broadleaf signalgrass (Table 2). Detection of antagonism for mixtures of glufosinate + glyphosate depended upon the rating and rates used. Glufosinate + glyphosate (22 + 22 fl oz/ac) was antagonistic at 4 WAT and for broadleaf signalgrass biomass. The only rate structure that did not exhibit antagonism for control was glufosinate at 29 + glyphosate at 44 fl oz/ac, indicating increasing the use rate of either herbicide, but especially glyphosate, may be beneficial toward mitigating observed antagonism.

Seedling Johnsongrass Control. Antagonism was identified for biomass when the high rate of glufosinate (29 fl oz/ac) was applied with both rates of clethodim and both rates of glyphosate. No significant antagonism occurred for the tank-mixtures with the low rates of glufosinate (Table 3), further indicating glufosinate is antagonizing the activity of both systemic herbicides. The only tank-mixture that provided significantly less johnsongrass control 4 WAT than any of the other tank-mixtures was glufosinate at 29 fl oz/ac + clethodim at 9 fl oz/ac. Glyphosate-alone provided 100% control of johnsongrass at both rates and all tank-mixtures of glufosinate + glyphosate provided ≥99% control both 4 WAT suggesting tank-mixtures of glufosinate + glyphosate may be superior to glufosinate + clethodim on glyphosate-susceptible johnsongrass.

Large Crabgrass Control. All tank-mixtures were considered antagonistic 4 WAT (Table 4). Of those tank-mixtures, all were antagonistic for biomass except for glufosinate at 22 fl oz/ac + glyphosate 44 fl oz/ac and glufosinate at 29 fl oz/ac + glyphosate 44 fl oz/ac. All tank-mixtures of glufosinate + glyphosate provided greater control than tank-mixtures of glufosinate + clethodim with the exception of glufosinate at 29 fl oz/ac + clethodim at 16 fl oz/ac. Thus, it appears tank-mixtures of glufosinate + glyphosate tend to provide consistently higher levels of large crabgrass control, despite antagonism, than mixtures of glufosinate + clethodim.

Practical Applications

Antagonism was observed for both mixtures of glufosinate + glyphosate and glufosinate + clethodim. Identification of antagonism was dependent upon the rate and species evaluated for glufosinate + glyphosate and glufosinate + clethodim mixtures. Increasing the rate of either herbicide in mixture increases control and decreases the likelihood of identifying antagonism using Colby's method. For control of barnyardgrass, broadleaf signalgrass, seedling johnsongrass, and large crabgrass, the optimum tank-mixture depends on the trait technology used: in a LibertyLink Soybean system, apply glufosinate at 22 fl oz/ac with clethodim at 16 fl oz/ac. If the technology allows the use of mixtures of glufosinate + glyphosate, (i.e. the Enlist system) apply 29 + 44 fl oz/ac.

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Table 1. Effect of glufosinate alone and in combinations with glyphosate or clethodim on observed and expected control and aboveground biomass of barnyardgrass.†

		4 WAT				Biomass‡			
Common name	**Rate**	**Obs**		**Exp**	***P*§**	**Obs**		**Exp**	***P***
	Fl oz/ac	--------%--------				--------%--------			
Nontreated						100.0	a		
Glufosinate	22	94	a			18.6	b		
Glufosinate	29	97	a			7.0	bcd		
Glyphosate	22	99	a			4.0	cd		
Glyphosate	44	99	a			0.0	d		
Clethodim	9	75	b			16.1	bc		
Clethodim	16	95	a			6.8	bcd		
Glufosinate + glyphosate	22 + 22	97	a	99	*	10.0	bcd	1.3	*
Glufosinate + glyphosate	22 + 44	97	a	100	NS	9.3	bcd	0.0	NS
Glufosinate + glyphosate	29 + 22	97	a	100	*	1.9	d	0.1	NS
Glufosinate + glyphosate	29 + 44	99	a	100	NS	5.5	cd	0.0	NS
Glufosinate + clethodim	22 + 9	95	a	98	NS	4.1	cd	1.4	NS
Glufosinate + clethodim	22 + 16	97	a	99	NS	0.6	d	1.0	NS
Glufosinate + clethodim	29 + 9	95	a	99	NS	0.7	d	0.3	NS
Glufosinate + clethodim	29 + 16	98	a	100	NS	0.1	d	0.0	NS

† Abbreviation: Obs, observed value; E, expected value; NS, not significant; WAT, weeks after treatment.
‡ Biomass is expressed as a percent of the nontreated control.
§ *, **, and *** denote significant antagonism at 0.05, 0.01, and 0.0001 level of significance, respectively, based on a two-sided *t*-test between observed and expected values. Expected values are based on Colby's equation [$E = (X + Y) - (XY)/100$].

Table 2. Effect of glufosinate alone and in combinations with glyphosate or clethodim on observed and expected control and aboveground biomass of broadleaf signalgrass.†

		4 WAT				Biomass‡			
Common name	**Rate**	**Obs**		**Exp**	***P*§**	**Obs**		**Exp**	***P***
	Fl oz/ac	**--------%--------**				**--------%--------**			
Nontreated						100.0	a		
Glufosinate	22	89	f			6.8	bcde		
Glufosinate	29	91	def			3.6	cde		
Glyphosate	22	99	a			2.9	e		
Glyphosate	44	100	a			3.0	e		
Clethodim	9	59	g			38.9	bc		
Clethodim	16	92	cdef			7.2	cde		
Glufosinate + glyphosate	22 + 22	95	abc	100	*	19.6	bcd	0.3	*
Glufosinate + glyphosate	22 + 44	97	ab	100	*	4.5	e	0.2	NS
Glufosinate + glyphosate	29 + 22	96	abcd	100	*	8.6	cde	0.2	NS
Glufosinate + glyphosate	29 + 44	97	ab	100	NS	13.5	bcde	0.2	NS
Glufosinate + clethodim	22 + 9	96	abcd	95	NS	17.9	b	3.3	NS
Glufosinate + clethodim	22 + 16	93	bcde	99	NS	12.2	de	0.4	NS
Glufosinate + clethodim	29 + 9	94	bcde	96	NS	6.4	e	1.8	NS
Glufosinate + clethodim	29 + 16	96	abcd	99	NS	9.6	cde	0.4	NS

† Abbreviation: Obs, observed value; E, expected value; NS, not significant; WAT, weeks after treatment.
‡ Biomass is expressed as a percent of the nontreated control.
§ *, **, and *** denote significant antagonism at 0.05, 0.01, and 0.0001 level of significance, respectively, based on a two-sided *t*-test between observed and expected values. Expected values are based on Colby's equation [$E = (X + Y) - (XY)/100$].

Table 3. Effect of glufosinate alone and in combinations with glyphosate or clethodim on observed and expected control and aboveground biomass of johnsongrass.†

		4 WAT				Biomass‡			
Common name	**Rate**	**Obs**		**Exp**	***P*§**	**Obs**		**Exp**	***P***
	Fl oz/ac	**--------%--------**				**--------%--------**			
Nontreated						100.0	a		
Glufosinate	22	73	d			22.1	b		
Glufosinate	29	88	c			4.5	cd		
Glyphosate	22	100	a			0.8	d		
Glyphosate	44	100	a			0.0	d		
Clethodim	9	65	e			18.0	b		
Clethodim	16	89	c			3.7	cd		
Glufosinate + glyphosate	22 + 22	99	a	100	NS	2.7	cd	0.1	NS
Glufosinate + glyphosate	22 + 44	99	a	100	NS	3.0	cd	0.0	NS
Glufosinate + glyphosate	29 + 22	99	a	100	NS	1.1	d	0.0	*
Glufosinate + glyphosate	29 + 44	99	a	100	NS	0.7	d	0.0	*
Glufosinate + clethodim	22 + 9	92	ab	90	NS	3.9	cd	5.1	NS
Glufosinate + clethodim	22 + 16	95	ab	96	NS	2.9	cd	0.1	NS
Glufosinate + clethodim	29 + 9	92	bc	94	NS	7.4	c	0.9	***
Glufosinate + clethodim	29 + 16	95	abc	98	NS	4.1	cd	0.1	**

† Abbreviation: Obs, observed value; E, expected value; NS, not significant; WAT, weeks after treatment.
‡ Biomass is expressed as a percent of the nontreated control.
§ *, **, and *** denote significant antagonism at 0.05, 0.01, and 0.0001 level of significance, respectively, based on a two-sided *t*-test between observed and expected values. Expected values are based on Colby's equation [$E = (X + Y) - (XY)/100$].

Table 4. Effect of glufosinate alone and in combinations with glyphosate or clethodim on observed and expected control and aboveground biomass of large crabgrass.†

		4 WAT				Biomass‡			
Common name	**Rate**	**Obs**		**Exp**	***P*§**	**Obs**		**Exp**	***P***
	Fl oz/ac	**-------%-------**				**-------%-------**			
Nontreated						100.0	a		
Glufosinate	22	83	g			12.4	def		
Glufosinate	29	89	def			13.9	def		
Glyphosate	22	98	ab			2.7	fg		
Glyphosate	44	100	a			0.0	g		
Clethodim	9	59	h			10.4	defg		
Clethodim	16	97	abc			2.4	fg		
Glufosinate + glyphosate	22 + 22	95	abcd	100	**	5.7	efg	0.3	*
Glufosinate + glyphosate	22 + 44	98	abc	100	*	3.7	fg	0.0	NS
Glufosinate + glyphosate	29 + 22	95	abcd	100	**	10.0	defg	0.6	**
Glufosinate + glyphosate	29 + 44	97	abc	100	*	3.7	fg	0.0	NS
Glufosinate + clethodim	22 + 9	84	fg	93	*	19.3	cd	0.1	**
Glufosinate + clethodim	22 + 16	87	efg	100	*	30.8	b	0.2	**
Glufosinate + clethodim	29 + 9	84	fg	96	**	26.3	bc	1.7	*
Glufosinate + clethodim	29 + 16	90	cdefg	100	**	19.7	bcde	0.1	**

† Abbreviation: Obs, observed value; E, expected value; NS, not significant; WAT, weeks after treatment.
‡ Biomass is expressed as a percent of the nontreated control.
§ *, **, and *** denote significant antagonism at 0.05, 0.01, and 0.0001 level of significance, respectively, based on a two-sided *t*-test between observed and expected values. Expected values are based on Colby's equation [$E = (X + Y) - (XY)/100$].

Utilization of the Integrated Harrington Seed Destructor on Weeds Commonly Found in Soybean Production

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Abstract

Herbicide-resistant weeds are affecting every major cropping system today. Alternatives to herbicides are necessary to help combat herbicide-resistant weeds and sustain farming practices, regardless of cropping system. The integrated Harrington Seed Destructor (iHSD) has been developed to destroy weed seeds during crop harvest, but has not been tested in soybean on weeds common to these crops in the southern United States. Thus, the objective of this research was to determine the effectiveness of the iHSD on common weed species in southern soybean. An experiment was conducted using a stationary iHSD mill to determine the efficacy of the iHSD on weed seeds individually incorporated into a known amount of soybean chaff. The iHSD demonstrated high weed seed destruction efficacy (<1% survival) for 11 of the 12 weed species. Common cocklebur seeds had 3% survival and was the only species that had >1% survival rate. Results show that the use of the iHSD can be highly effective in soybean production for reducing weed seed inputs to the soil seedbank. This study highlights the need for further research evaluating the iHSD as a combine-fitted system operating under commercial scale production fields as well as determining any potential limitations associated with the iHSD.

Introduction

Herbicide resistance is a major constraint to crop production worldwide. Currently, there are 477 unique cases of herbicide-resistant weed species confirmed worldwide (Heap 2017), and many of these biotypes have emerged to dominate (i.e., "driver weeds") agricultural production systems. Similar to many other places, herbicide-resistant weeds have become prevalent in southern soybean (*Glycine max* L. Merr.) and rice (*Oryza sativa* L.) production systems (Riar et al. 2013; Heap 2017). There is a high frequency of herbicide resistance in the weed species infesting both rice and soybean production systems. Weeds that escape control are likely to be mature at the time of crop harvest and the erect seed heads will likely enter the combine harvester (Walsh et al. 2013; Schwartz et al., 2016b). Harvested weed seeds are mostly expelled from the rear of the combine, resulting in their dispersal across the field as additions to the soil seedbank, a process that increases the risk of herbicide resistance evolution.

Alternatives to herbicides are necessary to help combat herbicide-resistant weeds and ensure the sustainability of cropping systems. Harvest-time weed seed control (HWSC) tactics incorporate mechanical and cultural management strategies to target weed seeds present at harvest (Walsh and Powles, 2007). There are three main HWSC options: narrow-windrow burning, chaff removal (using chaff carts), and mechanical seed destruction [e.g. Harrington Seed Destructor (HSD)] (Schwartz et al., 2016a; Walsh et al., 2013; Walsh and Newman, 2007). An integrated HSD system (iHSD) has been recently developed by de Bruin Engineering that is designed to fit within the rear of the combine, instead of a tow-behind mechanism (Lee, 2012). The iHSD has never been tested on weeds common to soybean production systems in the southern U.S. Thus, the objective was to determine the effectiveness of the iHSD on some major weeds of soybean.

Procedures

Chaff, which encompassed all material exiting the combine from the upper and lower sieves (chaff material exits the harvester from the sieves, straw material exits from the rotors that are above these sieves), was collected from a commercial soybean production field at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NREC) at Keiser, Arkansas in October 2016. The chaff was collected in a chaff cart and placed under a covered shelter until it was used for testing. Given the small amount of harvest residue (chaff and straw fractions) produced during soybean harvest, it was decided to use both the chaff and straw fractions. The moisture content of the chaff at the time of testing the iHSD was 14.8%. Estimates of the amount of soybean chaff sample sizes for processing was based on the average crop yields, harvest index, and operational capacity of a Class 9 combine in soybean production. It was assumed that a soybean field would produce a seed yield of 60 bu/ac at a harvest index of 55% and could process 30,000 lbs or 500 bu/h. Thus, to be equivalent to the same amount of chaff that a Class 9 combine could process, 4.4 lbs/s of soybean chaff (both top and bottom sieve fractions) would need to be fed through the iHSD.

Seeds of prominent weed species in soybean production in the mid-southern U.S. were selected. Twelve weed species were processed: Palmer amaranth, morningglory species (mixture of pitted morningglory and entireleaf morningglory), common cocklebur (*Xanthium strumarium* L.), johnsongrass (*Sorghum halepense* (L.) Pers.), barnyardgrass (*Echinochloa crus-galli* (L.) P. Beauv.), hemp sesbania (*Ses-*

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bania herbacea (Mill.) McVaugh), prickly sida (*Sida spinosa* L.), velvetleaf, sicklepod (*Senna obtusifolia* (L.) H.S.Irwin & Barneby), giant ragweed (*Ambrosia trifida* L.), common lambsquarters (*Chenopodium album* L.), and weedy rice (*Oryza sativa* L.). A sample size of 500 seed/treatment was used for all seed except for common cocklebur for which only 200 burs (2 seeds/bur) were included per sample. There were eight replications.

The processed material was brought to the Weed Science laboratory at the University of Arkansas System Division of Agriculture's Arkansas Agricultural Experiment Station in Fayetteville, Ark. where the replicates were hand sieved to remove large debris, while keeping all weed seeds within the processed material. Prior to the estimation of weed seed destruction in the samples, preliminary experiments were conducted to standardize a seed germination methodology (data not shown).

The number of emerged seedlings was recorded and presented as a percentage of the unprocessed control seed samples to estimate seed mortality caused by the iHSD. All data were analyzed individually using one-way analysis of variance (ANOVA), with mean separations based on Fisher's LSD values ($\alpha = 0.05$). Statistical tests were conducted using SAS 9.1 (SAS Institute Inc., Cary, N.C.).

Results and Discussion

The various weed species tested in soybean ranged in seed size, weight, and density (Table 1) and included both broadleaf and grass species. The iHSD effectively destroyed large-seeded weed species, such as morningglory and cocklebur, as well as small-seeded species such as Palmer amaranth. Common cocklebur showed 97.5% germination reduction in soybean chaff. Furthermore, this species had the greatest seed weight and the lowest density of all species (Table 1). The low density and the lightweight of common cocklebur appeared to allow the seeds to make it through the mill more readily than other weed species. Weed seed destruction ranged from 97.5% to 100% for all species. Thus, we conclude that the efficacy of the iHSD is not limited by seed size, whether small or large. Furthermore, no significant differences in seed mortality among weed species was found. However, further research is needed to test the iHSD mounted in a combine across various cropping systems and environments.

Practical Applications

The iHSD is a new weed control tool that has great potential for utility in various cropping systems and has the potential to help improve weed management. The effectiveness of the iHSD allows for a high proportion of weed seeds to be destroyed at harvest, which subsequently will help to lower the amount of weed seed in the seedbank. The iHSD has shown to be highly effective in Australian wheat cropping systems, and this experiment using the stationary unit has shown insight to the utility of the iHSD in soybean cropping systems of the mid-southern U.S. Further research needs to be conducted in additional cropping systems from a production standpoint to determine the threshold of the fully iHSD system.

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Table 1. Efficacy of Integrated Harrington Seed Destructor on various weed species. The seed weight and density of each weed species was conducted on unprocessed seeds. The percent of destroyed seeds was corrected for by the control.

Weed Species	Seed size (mm)[a]	Control	Treatment	Seed weight (g)	Density (g/cm^3)
		% emergence[b]	% destroyed[c]	-------- 100 seeds --------	
Barnyardgrass	1.57	85.7	0.2	0.18	0.26
Common cocklebur	7.58	87.5	2.5	15.6	0.21
Giant ragweed	2.07	68.9	0	0.22	0.08
Hemp sesbania	2.21	96	0	1.61	0.56
Johnsongrass[d]	1.79	88.4	0.1	0.41	0.32
Common lambsquarters	1.17	90.6	0	0.08	0.8
Morningglory	3.79	87.4	0	2.8	1.39
Palmer amaranth	1.01	98.1	0	0.07	1.68
Prickly sida	1.82	70	0	0.14	0.28
Weedy rice	2.51	72.4	0	1.3	0.54
Sickelpod	2.54	82.1	0.1	1.9	0.49
Velvetleaf	2.94	90.6	0	0.98	0.89

[a] Average seed width measured with Vernier calipers.
[b] Nonprocessed seed grown in a 1:1 v/v mixture of potting mix to soybean chaff.
[c] Percent destroyed is corrected relative to the % emergence that occurred in the control (nonprocessed) samples.

Evaluating CruiserMaxx® and NipsIT INSIDE® as Safeners Against Herbicide Drift in Soybean

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Abstract

Recent research has shown that the insecticide component of CruiserMaxx® (thiamethoxam) can serve as a herbicide safener in rice following exposure to drift events of the herbicides Roundup® (glyphosate) and Newpath® (imazethapyr). Field trials were conducted at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, in Marianna Arkansas in 2015, and repeated in 2016 at Marianna, in addition to at the Northeast Research and Extension Center, in Keiser, Arkansas, and at the Pine Tree Research Station, near Colt, Arkansas, in order to examine if a similar safening effect could be seen in soybean. CruiserMaxx® and NipsIT INSIDE® (clothianidin) insecticide seed treatments were applied to seeds prior to planting, in combination with eight herbicides that pose threats to soybean crops via drift. These herbicides included Roundup®, Liberty® (glufosinate), Clarity® (dicamba), Weedar® (2,4-D), Permit® (halosulfuron), Callisto® (mesotrione), Laudis® (tembotrione), and Stam® (propanil). Results from these trials showed that all herbicides, except for Stam were safened in at least one of four site years with an insecticide seed treatment. Permit was the most effectively safened herbicide, with injury reduction seen at three of the four site years evaluated. In the case of Permit, both CruiserMaxx and NipsIT INSIDE reduced injury over 30%, 2 weeks after application, which resulted in increased crop height and an increase in yield in the plot treated with NipsIT INSIDE. The degree of safening seen was highly variable between research sites, indicating a strong environmental effect on its effectiveness.

Introduction

Recent research published by the University of Arkansas System Division of Agriculture showed that injury to conventional rice varieties from drift rates of Roundup® and Newpath® could effectively be reduced by treating seeds with the insecticide/fungicide CruiserMaxx® (thiamethoxam) prior to planting (Miller et al., 2016). This incidence of safening presents a form of insurance to growers that plant treated varieties in close proximity to both Roundup Ready® soybean and Clearfield® rice, which is common in the state of Arkansas. Based on the success of insecticide seed treatments being used to reduce herbicide damage in rice, examining similar occurrences in other crops is of great interest. As the largest acreage agronomic crop in Arkansas, reducing injury in soybean using insecticide seed treatments could provide widespread grower benefits. Presently there are relatively few instances of effective safeners in soybean (Davies and Caseley, 1999). Thus, the use of insecticide seed treatments as a means of reducing crop injury from off-target herbicide movement would present a novel benefit for growers who utilize such treatments.

Procedures

In order to explore the potential for safening via insecticide seed treatments in soybean, field trials were conducted at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS) in Marianna, Ark. (2015 and 2016), at the Northeast Research and Extension Center (NEREC) in Keiser, Ark. (2016), and the Pine Tree Research Station near Colt, Ark. (2016). The UA 5213C soybean, a conventional, non-STS variety, was planted in 4-row plots measuring 12.7 ft. wide and 25 ft. long. Prior to planting, seeds were treated with CruiserMaxx (thiamethoxam), NipsIt® (clothianidin), or no insecticide seed treatment. All seeds were treated with the fungicide component of CruiserMaxx Vibrance® (mefenoxam+fludioxanil+sedaxane) in order to protect against early-season disease pressure. Eight post-emergence herbicides were applied to V3 soybean using a backpack sprayer calibrated to deliver a constant carrier volume of 15 gal/ac. Herbicides were applied using a 6-nozzle, handheld boom at 1/10X labeled rates for each herbicide, and included Roundup PowerMax® (glyphosate), Weedar® (2,4-D), Clarity® (dicamba), Permit® (halosulfuron), Liberty® (glufosinate), Callisto® (mesotrione), Laudis® (tembotrione), and Riceshot® (propanil). Visual crop injury ratings were taken at 1, 2 and 4 weeks after herbicide applications (WAA) and grain yield data were collected at the end of the growing season. Data collected were subjected to analysis of variance using JMP Pro 12.1 with means separated using Fisher's protected LSD ($\alpha = 0.05$).

Results and Discussion

Of the eight herbicides evaluated, all herbicides except for propanil were safened at one or more site years through the use of an insecticide seed treatment. Injury reduction from Permit was the most consistent, with safening seen at

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three of the four site years evaluated. Maximum injury reduction from Permit was seen 2 WAA at LMCRS (2015), where plots with no insecticide were injured 46% and those treated with Cruiser and NipsIt were injured 16% and 6%, respectively (Fig. 1). This level of injury reduction caused a resultant increase in crop height, where height was improved 11 cm and 13 cm via Cruiser and NipsIt, respectively (Fig. 2). Additionally, soybean yield relative to the non-treated plots was improved in the NipsIt treated plots (Fig. 3). While injury was reduced in all other herbicides except propanil, the level of safening seen in other herbicides was not as high as was seen with Permit at LMCRS (2015), nor did they cause increased crop height or yield (data not shown).

Practical Applications

The only instance where safening resulted in increased crop yield occurred following exposure to Permit drift. However, the fact that some degree of injury reduction was seen in 7 of 8 herbicides evaluated is noteworthy. The variability among results at different site years indicates environmental conditions likely play a role in the success of safening via insecticide seed treatments. Due to the fact that insecticide seed treatments are used on widespread acreage across a range of environmental conditions throughout Arkansas each year, it is likely that some growers will see these positive benefits of reduced injury in the case of herbicide drift events. This research supports the use of insecticide seed treatments as a potential means for protecting against crop injury in drift-prone areas of soybean production. In addition to the protection against early-season insect pest damage that can severely limit soybean yield, decreasing herbicide injury in seedling crops helps limit time to canopy closure, decreasing pressure from weeds, and potentially increasing yields.

Acknowledgements

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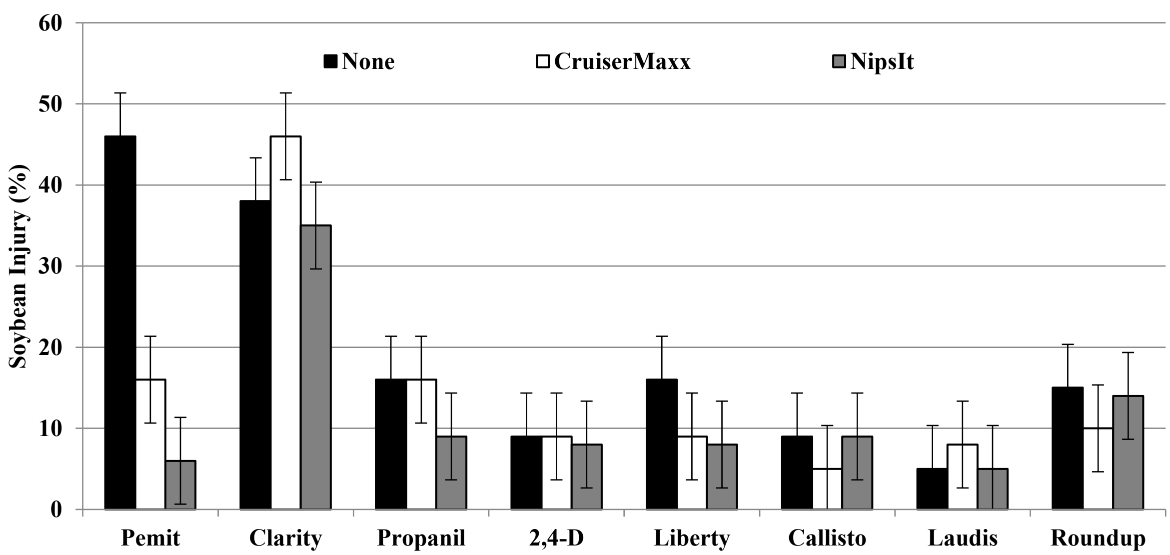

Fig. 1. Soybean injury 2 weeks after application for insecticide/herbicide combinations at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station in Marianna (2015). Where error bars overlap, mean crop injury is not significantly different (α = 0.05).

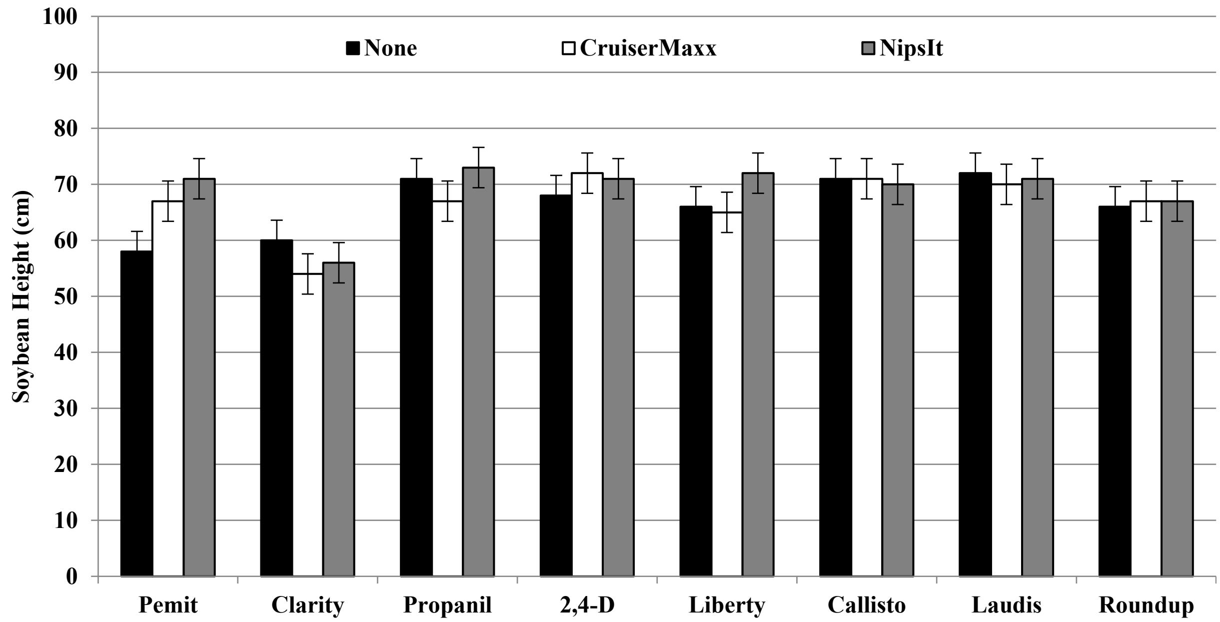

Fig. 2. Soybean height at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station in Marianna in 2016 prior to harvest for insecticide/herbicide combinations. Where error bars overlap, height is not significantly different (α = 0.05).

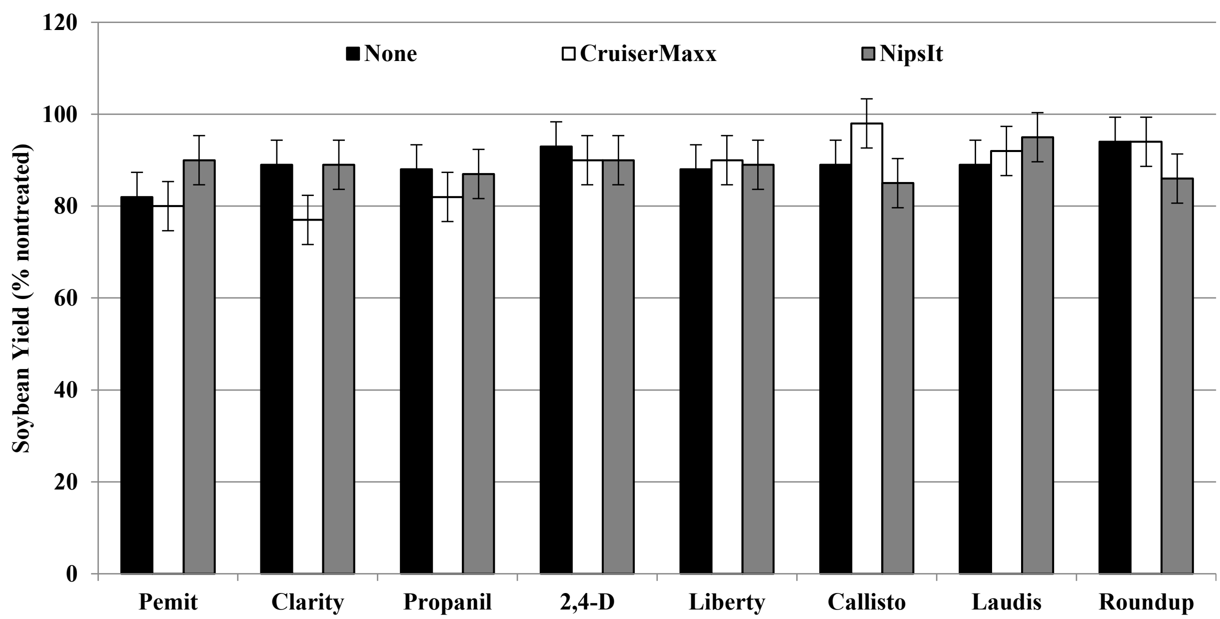

Fig. 3. Relative soybean yield for insecticide/herbicide combinations compared to the non-treated check (no insecticide + no herbicide)at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station in Marianna. Where error bars overlap, mean crop yield is not significantly different (α = 0.05).

Soybean Science Challenge: From the Ground Up

K. Ballard[1] and L. Wilson[1]

Abstract

This is the first generation with unlimited access to digital information about agriculture but few resources to help young adults filter accurate from inaccurate information about contemporary issues. The Soybean Science Challenge (SSC) was launched in 2014 in response to the Arkansas Soybean Promotion Board's (ASPB) desire to deliver effective youth education. The SSC's goal is to engage high-school science students in "real-world" education to support soybean production and agricultural sustainability, to reward student scientific inquiry, and to expand student understanding of career opportunities in agricultural fields. A continuum of educational products and methods were deployed to support this goal, including: needs assessment and program evaluation, curriculum development, product branding, online course development and management, classroom and lab instruction, virtual live-streaming education, student mentoring, student-led research and award recognition facilitated through partnerships with diverse state and national educators, agencies and traditional and popular media. The SSC supported and engaged high-school students and teachers in active learning and the co-creation of knowledge through support and recognition of applied student research.

Introduction

The Soybean Science Challenge (SSC) is first and foremost a real-life "challenge" for students. The program was designed with ongoing engagement in mind; students have different ways to "opt in." A Program and Staff Development team led multidisciplinary scientists, educators, communications and Information Technology (IT) specialists in producing original educational products which expanded the traditional reach of agricultural education by delivering online courses, instructional labs, ZOOM webinar classrooms, mentoring sessions, and Virtual Field Trips (VFT) to statewide non-traditional 9-12 grade Arkansas science teachers and students. The SSC utilized a range of digital and traditional methods and tools to educate and engage students and teachers and piloted an entirely new educational method: the Virtual Field Trip. Over the past three years, this new method, delivered live, took entire classrooms into fields and research labs making agriculture a real-life first-hand experience for large groups of Arkansas and other multi-state youth. This "high-tech" approach was supported by online classes and virtual mentoring, and facilitated with the "high-touch" traditional methods that Extension is known for—multi-agency networking, education, and support of grass-roots stakeholders.

The SSC supported the Arkansas STEM education goals, was aligned with the Next Generation Science Standards (NGSS) and engaged high-school students in active learning and the co-creation of knowledge through support, awards and recognition for independent student research.

ACT, Inc. has been a leader in measuring college and career readiness trends. The 2014, 2015, and 2016 Arkansas Condition of STEM (Science, Technology, Engineering, and Mathematics) annual reports continued to document the low interest of Arkansas high school students in agricultural fields as a major study area. In 2014, Arkansas students reported little interest in agronomy and crop science as a major (3/978/0%); in 2015, there was a minor increase in interest (20/1054/2%). The 2016 ACT Arkansas STEM report reflected that the number of students expressing an interest in agronomy and crop science as a major/occupation fell 1% from ACT 2015 (11/1046/1%).

The critical challenge of engaging and inspiring Arkansas youth regarding the value and relevance of agricultural science to their lives was well documented. The SSC focused on teacher and student engagement as a key strategy to help students discover how significant and rewarding a career supporting Arkansas agriculture could be.

A national search yielded no science curriculum on agricultural sustainability targeting our target audience (15-18 year-olds). Creation of original content for most of SSC's educational products was required. The Arkansas environmental scan of resources for this age-group likewise identified that prior to 2014, there was no recognition or incentives in the form of special awards at the Arkansas State Science and Engineering Fair for students conducting inquiry focusing on agricultural sustainability.

Procedures

From the start, the vision for the Soybean Science Challenge Team was to engage high-school science students and teachers, by producing and delivering content that was timely, relevant and relatable. It also meant understanding the delivery formats our high-school audience preferred and finding a way to deliver. It required development and utilization

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of unproven distance delivery methods (broadcasts from the middle of a rural Delta soybean field with multiple wireless routers and a boat battery for computer back-up). It required pushing the envelope with education to deliver content and provide unprecedented access to scientists who made this novel and fascinating to science teachers and students who had no primary interest in agriculture.

The Soybean Science Challenge management strategy included: boots on the ground; broad collaboration; leveraged resources; original content creation; use of real-time digital education across multiple platforms; development of a responsive system providing access to scientists and support for student research; and recognition for student scholarship. An online "Seed Store" was opened with the help of our University of Arkansas System Division of Agriculture research partners in Fayetteville to support student research. During the past three years, SSC developed and delivered two online courses, six online teacher curriculum resource modules; a SSC High School Curriculum Resource Guide (publication); three Virtual Field Trips with Teacher Guides, fourteen hands-on educational labs, student mentoring, a Soy What's Up web page, an Arkansas High School Science Project Development Guide (publication), Arkansas Department of Education approved in-service credit for teachers, sponsorships of ISEF regional and state science fairs, and cash awards for student researchers and teacher mentors.

Results and Discussion

Process and outcome/impact evaluation of the SSC was an integral component of the project implementation. The SSC team utilized qualitative and quantitative evaluation methods that included needs assessment, participant data, pre/post-test knowledge testing, online post-event surveys, key informant interviews with teachers and students, independent third-party data, and the use of digital analytics. From 2014 to 2016, process evaluation reflected a total of over 28,565 direct and indirect education contacts delivered by project team members (excluding media coverage) including a diverse Arkansas student population.

The VFTs generated 14 media publications, one Rural Free Delivery television network (RFD-TV) interview and two radio features. The Challenge's distribution reach through newspapers, magazines and other publications was 276,529; one national network television interview and two national radio features had a combined household reach of 71 million. Direct contacts with teachers through Constant Contact, the ARSTEM Science List Serve, Arkansas Educational Cooperatives and individual science teacher emails were over 25,000. There were also over 2,500 page views for the www.uaex.edu/soywhatsup webpage since the program began.

Objective evidence of student learning as a result of education delivered through the Soybean Science Challenge online course was reflected through the pre-test/post-test student knowledge scores for the online course (Table 1.).

Along with the online course, the Soybean Science Challenge student research awards presented at Arkansas regional and the state science fairs played a major role in increasing student knowledge about the sustainability and impact of the Arkansas soybean industry. As part of changing the status quo, SSC sponsored the Little Rock Central High School Real World Design Team so they could attend the 2016 8th Real World Design Challenge National Championship competition in Washington D.C. The SSC team won the Against All Odds award for their project, "Moisture Detection in Precision Agriculture with the Use of Unmanned Aircraft Systems."

Through this program, the Arkansas Soybean Promotion Board (ASPB) invested $26,500 in student research awards for science projects with a soybean-related focus. This recognition raised the educational profile about soybeans in Arkansas and the importance of ASPB's goal of supporting effective youth education emphasizing agriculture. A total of 58 individual projects were judged with 25 student awards presented on behalf of ASPB.

The Soybean Science Challenge was acknowledged on a state and national level for innovative and effective educational outreach. Recognition for this project included: Contributor Awards: Southwestern Energy Arkansas State Science Fair Board of Directors (2015, 2016 & 2017); 2015 Excellence Award for Innovation: University of Arkansas System Division of Agriculture, Cooperative Extension Service; and the 2016 Creative Excellence Award: Joint Council of Extension Professionals, National Association of Extension Program and Staff Development Professionals.

Practical Applications

The Arkansas Soybean Science Challenge has come into fruition by helping to close the disconnection between good science and the eroding public perception of farming. This program placed us "at the table" to help shape the attitudes of high-school age youth regarding agricultural issues related to food, fuel, feed, emerging farming issues and research.

Acknowledgements

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

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Table 1. Year to Date Soybean Science Challenge Online Courses Enrollment: July 1, 2014 – March 31, 2017*

Student Enrollment	Current Student Course Completion	Average Student Pre-Test Score	Average Student Post-Test Score	Teacher In-Service Enrollment
218	94	42.5	93.9	42

*Students generally complete the online course immediately prior to the spring science fair competitions.

ECONOMICS

2017 Soybean Enterprise Budgets and Production Economic Analysis

W.A. Flanders[1]

Abstract

Crop enterprise budgets are developed that are flexible for representing alternative production practices of Arkansas producers. Interactive budget programs apply methods that are consistent over all field crops. Production practices for base budgets represent University of Arkansas System Division of Agriculture's Cooperative Extension Service's recommendations from the Soybean Research Verification Program. Unique budgets can be customized by users based on either Cooperative Extension Service recommendations or information from producers for their production practices. The budget program is utilized to conduct economic analysis of field data collected from the Soybean Research Verification Program.

Introduction

Technologies are continually changing for soybean production. Simultaneously, volatile commodity prices and input prices present challenges for producers to maintain profitability. Producers need a means to calculate costs and returns of production alternatives to estimate potential profitability. The objective of this research is to develop an interactive computational program that will enable stakeholders of the Arkansas soybean industry to evaluate production methods for comparative costs and returns.

Procedures

Methods employed for developing crop enterprise budgets include input prices that are estimated directly from information available from suppliers and other sources, as well as costs estimated from engineering formulas developed by the American Society of Agricultural and Biological Engineers. Input costs for fertilizers and chemicals are estimated by applying prices to typical input rates. Input prices, custom hire rates, and fees are estimated with information from industry contacts. Methods of estimating these operating expenses presented in crop enterprise budgets are identical to producers obtaining costs information for their specific farms.

Ownership costs and repair expenses for machinery are estimated by applying engineering formulas to representative prices of new equipment (Givan, 1991; Lazarus and Selly, 2002). Repair expenses in crop enterprise budgets should be regarded as value estimates of full service repairs. Repairs and maintenance performed by hired farm labor will be partially realized as wages paid to employees. Machinery performance rates of field activities utilized for machinery costs are used to estimate time requirements of an activity which is applied to an hourly wage rate for determining labor costs (USDA-NASS, 2016). Labor costs in crop enterprise budgets represent time devoted to specified field activities.

Ownership costs of machinery are determined by the capital recovery method which determines the amount of money that should be set aside each year to replace the value of equipment used in production (Kay and Edwards, 1999). This measure differs from typical depreciation methods, as well as actual cash expenses for machinery. Amortization factors applied for capital recovery estimation coincide with prevailing long-term interest rates (Edwards, 2005). Interest rates in this report are from Arkansas lenders as reported in November 2015. Representative prices for machinery and equipment are based on contacts with Arkansas dealers and industry list prices (Deere & Company, 2016; MSU, 2016). Revenue in crop enterprise budgets is the product of expected yields from following Extension practices under optimal growing conditions and projected commodity prices.

Results and Discussion

The University of Arkansas System Division of Agriculture's Northeast Research and Extension Center (NEREC) develops annual crop enterprise budgets to assist Arkansas producers and other agricultural stakeholders in evaluating expected costs and returns for the upcoming field crop production year. Production methods analyzed represent typical field activities as determined by consultations with farmers, county agents, and information from Crop Research Verification Program Coordinators in the University of Arkansas System Division of Agriculture's Department of Crop, Soil, and Environmental Sciences. Actual production practices vary greatly among individual farms due to management preferences and between production years due to climatic conditions. Analyses are for generalized circumstances with

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a focus on consistent and coordinated application of budget methods for all field crops. This approach results in meaningful costs and returns comparisons for decision-making related to acreage allocations among field crops. Results should be regarded only as a guide and basis for individual farmers developing budgets for their production practices, soil types, and other unique circumstances.

Table 1 presents a summary of 2017 costs and returns for Arkansas furrow-irrigated soybeans. Costs are presented on a per acre basis and with an assumed 1000 acres. Program flexibility allows users to change total acres, as well as other variables to represent unique farm situations. Returns to total specified expenses are $169.77/ac. The budget program includes similar capabilities for center pivot-irrigated and non-irrigated soybean production.

Crop insurance information in Table 1 associates input costs with alternative coverage levels for insurance. For example, with an actual production history (APH) yield of 54.0/ac and an assumed projected price of $10.00/bu, input costs could be insured at selected coverage levels greater than 51%. Production expenses represent what is commonly termed as "out-of-pocket costs," and could be insured at coverage levels greater than 59%. Total specified expenses could be insured at coverage levels of 79%.

Practical Applications

The crop enterprise budget program has a state level component that develops base budgets. County extension faculty can utilize base budgets as a guide to developing budgets that are specific to their respective counties, as well as customized budgets for individual producers. A county delivery system for crop enterprise budgets is consistent with the mission and organizational structure of the University of Arkansas System Division of Agriculture's Cooperative Extension Service.

The benefits of the economic analysis of alternative soybean production methods provide a significant reduction in financial risk faced by producers. Arkansas producers have the capability with the budget program to develop economic analyses of their individual production activities. Unique crop enterprise budgets developed for individual farms are useful for determining credit requirements. Flexible crop enterprise budgets are useful for planning that determines production methods with the greatest potential for financial success. Flexible budgets enable farm financial outlooks to be revised during the production season as inputs, input prices, yields, and commodity prices change. Incorporating changing information and circumstances into budget analysis assists producers and lenders in making decisions that manage financial risks inherent in agricultural production

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Table 1. 2017 Summary of revenue and expenses, furrow-irrigated soybeans, per acre and 1000 acres.

			Crop Insurance Information	
Revenue	**Per Acre**	**Farm**		**Per Acre**
Acres	1	1000	**Enter for Farm**	
Yield (bu)	60.00	60,000	APH Yield	54.0
Price ($/bu)	10.00	10.00	Projected Price	10.00
Grower Share	100%	100%		
Total Crop Revenue	**600.00**	**600,000**	**Revenue**	**540.00**
Expenses			**Percent of Revenue**	
Seed	72.60	72,600		13%
Fertilizers & Nutrients	30.80	30,804		6%
Chemicals	119.00	118,999		22%
Custom Applications	14.00	14,000		3%
Diesel Fuel, Field Activities	11.09	11,095		2%
Irrigation Energy Costs	24.80	24,804		5%
Other Inputs	3.88	3880		1%
Input Costs	**276.18**	**276,182**		**51%**
Fees	7.00	7000		1%
Crop Insurance	7.00	7000		1%
Repairs & Maintenance, Includes Employee Labor	16.88	16,884		3%
Labor, Field Activities	10.78	10,777		2%
Production Expenses	**317.84**	**317,843**		**59%**
Interest	6.67	6675		1%
Post-harvest Expenses	18.00	18,000		3%
Custom Harvest	0.00	0		0%
Total Operating Expenses	**342.52**	**342,518**		
Returns to Operating Expenses	**257.48**	**257,482**		
Cash Land Rent	0.00	0		0%
Capital Recovery & Fixed Costs	87.71	87,708		16%
Total Specified Expenses	**430.23**	**430,225**		
Returns to Specified Expenses	**169.77**	**169,775**		
Operating Expenses/bu	5.71	5.71		
Total Specified Expenses/bu	7.17	7.17		

Simulation Farm Analysis with Soybeans and Rotation Crops

W.A. Flanders[1]

Abstract

The University of Arkansas System Division of Agriculture's Row Crop Research Verification Programs for corn and grain sorghum, cotton, rice, soybeans, and wheat (UA-CES, 2016b) apply field activities and help establish enterprise budgets (UA-CES, 2016a). The objective of this research is to expand crop enterprise budgets with per acre costs and returns to a whole farm analysis by applying county-level aggregate data to represent a case study farm. Expanding enterprise budgets on a per acre basis to a whole farm budget as a case study requires total farm acreage that corresponds to representative farm acreage for efficient utilization of equipment units. Representative total acreage in this analysis is evaluated as a farm owning one combine with approximately 300 total annual hours of use.

Introduction

U.S. agricultural policy establishes commodity programs for field crops in an attempt to stabilize farm revenue during periodic cycles of decreased prices. Price Loss Coverage (PLC) payment rates are triggered when annual national prices are less than a reference price that is fixed for the duration of the farm bill legislation. The PLC payment rates are determined by farm payment yields for each crop that are established by historical farm yields. The county version of the Agricultural Risk Coverage (ARC) program sets payment rates in each county that are based on historical national prices and county yields. Payments are triggered when current revenue for a county, determined by national price and county yield, are below a moving benchmark revenue. The moving benchmark revenue is determined by five-year Olympic averages for county yield and national price (USDA-ERS 2016).

Procedures

The whole farm case study for this analysis has 700 acres of soybeans and 700 of corn at one location, and another location has 700 acres of soybeans and 700 acres of long-grain rice. Field activities for each of the crops are applied from 2016 crop enterprise budgets. With 2800 total acres, a single combine has 326 annual hours of use. Total acres applied to the whole farm result in fixed costs estimates that represent whole machinery units.

Yields for the case study farm are averages of University of Arkansas System Division of Agriculture's Research Verification Program fields over 5 years. Irrigated yields per acre are corn (210 bu), rice (180 bu), and soybeans (55 bu). Prices received for this analysis are determined by the July estimates from the USDA (USDA, 2016). Applied crop prices are \$3.50/bu for corn, \$4.73/bu for long-grain rice, and \$9.50/bu for soybeans. All land is assumed rented, and typical rental arrangements represented by the case study crop yields are 25% of crop revenue and an equal percentage of any revenue derived as payments from government programs.

Results and Discussion

Case study acreage, yields, and crop prices are applied to the Whole Farm Budget calculator of the University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES, 2016a). Costs and returns for the farm are presented in Table 1. Inputs are composed of seed, chemicals, fuel, and custom applications. Production expenses are inputs, crop insurance, equipment repairs, and hired labor. This is the amount that would typically be represented by an annual production loan. Operating expenses are production expenses, interest paid on production loans, and post-harvest expenses. Returns to operating expenses of \$161,595 is the amount available to pay capital recovery and to provide a return for farm management to the operator. With capital recovery of \$234,548, farm income from operations is -\$72,953. The \$63,850 estimate for farm management is for Standard Occupational Classification (SOC) code 119013 and is derived as the average of Arkansas, Louisiana, Mississippi, and Missouri annual income (USDOL, 2016). Farm management includes value accrued to the operator for living expenses, as well as fees paid for management activities such as production consulting or financial services. Net returns for the farm are -\$136,803.

Price Loss Coverage and Agricultural Risk Coverage parameters (USDA-ERS 2016) corresponding to Mississippi County yields and national prices (USDA-NASS, 2016) are applied to the PLC, ARC, and LDP calculator of the CES (UACES. 2016a). Farm costs and crop revenue in Table 2 are identical to Table 1. The PLC and ARC payments of \$161,382 in Table 2 are composed of \$97,329 of PLC payments and \$64,053 of ARC payments. Net returns are \$24,579 for the farm. To achieve these net returns, the case study farm has \$1,022,937 of current operating debt and an additional \$234,548 of long-term debt obligations for machinery and equipment. Total annual expenses are \$1,454,438 and \$63,850 for management to realize \$24,579 in net returns.

Applying statistical results of price trends (Irwin and Good, 2013) leads to \$4.50/bu for corn and approximately

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$10.50/bu for soybeans as long-term expected prices. Applying the PLC reference price for long-grain rice of $6.30/bu with long-term expected prices for corn and soybeans to the PLC, ARC, and LDP calculator represents market conditions in which there are no PLC and ARC payments. Net returns of $179,177 in Table 3 represent a situation in which all farm revenue is derived from market receipts. All costs in Table 3 are identical to costs in Table 1 and Table 2 except for soybean operating costs. Soybean check-off fee calculations include crop price, and the higher soybean price applied in Table 3 leads to greater operating expenses.

Comparing net returns in Table 3 to net returns in Table 1 indicates the nature of profit margins for field crop production. Commodity prices in Table 3 represent expectations for prices that correspond to levels in which no commodity program payments are received. Commodity prices in Table 1 are at levels in which current agricultural policy triggers program payments. Changes in commodity prices between Table 3 and Table 1 are reductions of 22% for corn, 25% for rice, and 10% for soybeans. These price declines result in a net returns decrease of 176% to a level of -$136,803 for the farm without a safety net provided by commodity programs.

Practical Applications

Analysis with whole farm budgets includes total costs and returns for a farm production unit. Producers have the capability to represent situations for complete operations and to include projections for commodity program payments during periods of low commodity prices. Production planning is enhanced by comparing crop alternatives with varying acreage combinations. Efficacy of agricultural policy may be evaluated with whole farm budgets. Results of this analysis indicate that current programs of Price Loss Coverage and Agricultural Risk Coverage are effective for enabling a representative farm to meet all financial obligations of production. Without these programs, production expenses are greater than revenue from market prices.

Acknowledgements

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Table 1. Case study farm results of the Whole Farm Budget calculator with corn ($3.50/bu), soybean ($9.50/bu), and rice ($4.73/bu).

Crop	Corn ($)	Soybean ($)	Rice ($)	Farm ($)
Total Revenue	514,500	731,500	595,980	1,841,980
Grower Revenue	385,875	548,625	446,985	1,381,485
Input Costs	262,417	379,595	277,500	919,512
Production Expenses	292,649	425,418	304,869	1,022,937
Operating Expenses	365,750	458,429	395,711	1,219,890
Returns to Operating Expenses	20,125	90,196	51,274	161,595
Capital Recovery				234,548
Farm Income from Production				-72,953
PLC, ARC Payments				0
Management				63,850
Net Returns				-136,803

Table 2. Case study farm results of the Whole Farm Budget calculator with corn ($3.50/bu), soybean ($9.50/bu), rice ($4.73/bu), and price loss coverage (PLC), agricultural risk coverage (ARC)-county payments.

Crop	Corn ($)	Soybean ($)	Rice ($)	Farm ($)
Total Revenue	514,500	731,500	595,980	1,841,980
Grower Revenue	385,875	548,625	446,985	1,381,485
Input Costs	262,417	379,595	277,500	919,512
Production Expenses	292,649	425,418	304,869	1,022,937
Operating Expenses	365,750	458,429	395,711	1,219,890
Returns to Operating Expenses	20,125	90,196	51,274	161,595
Capital Recovery				234,548
Farm Income from Production				-72,953
PLC, ARC Payments				161,382
Management				63,850
Net Returns				24,579

Table 3. Case study farm results of the Whole Farm Budget calculator with corn ($4.50/bu), soybean ($10.50/bu), and rice ($6.30/bu).

Crop	Corn ($)	Soybean ($)	Rice ($)	Farm ($)
Total Revenue	661,500	808,500	793,800	2,263,800
Grower Revenue	496,125	606,375	595,350	1,697,850
Input Costs	262,417	379,595	277,500	919,512
Production Expenses	292,649	425,418	304,869	1,022,937
Operating Expenses	365,750	458,814	395,711	1,220,275
Returns to Operating Expenses	130,375	147,561	199,639	477,575
Capital Recovery				234,548
Farm Income from Production				243,027
PLC, ARC Payments				0
Management				63,850
Net Returns				179,177

Reduced Oxygen In-Bin Storage Environment and Potential Effect on Soybean Seed Germination, Vigor and Nutrient Composition

G. Olatunde[1] *and G.G. Atungulu*[1]

Abstract

The objective for this study was to experimentally simulate typical soybean storage conditions in natural air in-bin drying systems and determine the impacts on the germination potential, vigor, and degradation of major nutrients in the seed. Soybean with initial moisture content (MC) of 24% wet basis (w.b.) was divided into four sub-lots with MCs reconditioned to 20%, 16%, 13% and 10% w.b. Each sub-lot was packed and stored in quart-sized, glass containers for up to 60 days in environments typical of in-bin drying and storage 50 °F, 68 °F, 86 °F, and 104 °F (10 °C, 20 °C, 30 °C, and 40 °C). Samples from each of these treatments were collected after 0 (24 h), 10, 20, 30, 40, 50, and 60 days of storage for germination, vigor (electrical conductivity) and nutrient compositional (protein, ash fiber, and NDF) test. The International Seed Testing Association's (ISTA) standard procedures were used. The results showed the seed germination potential dropped from 86% at day 0 to 0% at day 60 as temperature increase from 50 °F to 104 °F (10 °C to 40 °C). Similarly, the electrical conductivity increased from 1000 µ/s to 5000 µ/s with increase in storage durations and temperature ($P < 0.05$). Generally, soybean stored at 50 °F to 68 °F (10 °C to 20 °C), had the least reduction of viability (vigor and germination) for the entire study duration. For seed stored at above 86 °F (30 °C), destruction of cellular membranes seems to accelerate reaction of protein, lipid and other constituents as duration increased. The study revealed that long-term storage of soybean is possible when the moisture content and storage temperature are below 13% and 68 °F (20 °C), respectively.

Introduction

The traditional in-bin drying and storage systems that utilize unconditioned natural air (NA) typically exhibit moisture content (MC) gradient profiles across the bin. The layers of soybean closer to the air inlet position typically have low MC while those at the topmost layer remain at an elevated MC (Young et al., 2016). In certain conditions of air relative humidity (RH) and temperature, the upper layers may remain at high MC for prolonged periods. Also, bin conditions such as dockage level and grain mass configuration could impact the airflow distribution in the bin. Area with limited air exposure may also experience stagnation in moisture change for an extended duration (Atungulu et al., 2013; Olatunde et al., 2016). Such conditions may trigger an uptick in microbial activities and stress in seed with resultant effect on deterioration of nutritional composition, reduced germination potential, vigor, and possibility of aflatoxin production; a carcinogenic compound that is dangerous to both animal and human (De Alencar et al., 2011; Frankel et al., 1987). It is therefore important to investigate how storage duration and different storage conditions such as soybean MC impact the germination potential, vigor and nutritional constituents of soybean.

The main goal of any storage strategy is preservation and or enhancement of nutritional composition of stored grains especially for grains intended for food; high viability, in the case of seed intended for seedling. The major nutritional composition of soybean that must be preserved during storage includes crude protein, ash, crude fat, fiber, neutral detergent fiber (NDF), and acid detergent fiber (ADF). Deterioration of the major nutrients implies negative impact on macro nutrient in the seed (Banaszkiewicz, 2011). Similarly, storage strategy should prevent the rupturing of the cell membrane which occurs during water absorption and desorption. Weakening of cell membrane could also happen when the MC is high for a long duration, causing the seed to lose vigor with negative implication on germination. (Bellaloui et al., 2010; Rahim et al., 2015; Van Eys et al., 2004). The seed vigor is measured by the amount of electrolyte released in soaking solution (Young et al., 2016). In the case of soybean seeds, the range has not yet been defined because of new varieties and cultivars.

The objective for this study was to simulate typical moisture content in situations of limited airflow exposure for soybean seed and determine the effects of duration of storage on seed germination potential, vigor (electrical conductivity), and major nutrient constituents.

Procedures

Material, Sorption Equation and Coefficient Determination. The experiments used freshly harvested soybean that was grown in an experimental field at the University of Arkansas System Division of Agriculture's Agricultural Experiment Station in Fayetteville, Ark. The soybean was

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harvested at 24% (wet basis) MC and then manually cleaned to remove chaff, stones and foreign matter. The samples were subsequently conditioned by drying to four initial MC levels (13%, 16%, 18%, and 21%). The MC reconditioning was accomplished periodically by monitoring the soybean placed on a tarp at ambient conditions (temperature and relative humidity at 26 °C and 65%, respectively). The MC measurements were performed with a moisture tester (AM 5200, Perten Instruments, Hägersten, Sweden). After the conditioning, the soybean was immediately packed and stored in individual clearly labeled quart-sized, glass containers to prevent significant alterations of its initial MC and then placed in four separate temperature environments 50 °F, 68 °F, 86°F, and 104 °F (10 °C, 20 °C, 30 °C, and 40 °C). The storage conditions can be considered as those representing reduced oxygen environment. The temperature ranges studied are typically encountered during on-farm, natural-air drying and storage in the U.S. mid-South climate.

The chosen storage environments were attained by using two incubators (BINDER, Bohemia, N.Y.) and two chest freezers (HMCM148PA, Haier, Qingdao, China). The soybean samples were stored for a period of 60 days and collected every 10 days (Table 1). In total, 72 jars (four moisture contents × 7 storage duration × three replication) were placed in each of the environmental units, resulting in a total of 288 experimental units.

Germination Test. Standard methods for determination of germination potential of the soybean seeds were followed (ISTA, 2015). A cheese cloth was used as the germination medium. 100 seed samples were randomly selected from the conditioned samples. The 100 seeds were soaked in distilled water for 24 h (ISTA, 2015) and then placed between two sheets of cheese cloth positioned on a tray inside a germinator (Conviron G 2100 Germination Chamber, Winnipeg, Manitoba, Canada). The germinator was set at 78.8 °F (26 °C) and 8 h light regime of 1250 lux (simulation of daylight) and a relative air humidity of 97% for 7 days. Germination is calculated as the number of seeds that germinated out of the total seeds tested.

Electrical Conductivity Test. Seed vigor was determined by selecting 100 seeds from the conditioned samples. Then, soaked in 75 mL deionized water at 77 °F (25 °C) for 24 h. After this period, electrical conductivity was read by a conductivity meter (Traceable, 89094-958, VWR, China); the results are expressed in µ/S.

Soybean Composition Analysis. The soybean composition profile was determined by using near-infrared (NIR) spectroscopy (7250, Perten Instruments, Hägersten, Sweden). The conditioned samples were loaded and leveled on the holding cup of the instrument. The loaded cup was then placed under the focus of the scanner of the instrument. After measurement, the result was displayed on the monitor on a dry basis (db) and exported to Microsoft Excel® for further analysis.

Statistical Analysis. The effect of storage on conditions on germination, vigor and nutrient deterioration were analyzed using SAS for the analysis of variance (ANOVA), surface response methodology and the Duncan multiple range test (SAS Institute, Inc., Cary, N.C.).

Results and Discussion

Figures 1 and 2 show the effect of storage conditions on germination and vigor (electrical conductivity) of the conditioned soybean. Drastic reduction in germination potential was observed when the seeds were stored at 86 °F and 104 °F (30 °C and 40 °C) irrespective of the MC. The soybean stored between 50 °F and 68 °F (10 °C and 20 °C) maintained its initial germination potential until the seed MC attained 20% when the germination potential of seed stored at 68 °F (20 °C) reduced rapidly. It is possible to maintain seed viability of more than 70% when the temperature is 50 °F (10 °C) for 60-day storage duration. At 50 F (10 °C), it may be possible that the microbial and respirational activities are reduced: limited conversion of available oxygen to energy, carbon dioxide and water vapor make the seed active for long time. However, as temperatures increase and with the availability of more water (increase in MC), elevated respirational activities induced stress in the seed as shown from the result of the vigor test. Figure 2 shows the profile of the vigor of the conditioned seed during storage. As temperature and moisture content increased, the vigor increased almost linearly with duration for seeds stored at 86 °F and 104 °F (30 °C and 40 °C). Marginal increase in electrical conductivity was recorded for soybean stored at 50 °F and 68 °F (10 °C and 20 °C irrespective of MC) with storage duration.

The kinetics of soybean constituents on storage condition for protein, ash, fiber and NDF is show in Figs. 3, 4, 5 and 6, respectively. The nutrient constituent response depended strongly on MC, temperature and storage duration ($P < 0.05$). The protein content ranged between 36% and 39% dry basis and generally increased with increase in storage duration except at 10% and 20% when the protein attained maximum levels at 30 to 40 day storage duration. The storage temperature effected the protein content. Apart from conditioned sample at 20% MC, the deterioration of protein in the stored soybean with increase in temperature was inversely linear. The range obtained in this study falls within the values (23% to 42%) reported by other authors (Banaszkiewicz, 2011; Van Eys et al., 2004). Figure 4 shows the response of ash content to storage conditions and duration. The initial ash content of soybean was found to be around 6.4% (db, dry basis) which is comparable to the value (4.5% to 6.4%) of ash content reported by Van Eys et al. (2004). The ash content slightly decreased to 5.6% at about 40 day storage when the MC were at 10%, 13% and 16%. However, for 16% MC, the ash marginally decreased at lower temperature and slightly increased at higher temperature even as storage duration increased. Storage temperature appears to have no effect on soybean ash content dynamics when the MC was below 16% w. b. ($P > 0.05$). The response of fiber to storage duration depends strongly on the storage MC ($P < 0.05$). At

10% MC, the largest reduction in fiber content was obtained at day 10 when fiber content reduced from 5.8% to 5.3% db as temperature increased from 50 °F to 104 °F (10 °C to 40 °C). However, as storage duration increased, the rate of fiber deterioration reduced as the fiber content stabilized at 5.5% db by 60 days of storage. But when the MC increased to 16% w.b., the fiber content reduced from 5.5% to 5.0% db between 30 days and 40 days before increasing back to 5.2% db. The impact of storage effect on the NDF content is shown in Fig. 4. The NDF varied between 15% and 18% depending on storage duration and temperature. The value of NDF obtained in this study is higher than that reported by Banaszkiewicz (2011). The NDF reduced with increase in temperature for MC at 16% and below. However, as storage duration increased, the NDF generally increased. Conditioned seed stored at 104 °F (40 °C) were observed to yield the highest level of NDF content. The relationship between the major nutrient composition in relation to storage condition has been found to be complex and interrelated, and the chief driver of the relationship has been attributed to the destruction of cellular membranes, high temperature and humidity (Saio et al., 1982).

Practical Applications

The study presents scenarios of soybean conditions in natural air drying and storage and impact on the germination, vigor and major nutrient composition. The information will be critical to managing soybean in a bin, maintaining quality and preventing mold development.

Acknowledgements

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Table 1. Experimental design showing storage conditions for soybean.

Moisture content (% w. b.)	Temperature (°C)	Storage duration
10	10	Day 0 (24 h.)
13	20	Day 20
16	30	Day 20
20	40	Day 30
		Day 40
		Day 50
		Day 60

The experiment was setup as a full factorial design, with day 0 serving as the control. The Day 0 samples were in the respective storage condition for 1 day.

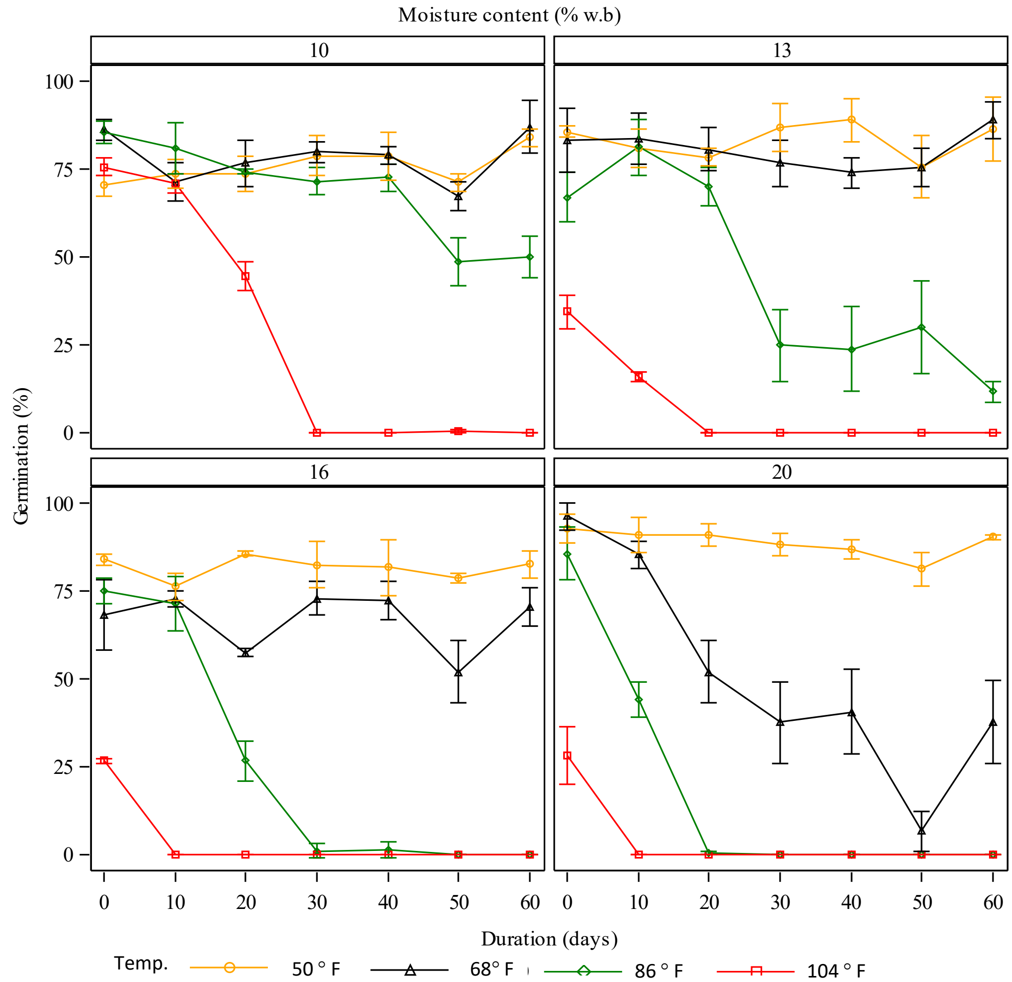

Fig. 1. The effect of reduced oxygen storage conditions on the germination potential of soybean stored for 60 days [50 °F, 68 °F, 86°F, and 104 °F (10 °C, 20 °C, 30 °C, and 40 °C)].

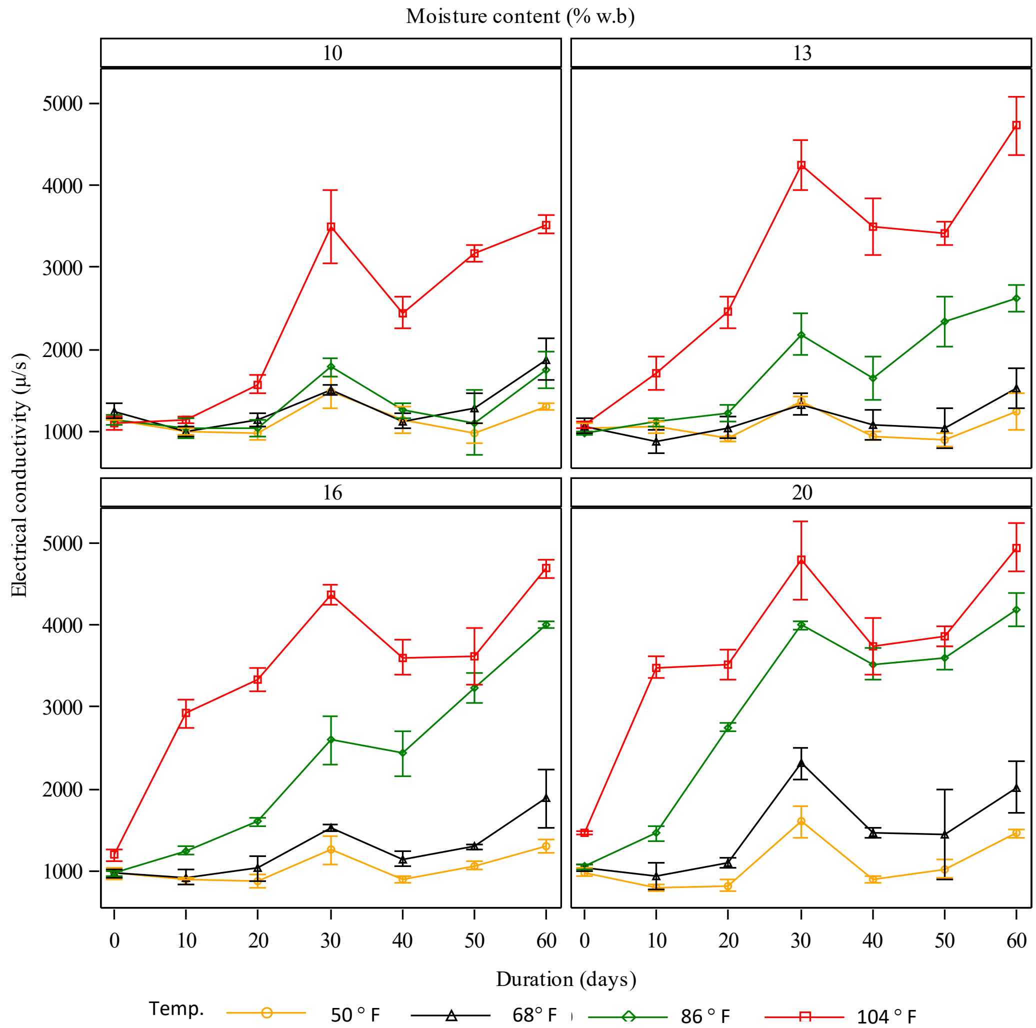

Fig. 2. The effect of reduced oxygen storage conditions on the vigor (electrical conductivity) of e soybean stored for 60 days [50 °F, 68 °F, 86°F, and 104 °F (10 °C, 20 °C, 30 °C, and 40 °C)].

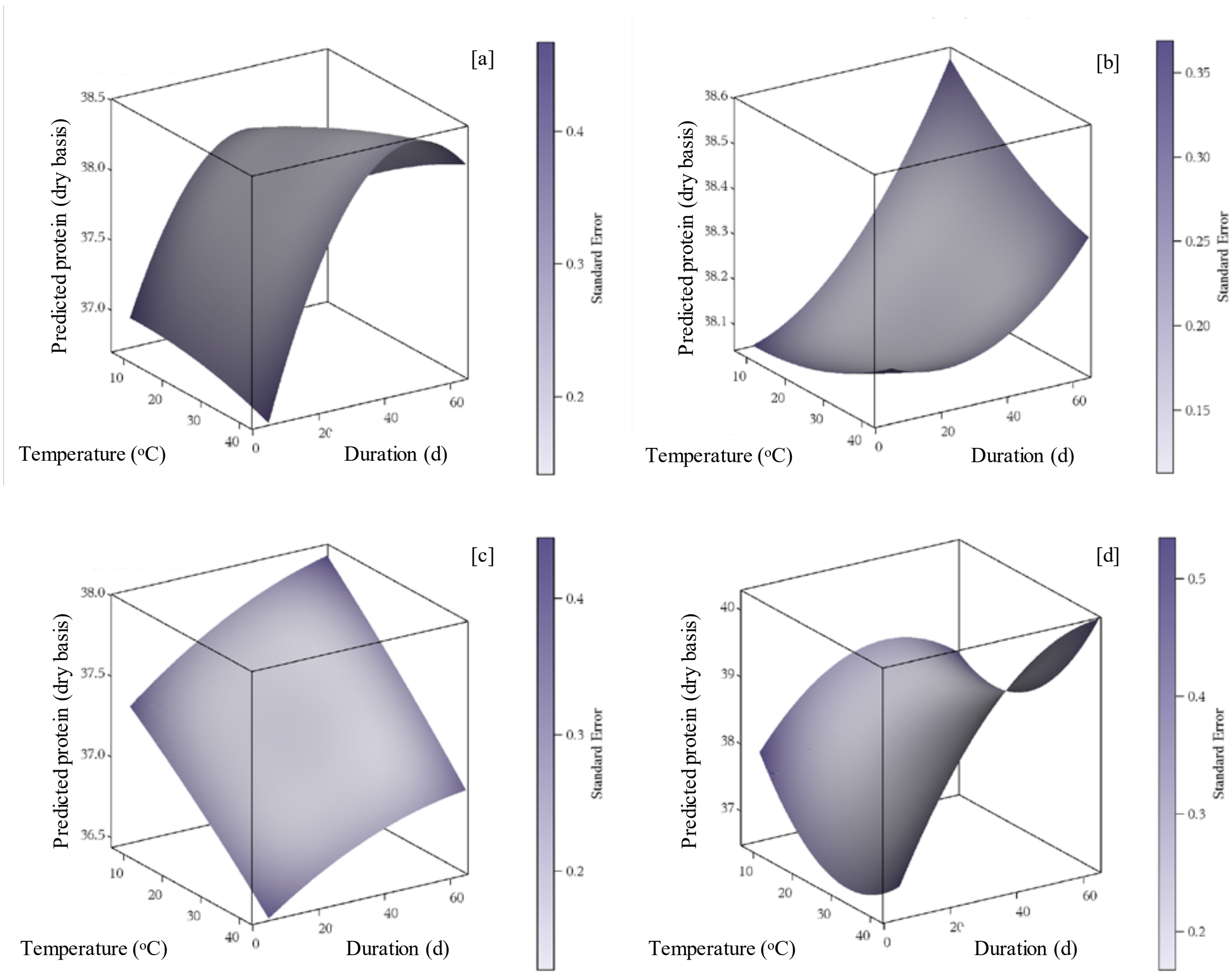

Fig. 3. The effect of reduced oxygen storage conditions on the deterioration of the protein content of soybean stored for 60 days [50 °F, 68 °F, 86°F, and 104 °F (10 °C, 20 °C, 30 °C, and 40 °C)].

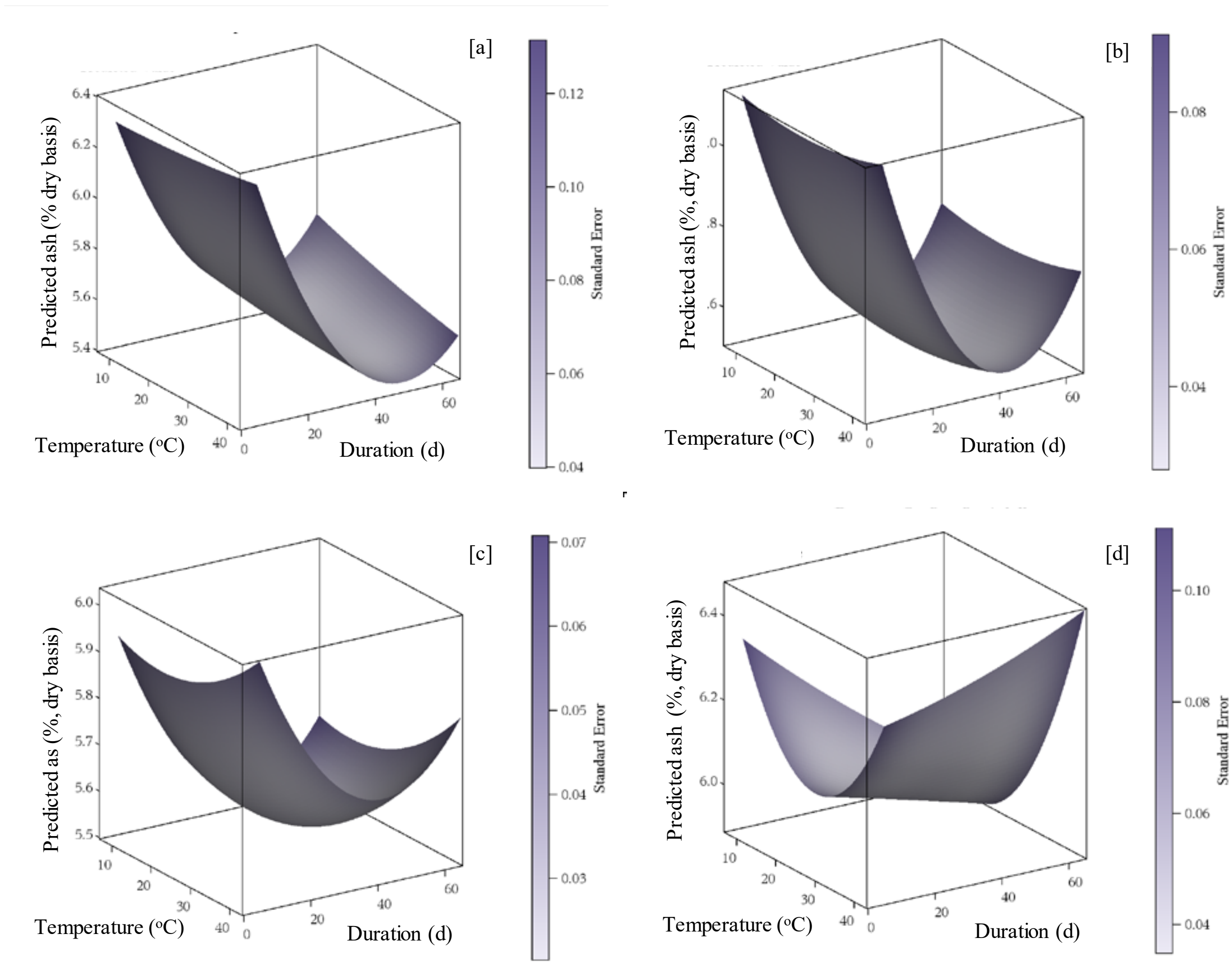

Fig. 4. The effect of reduced oxygen storage conditions on the deterioration of the ash content of soybean stored for 60 days [50 °F, 68 °F, 86°F, and 104 °F (10 °C, 20 °C, 30 °C, and 40 °C)].

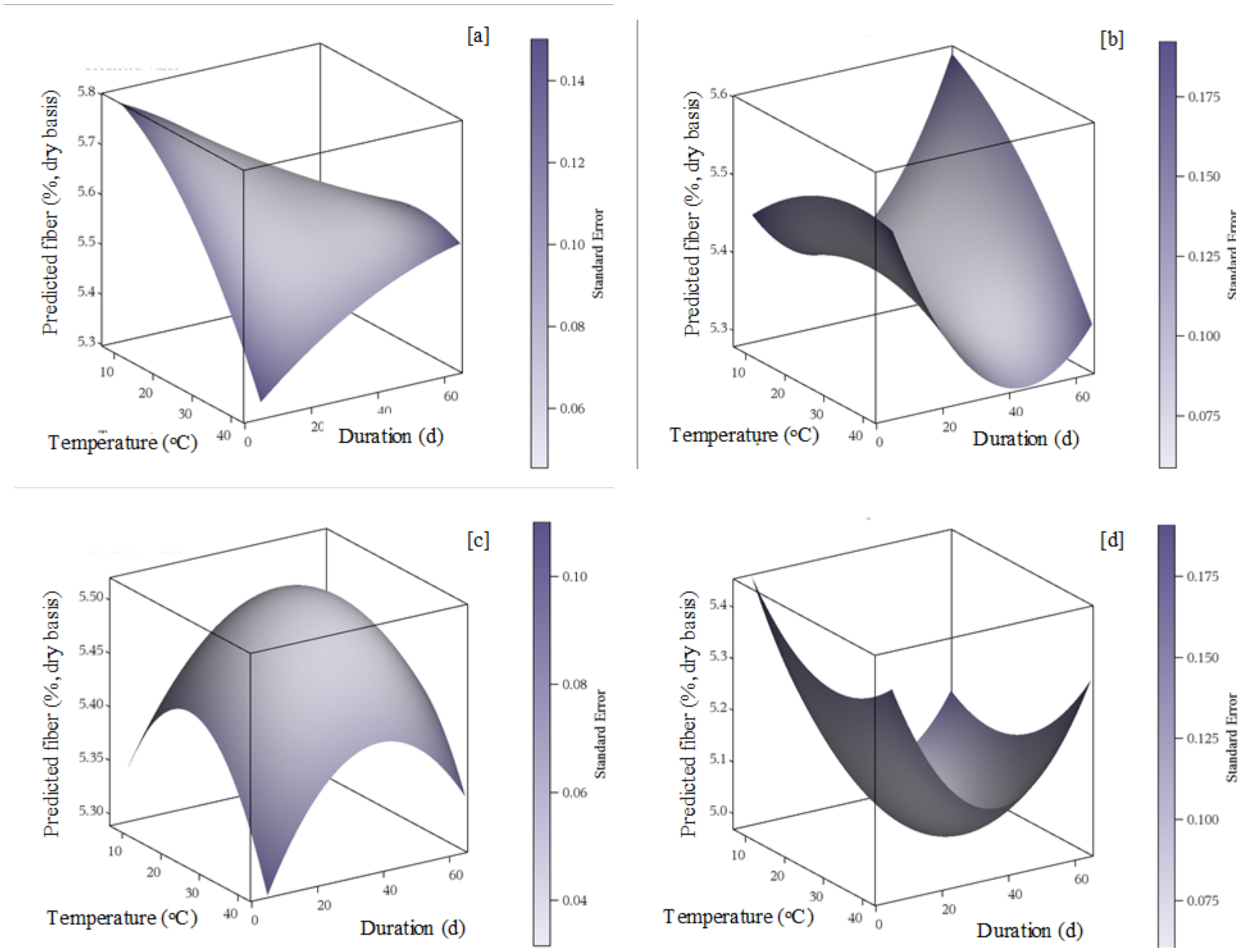

Fig. 5. The effect of reduced oxygen storage conditions on the deterioration of the fiber content of soybean stored for 60 days [50 °F, 68 °F, 86°F, and 104 °F (10 °C, 20 °C, 30 °C, and 40 °C)].

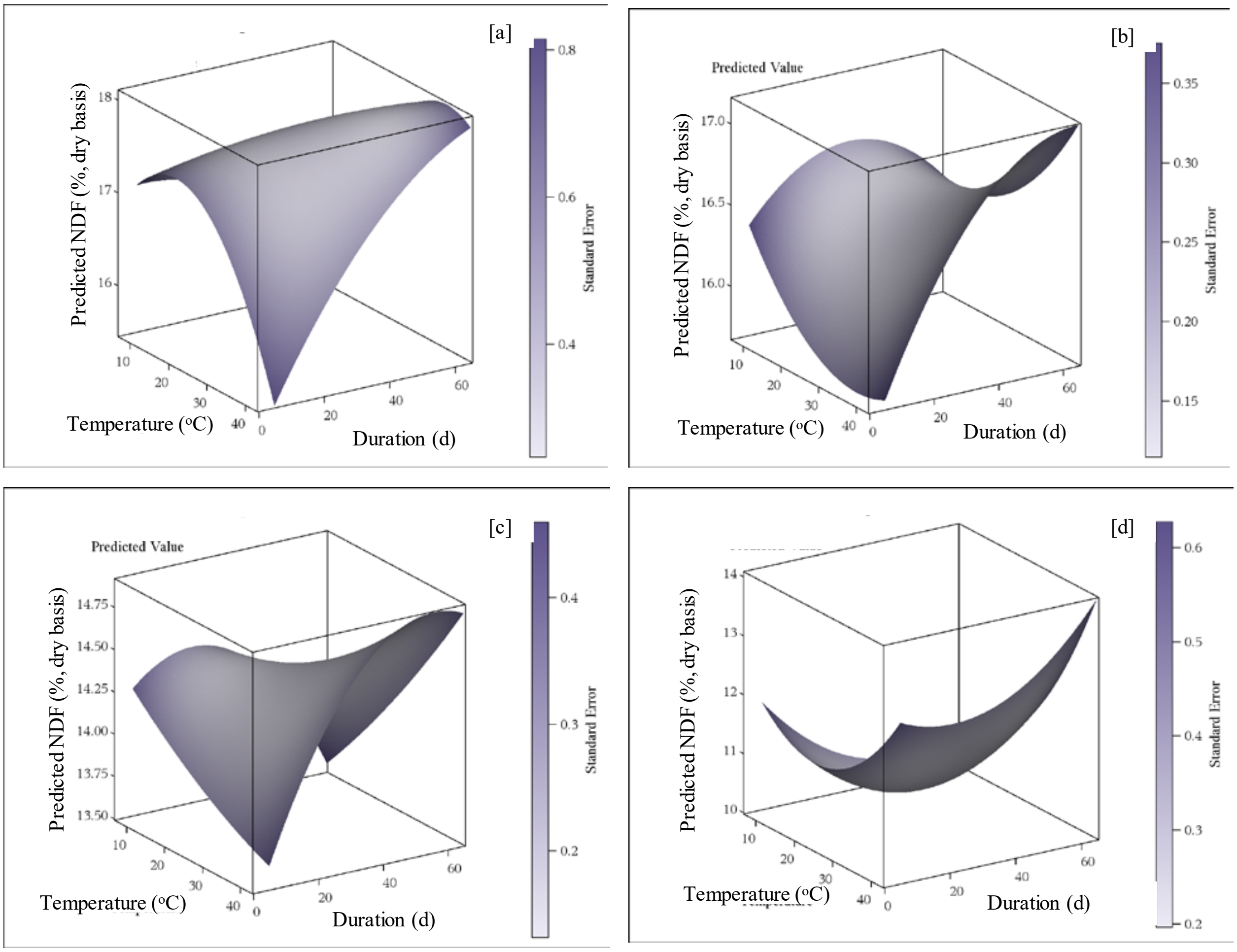

Fig. 6. The effect of reduced oxygen storage conditions on the deterioration of the neutral detergent fiber (NDF) content of soybean stored for 60 days [50 °F, 68 °F, 86°F, and 104 °F (10 °C, 20 °C, 30 °C, and 40 °C)].

Irrigation Initiation Timing in Soybean Grown on Sandy Soils in Northeast Arkansas- Year 3

A.M. Mann[1] *, N.R. Benson*[2]*, J.L. Chlapecka*[3]*, M.L. Reba*[4]*, and T.G. Teague*[5]

Abstract

Decision-making about when to initiate irrigation in soybean production may be improved by using technology to assess water deficits using estimates of evapotranspiration (ET). Management guides from the University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) recommend using ET deficit along with field-specific measures of plant growth stage and the predominant soil type. Current recommendations on initiation timing have not been validated on sandy soils in northeast Arkansas. In the final year of a 3-year study, we evaluated irrigation initiation timing in a commercial field using cues based on ET estimates, determined information from a local weather station and atmometers. Four treatments were evaluated with irrigation starting when ET deficits reached 1 inch (early), 2 inches (standard), and 3 inches (late); there also was a rainfed check. The strip-plot experiment was arranged as a randomized complete block with 3 replications. Cultivar Asgrow AG3735 (MG 3.7) was planted 30 April 2016 on twin rows on raised beds spaced at 38 inches. Estimates of soil texture throughout the field were based on soil electrical conductivity (EC) measures made using a dual depth Veris Soil Surveyor; these ranged from coarse sand (sand blows) to loamy sand. Yields were obtained using grain cart catch weights as well as yield monitor data from the cooperating growers' combine. There were low rainfall periods during crop reproductive development, and measured ET exceeded deficit thresholds in the delayed and rainfed treatments. Yields were reduced in the rainfed compared to irrigated treatments in grain cart and yield monitor measures for the entire length of field ($P < 0.001$); there were no significant differences among irrigation start times. When the yield response from yield monitor measurements was segregated by soil textural class—coarse sand and loamy sand—there was a significant irrigation treatment by soil texture interaction ($P < 0.001$). In loamy sand, yields were similar among irrigated treatments; however in coarse sand, yields were reduced as irrigation start times were delayed. Coarse sand areas encompassed approximately 12% of the field. Current CES guidelines suggest a conservative irrigation regime, and results from this trial validate those recommendations. Adjustments in irrigation scheduling may be appropriate for spatially variable fields. Improving irrigation water use efficiency will help Arkansas producers to advance sustainability.

Introduction

Irrigation initiation timing recommendations for Arkansas soybean are based on predominant soil texture as well as plant growth stage (Henry et al., 2014; Tacker and Vories, 1998). For sandy soils, the University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) recommended guidelines suggest initiating irrigation after the R1 stage at a 2-inch evapotranspiration (ET) deficit. This 2016 field trial was designed to validate current recommendations including plant response across different soil textures in a spatially variable field.

Procedures

The research site was a 35-acre field near Manila, Ark with soils mapped as a Routon-Dundee-Crevasse complex (fine-silty, mixed, active, thermic typic epiaqalfs-udipsamments) (SSURGO, 2015). Within-field variability of soil texture ranged from coarse sand (sand blows) (approximately 12% of the total field) to loamy sand. Treatment descriptions and production details are summarized in Table 1. Plots extended the length of the field (1250 ft.), and plot width was the equivalent of two harvest swaths with the producer's combine. The four irrigation treatments were arranged in a strip-plot, randomized complete block design with 3 replications. Irrigation was applied using 18-in. × 10-mm poly irrigation tubing and a computerized hole selection program (PHAUCET) was used to improve uniformity of irrigation sets. A surge valve was used to control irrigation and to maintain equal applications on both sides of the riser. Asgrow AG3735 (MG 3.7) was planted 30 April 2016 on twin rows on raised beds spaced at 38 inches. The cooperating producer performed all standard field operations, and only irrigation initiation timing was altered among treatments. To increase understanding of how in-field soil variability impacted ir-

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rigation effects, sample allocations for weekly plant, insect and soil moisture monitoring were made among soil textural zones based on a soil electrical conductivity (EC) map for the study field. Soil EC measurements were obtained in fall 2015 using a Veris® 3150 dual depth Soil Surveyor (Veris Technologies, Salina, Kan.) and were collected from every row within the field. Soil moisture measurements were monitored using Watermark sensors (Irrometer; Riverside, Calif.) installed at three different depths (6-in., 12-in., and 24-in.) and positioned in the top of the bed at two sites near the center of each irrigation plot. The reference ET was estimated using both the Penman-Monteith equation (Bachelor, 1984) and an atmometer (ET Gage Company, Loveland, Colo.). Meteorological data were collected at the on-farm weather station (Campbell Scientific, Inc., Logan, Utah) located approximately one quarter mile from the field site. The accumulated ET deficit was calculated each day by adding the recorded daily ET and subtracting the daily rainfall from the accumulated ET deficit of the previous day (Irmak et al., 2005). We followed the practice suggested by Pryor (2015) and adjusted ET deficits to zero following irrigation only if readings from Watermark sensors at the 6-inch depth rose above -30 centibars (kPa). If there was poor irrigation water infiltration, the irrigation event was considered only 50% effective, and the ET deficit was reduced only 50% compared to the previous day. Yield evaluations were made using a grain cart catch weight as well as yield monitor with measurements taken from a harvest swath (12 rows) in the center of each plot running the length of the field. Yield was adjusted to 13% moisture. A two-way factorial treatment structure was used for analysis of the yield-monitor-measured yield with irrigation treatment and soil EC classifications included as a co-variate. Georeferenced data layers from the yield monitor were joined with soil EC measurements. For the final analysis, soil EC values were stratified into two categories—coarse sand (deep < 3.3 mS/m) and loamy sand (> 3.3) mS/m). These categories were based on soil EC data distributions evaluated using ArcGIS©10.2 (ESRI; Redlands, Calif.). Two soil EC classes were set using natural breaks, with the higher EC class designated the loamy sand category, and lower soil EC class designated as coarse sand. Soil textural classes were confirmed based on previous field experience including historical measures from yield, plant and soil monitoring. Data were analyzed using GLM and MIXED procedure in SAS v. 9.0 (SAS Institute, Inc., Cary, N.C.).

Results and Discussion

Precipitation amounts were average for the growing season of May through August; however, with below average rainfall in June, conditions were favorable for an irrigation initiation trial (Table 2). The ET deficit thresholds were reached for each initiation treatment (Fig. 1). The early initiation treatment remained below the prescribed deficit threshold for ET through the growing season. (Table 3). No differences in insect pest numbers were observed among irrigation treatments (data not shown). Soil moisture readings were highly variable among soil textural classes and initiation treatments (data not shown). These observations indicate that irrigation managers should take extra care in positioning sensors in fields with spatially variable soils; multiple sensing stations likely will be required. Lowest yields were associated with the non-irrigated, rainfed treatment ($P < 0.0001$) as measured by grain cart catch weight and for yield monitor evaluations for the length of field plots (Table 1); for irrigated treatments, there were no statistical differences in yields among the three initiation timings. When georeferenced yield monitor data were sorted and evaluated by soil texture, there were significant irrigation timing ($P < 0.001$), soil texture ($P = 0.06$), and irrigation by soil texture interactions ($P < 0.001$; Fig. 2). In loamy sand areas of the field, yields were similar among irrigated treatments; however, in coarse sand areas, yields were reduced as irrigation start times were delayed. Yield patterns in response to irrigation and timing are apparent in the soil EC and yield maps (Fig. 3). The areas of coarse sand encompassed approximately 12% of the field.

Practical Applications

Results from 2016 as well as our earlier field studies (Chlapecka et al., 2016, 2017) confirm current CES recommendations using ET for irrigation initiation timing in sandy soils in Arkansas conditions. Improved understanding of spatial variability in fields with heterogeneous soils and the impact on irrigation management decisions should help producers stabilize yields while reducing costs and improving profitability. Improved irrigation water use efficiency should reduce nutrient loss due to runoff leaving agricultural fields, reducing negative effects to the hypoxic zone in the northern Gulf of Mexico. Water table declines in Arkansas continue to impact production costs and long-term water resource availability for irrigation. Improving irrigation water use efficiency will advance soybean production sustainability in Arkansas.

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Table 1. Treatments, irrigation dates, † and timing and mean yields from yield monitor and from grain cart catch weights in the 2016 irrigation initiation field trial –Manila, Ark.

Treatment (planned ET deficit for irrigation initiation)†	Date of first irrigation	Days after planting	Plant growth stage	Actual ET at irrigation (inches)	Mean yield	
					Yield monitor (bu/ac)‡	Grain cart (bu/ac)‡
Early (1 inch)	10-Jun	41	R1	1.3	53.4 a	58.9 a
Standard (2 inch)	17-Jun	48	R2	2.6	52.4 a	59.1 a
Late (3 inch)	22-Jun	53	R2.5	3.7	52.9 a	58.7 a
Rainfed					34.6 b	39.9 b

† Dates of irrigation (days after planting) for all irrigated treatment plots were 22 June (53), 29 June (60), 5 July (66), 11 July (72),18 July (79), 22 July (83), 2 Aug (94), 8 Aug (100), and 12 Aug (104).
‡ Means within a column followed by different letters are significantly different ($P < 0.001$).

Table 2. Monthly precipitation compared to long-term average from Manila, Ark.

Month	Average precipitation	2016 precipitation	Variation from average
	----------	inches	----------
May	5.37	5.7	0.33
June	3.99	2.55	-1.44
July	4.04	3.88	-0.16
August	2.36	4.16	1.80
Total season	15.76	16.29	0.53

Table 3. Days above the recommended accumulated evapotranspiration deficit for each irrigation timing treatment in 2016 during bloom (R1-R2), pod (R3-R4), pod fill (R5-R6), and the entire season for soybean irrigation initiation trial, 2016, Manila, Ark.

Treatment	Bloom	Pod	Pod Fill	Total
	----------	----------days	----------	----------
Rainfed	12	16	0	28
Late Initiation	3	1	0	4
Standard Initiation	1	0	0	1
Early Initiation	0	0	0	0

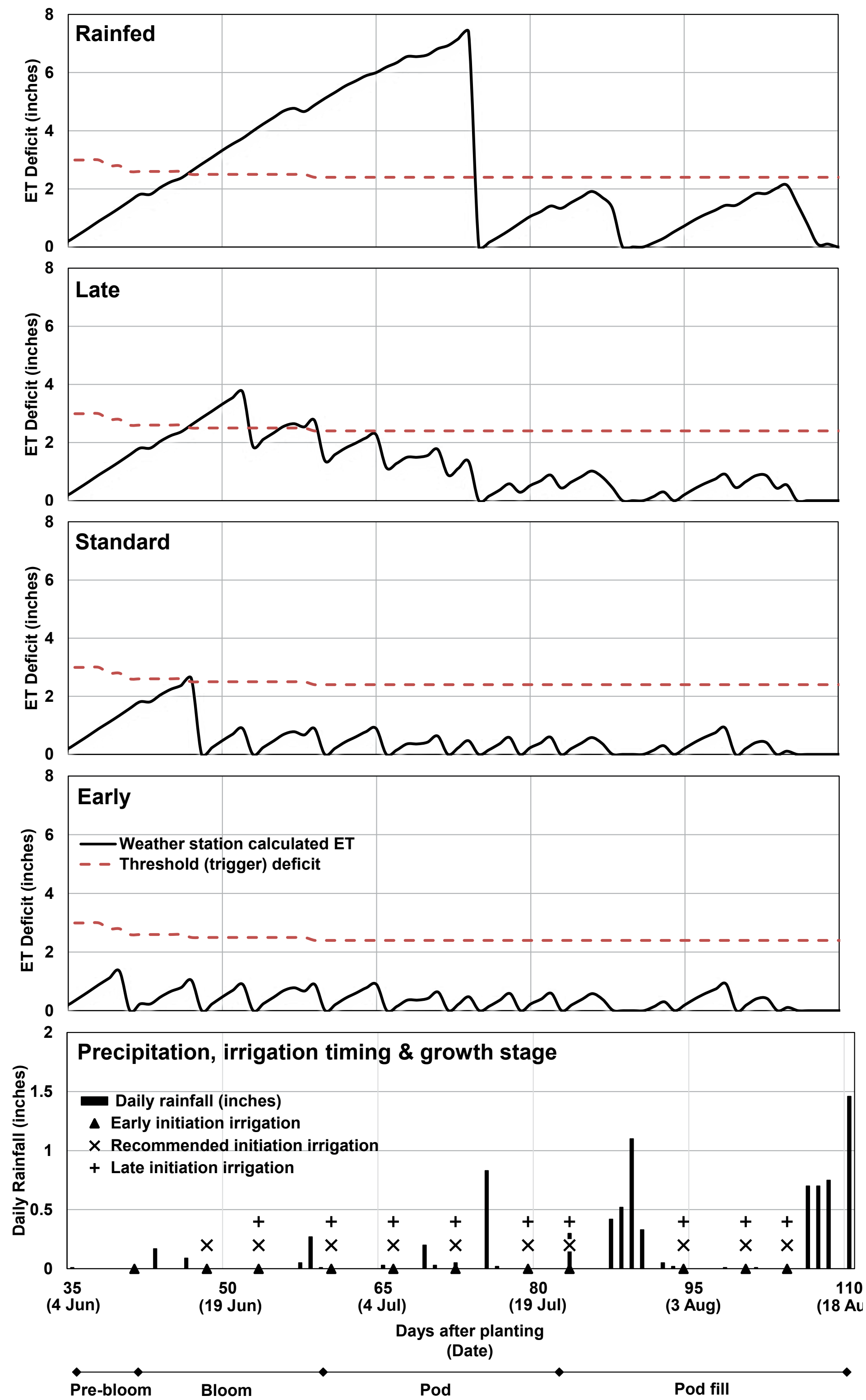

Fig. 1. Accumulated evapotranspiration deficit for each irrigation initiation treatment along with rainfall and irrigation events and plant growth stage for 2016 soybean irrigation initiation trial, Manila, Ark.

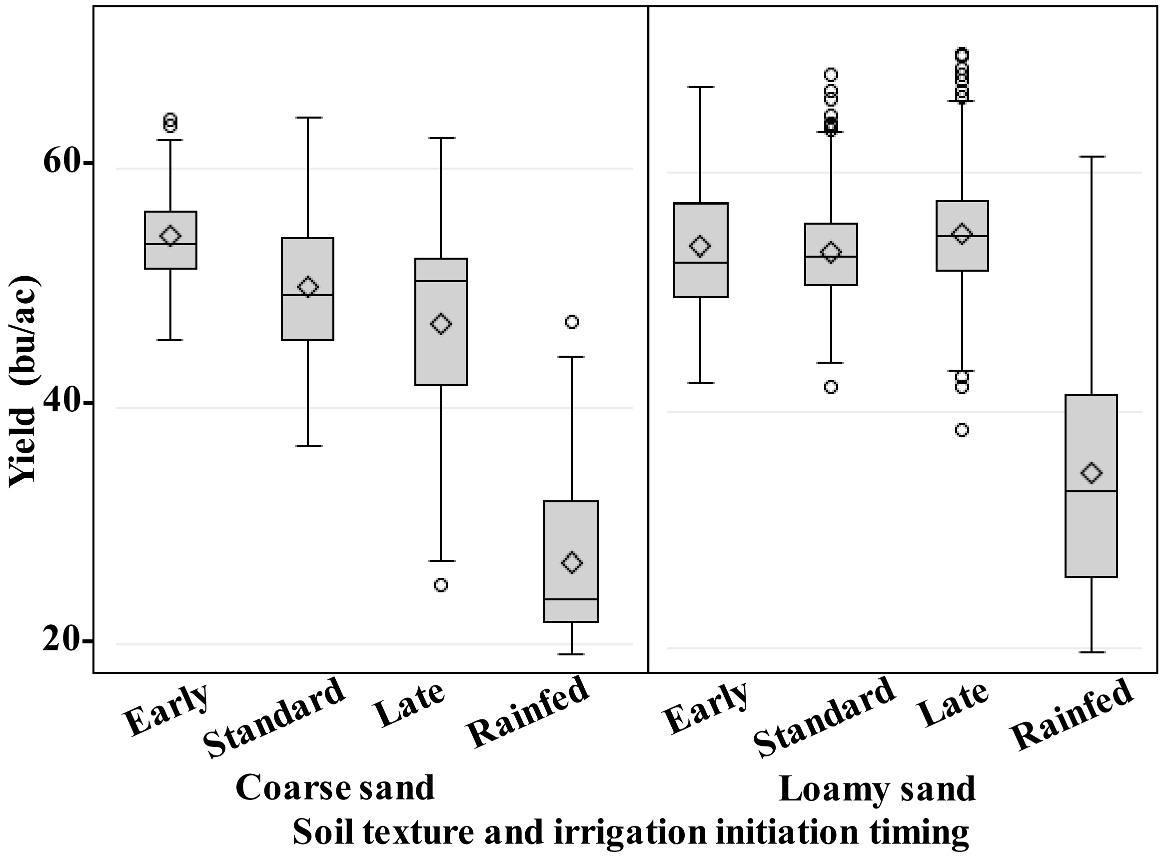

Fig. 2. Soybean yield (bu/ac) for each irrigation timing treatment was measured with yield monitor (YM) and segregated by soil texture classed using soil electrical conductivity (EC) measures from a Veris Soil Surveyor. Diamond represents the mean, the bottom and top edges of the box are located at the sample 25th and 75th percentiles, the horizontal line inside the box is drawn at the 50th percentile (median), the vertical lines (whiskers) extend from the box as far as the data extend (to a distance of at most 1.5 interquartile ranges), and the circles represent outlier YM data points – 2016 soybean irrigation initiation trial, Manila, Ark.

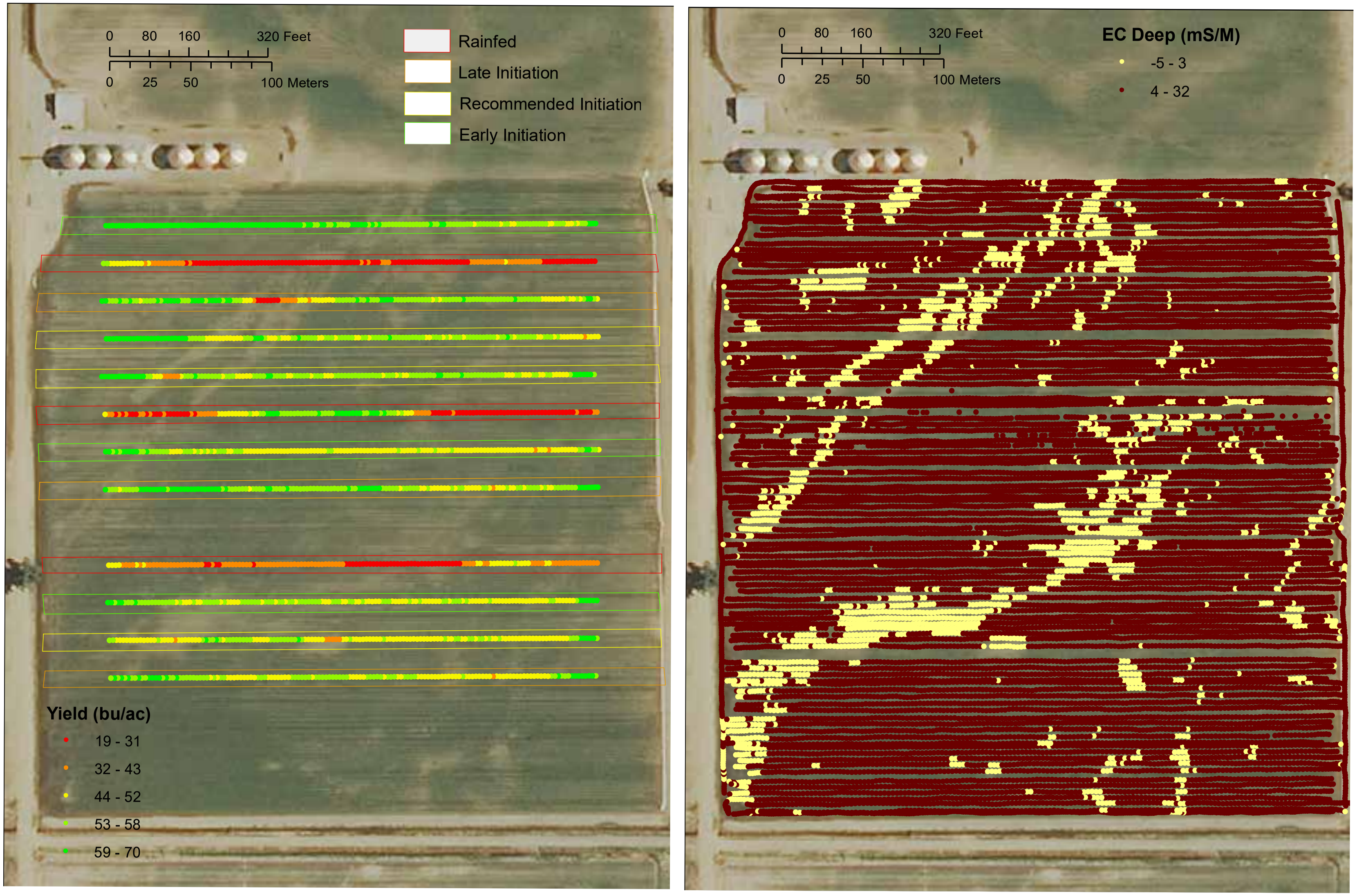

Fig. 3. Yield monitor map with plot strips (left) and soil electrical conductivity (EC) map with the two soil textures (right) for 2016 soybean irrigation initiation trial - Manila, Ark.

Preliminary Evaluation of Long-Term Residue Management and Irrigation Practice Effects on Particulate Organic Matter Fractions in a Wheat-Soybean, Double-Crop System

J. Desrochers[1] *and K.R. Brye*[1]

Abstract

Decades of intense annually cultivated, row-crop agriculture in the Lower Mississippi River Delta region of eastern Arkansas have resulted in reduced soil organic matter (SOM) and soil aggregation. The objective of this field study was to assess the effects of long-term agricultural management practices (i.e., residue level, residue burning, tillage, and irrigation) on particulate organic matter (POM) in the top 10 cm in a wheat (*Triticum aestivum)*-soybean (*Glycine ma*x L. [Merr.]), double-crop production system on a silt-loam soil following 14 complete cropping cycles in eastern Arkansas. A wet-sieving procedure produced macro- and micro-aggregate size fractions [> 0.01 in (250 µm) and > 0.002 to < 0.01 in (> 53 to < 250 µm), respectively] as well as a silt-clay fraction [< 0.002 in (53 µm)]. Averaged across irrigation, tillage, and residue level, the macro-aggregate size fraction was greater when non-burned (62.2%) compared to when burned (58.0%). Averaged across burn and irrigation, macro-aggregate percentage was greater under conventional tillage (CT) in both high- and low-residue levels (65.8 and 63.1%, respectively), which did not differ, compared to under no-tillage (NT) in both high- and low-residue levels (54.1 and 57.4%, respectively). Averaged across tillage, burn, and residue-level treatments, micro-aggregate percentage was greater under NT (29.2%) than CT (21.0%). A greater understanding of the effects of management practices on POM can increase soil health, fertility, and the long-term sustainability of agricultural soils in eastern Arkansas.

Introduction

Increasing resiliency of agricultural soils in the Lower Mississippi River Delta region of eastern Arkansas is gaining importance as groundwater aquifer levels continue to decline due to extensive withdrawals for agricultural irrigation in addition to increasing volatility and unpredictability of weather patterns due to climate change (Scott et al., 1998; IPCC, 2013). Long-term conventional agricultural management practices in the Lower Mississippi River Delta region of eastern Arkansas have led to a reduction in soil health, fertility, capacity to absorb/hold water, and organic matter concentration, effectively reducing the inherent resiliency of agricultural soils (Scott et al., 1998; Six et al., 2004). Alternatively, sustainable agricultural management practices implement agricultural technologies and practices that lead to at least similar production, without deteriorating agricultural conditions (Pretty, 2008).

In a process facilitated by microbial activity, fresh plant or crop residue is bound to soil particles to form macro-aggregates >0.01 in.(>250 µm), which subsequently break down to form macro-aggregates 0.002-0.01 in. (53-250 µm; Six et al., 2004). Increased soil disturbances can decrease soil macro-aggregate composition and result in greater soil micro-aggregate concentration, but ultimately reduce total soil macro- and micro-aggregate concentration leading to increased non-aggregated soil, i.e., the silt-clay fraction <0.002 in. (<53 µm). Differences in particulate organic matter (POM) fractions, partially stabilized organic residue fractions, including inter-aggregate (i.e., organic matter between aggregates) and intra-aggregate (i.e., organic matter within aggregates), within micro- and macro-aggregate fractions due to alternative management practices can be indicative of soil and agronomic benefits (Six et al., 1998).

The objective of this field study was to assess and compare the effects of long-term agricultural management practices (i.e., residue level, residue burning, irrigation, and tillage) on soil particulate organic matter (POM) aggregate-size fractions (i.e. macro-aggregate, micro-aggregate, and silt-clay) in a wheat (*Triticum aestivum*)-soybean (*Glycine max* L. [Merr.]), double-crop production system on a silt-loam-textured, loess soil following 14 complete cropping cycles in eastern Arkansas. Compared to the currently common practices of residue burning and conventional tillage (CT), the effects of non-residue burning and no-tillage (NT) are hypothesized to increase soil POM aggregate fractions and subsequently increase the fraction of macro-aggregates in the soil.

Procedures

On 15 Sept. 2015, 12 to 15 soil samples were collected at random from the top 10 cm of 48, 10 ft wide by 20 ft long plots at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Branch Experiment Station near Marianna, Ark that have been managed since 2002 in a wheat-soybean, double-crop production system with three replications of 16 different residue and water management practice combinations. The management practices include wheat residue burn and no burn, CT and NT, high- and low-wheat residue, and irrigated and dryland soybean production. Amuri et al. (2008) and Norman et al. (2016) provided additional details of the annual plot management and imposed treatments.

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After drying for 48 hours at 70 °C, soil samples were hand-crushed to pass through a 0.28-in (7-mm) sieve, then two batches per plot of approximately 95 g of air-dried soil were separately wet-sieved using a soil-slaking procedure to derive macro-aggregate [> 0.01 in (> 250 μm)], micro-aggregate [> 0.002 to < 0.01 in (> 53 to < 250 μm)], and silt-clay [< 0.002 in (< 53 μm)] POM fractions (Cambardella and Elliott, 1993; Six et al., 1998).

To induce slaking, soil batches were individually sieved by allowing the soil to soak in a 12-in (30-cm) diameter, 0.01-in sieve within an 3.1-in (8-cm) tall, plastic basin filled with distilled (DI) water to 0.4 in (1 cm) above the sieve for 5 minutes. Following slaking, the sieve and soil were oscillated for 2 minutes by manually moving the sieve up and down 50 times at a 1.2-in (3-cm) amplitude in the water. Soil retained on the 0.01-in sieve was transferred to a pre-weighed metal pan, floating organic material was decanted, then dried for 24 h at 105 ˚C to obtain the macro-aggregate fraction weight. The remaining soil in the plastic basin was transferred onto a 0.002-in sieve, placed in another 3.1-in (8-cm) tall plastic basin, upon which the sieving procedure was repeated. The soil remaining on the 0.002-in sieve was transferred onto a pre-weighed metal pan and then dried for 24 h at 105 ˚C to obtain the micro-aggregate fraction weight. The difference in weight from the initial soil batch minus the macro- and micro-aggregate fraction weights was assumed to be the silt-clay mineral fraction..

Due to confounding logistical constraints, the irrigation and wheat residue burning treatments were unable to be simultaneously statistically evaluated. As a result, two separate three-factor analyses of variance (ANOVAs) were conducted using PROC MIXED in SAS (version 9.4, SAS Institute, Inc., Cary, N.C.) to evaluate the effects of tillage, burning, and residue level, (and their interactions) and tillage, irrigation, and residue level, (and their interactions) on the three soil POM aggregate fractions [i.e., macro-aggregate (> 250 μm), micro-aggregates (> 53 to < 250 μm), and silt-clay (< 53 μm)]. Significance was judged at $P \leq 0.05$. When appropriate, means were separated by least significant difference at the 0.05 level.

Results and Discussion

Results for Tillage-Burn-Residue Level Treatment Combinations. Averaged across irrigation, tillage, and residue level, the macro-aggregate size fraction was greater ($P = 0.05$; Table 1) when non-burned (62.2%) compared to when burned (58.0%), contrary to the hypothesis. Burning removed above-ground plant residue, a necessary component for the formation of aggregates, thus likely reducing macro-aggregates concentration over time in the long-term rotation. In addition to the effect of burning, averaged across burn and irrigation, macro-aggregate percentage was greater ($P \leq 0.05$) under CT in both high- and low-residue levels (65.8 and 63.1%, respectively), which did not differ, compared to under NT in both high- and low-residue levels (54.1% and 57.4%, respectively), which differed between them (Fig. 1). A greater macro-aggregate concentration as a result of tillage was contrary to the hypothesis. An increase in tillage can cause an increase in macro-aggregation due to increasing plant residue incorporation and soil contact, thus increasing the potential for macro-aggregate formation.

Averaged across tillage, burn, and residue-level treatments, micro-aggregate percentage was greater ($P < 0.03$) under NT (29.2%) than CT (21.0%). This result supports the concept of soil aggregate turnover rates, whereby tillage results in the physical disintegration of macro- into micro-aggregates prior to attaining micro-aggregate stability, thus resulting in a lower micro-aggregate percentage over time (Six et al., 2000).

The silt-clay fraction can provide a useful measurement to assess the aggregated versus non-aggregated amount of soil. Averaged across irrigation and tillage treatments, the silt-clay percentage was 1.3% greater ($P < 0.02$) in the burn-low-residue than in the other three burn-residue-level treatment combinations, which did not differ (Fig. 2). Residue burning coupled with the low-residue (i.e., non-fertilized) condition likely contributed to lower plant residue inputs, thus reducing aggregate formation.

Results for Tillage-Irrigation-Residue Level Treatment Combinations. Under a loess-derived soil with a silt-loam surface texture in the Lower Mississippi River Delta region of eastern Arkansas, irrigation did not affect macro- or micro-aggregate concentration. However, averaged across irrigation and burn treatments, micro-aggregate percentage was greater ($P \leq 0.04$) under the NT-high-residue (31.0%) than each of the other three tillage-residue-level treatment combinations, while the NT-low-residue (27.4%) was greater than both the high- and low-residue levels under CT, which did not differ (20.5% and 21.5%, respectively; Fig. 1). Greater micro-aggregate percentage is likely attributed to increased aggregate stability resulting from reduced soil disturbance and greater plant residue from NT and N fertilization creating a high-residue environment, respectively, over several years of consistent management.

Averaged across tillage and burn treatments, the silt-clay percentage (i.e., the non-aggregated portion of the soil) was greater ($P < 0.01$) under the irrigated-low- (15.6%) than under the irrigated-high-residue levels (13.6%), while the silt-clay percentages from the non-irrigated-residue-level treatment combinations, which did not differ and averaged 15.0%, were intermediate between the two irrigated-residue-level treatment combinations (Fig. 2). A greater silt-clay percentage under irrigated soybean production can be attributed to increased slaking of unstable aggregates in addition to greater microbial activity, although greater plant residue likely results in greater aggregation due to increased plant residue (Six et al., 2000). In addition, averaged across burn and residue level, the silt-clay percentage was greater ($P < 0.01$) under the NT-irrigated (15.1%) than under the CT-irrigated (14.1%) treatment combination, while the silt-clay percentage from the CT- and NT-non-irrigated, which did not differ and averaged (15.0%), was intermediate between the CT- and NT-irrigated treatment combinations (Fig. 2). No-tillage, in combination with irrigation, likely increased silt-clay percentage, the non-aggregated fraction, due to increasing favorable conditions for microbial decomposition, coupled with a lack of plant-residue-to-soil-particle contact attributed to CT that would otherwise likely increase aggregate formation. These results are consistent with water-stable-aggregate observations made following 10 years of consistent management in the same field study (Smith et al., 2014).

Practical Applications

Greater overall POM, and subsequent macro- and micro-aggregate fractions, will lead to improved soil structure and increased porosity, thus likely increasing root penetration, water infiltration, and potential groundwater recharge. Additionally, an increase in POM will increase soil health and, therefore, increase the natural resiliency of soils to sustain crop yields in the Lower Mississippi River Delta region of eastern Arkansas. Sustainable management practices in a wheat-soybean, double-crop production system in eastern Arkansas, such as NT and non-burning of crop residues, compared to the traditional practices of CT following residue burning, provide alternative management practices that can potentially reduce the dependency on external inputs, including irrigation and nutrient inputs.

Acknowledgements

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Table 1. Summary of the effects of tillage, residue level, and burning, (and their interactions) and tillage, residue level, and irrigation, (and their interactions) on macro- and micro-aggregate and silt-clay particulate organic matter fractions following 14 complete cropping cycles in a wheat-soybean, double-crop production system on a loess soil in eastern Arkansas.

Source of Variation	Macro-aggregate	Micro-aggregate	Silt-Clay
		P	
Tillage	0.03	0.03	0.13
Residue Level	0.81	0.45	0.15
Burn	0.05	0.16	0.25
Tillage × Residue Level	0.05	0.13	0.06
Tillage × Burn	0.15	0.20	0.83
Burn × Residue Level	0.65	0.50	0.02
Tillage × Burn × Residue Level	0.60	0.72	0.40
Tillage	0.03	0.03	0.13
Residue Level	0.81	0.36	0.02
Irrigation	0.31	0.25	0.77
Tillage × Residue Level	0.01	0.04	0.11
Tillage × Irrigation	0.47	0.74	< 0.01
Irrigation × Residue Level	0.48	0.24	< 0.01
Tillage × Irrigation x Residue Level	0.32	0.26	0.90

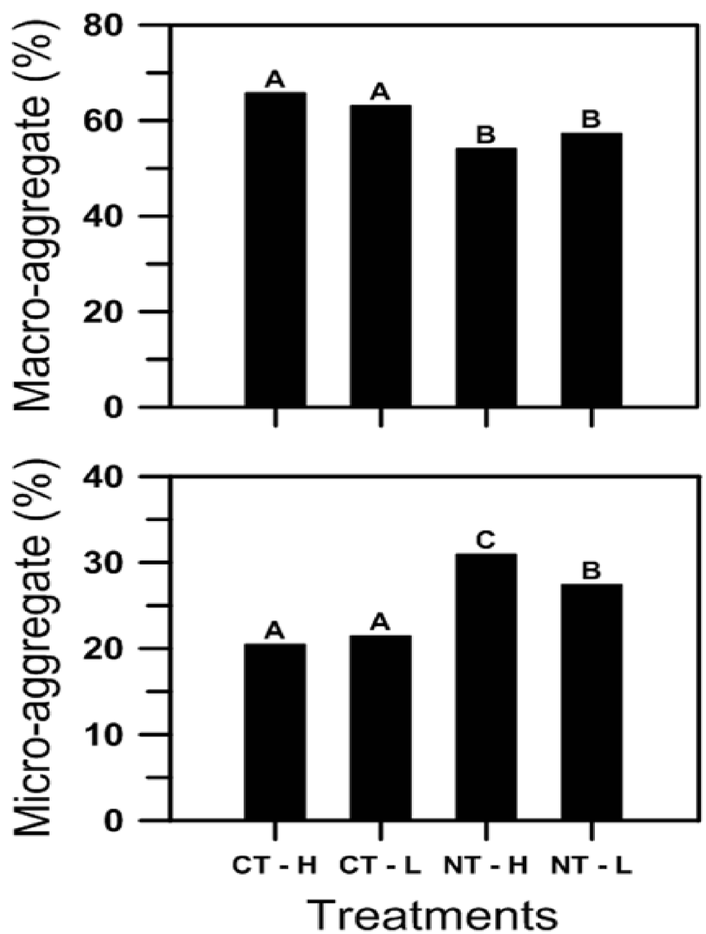

Fig. 1. Tillage-residue-level management practice combination effects on macro- (top) and micro-aggregate (bottom) percentage. Bars with different letters are significantly different at the *P* < 0.05 level. Treatment abbreviations are defined as follows: conventional tillage (CT), no-tillage (NT), and high (H) and low (L) residue level.

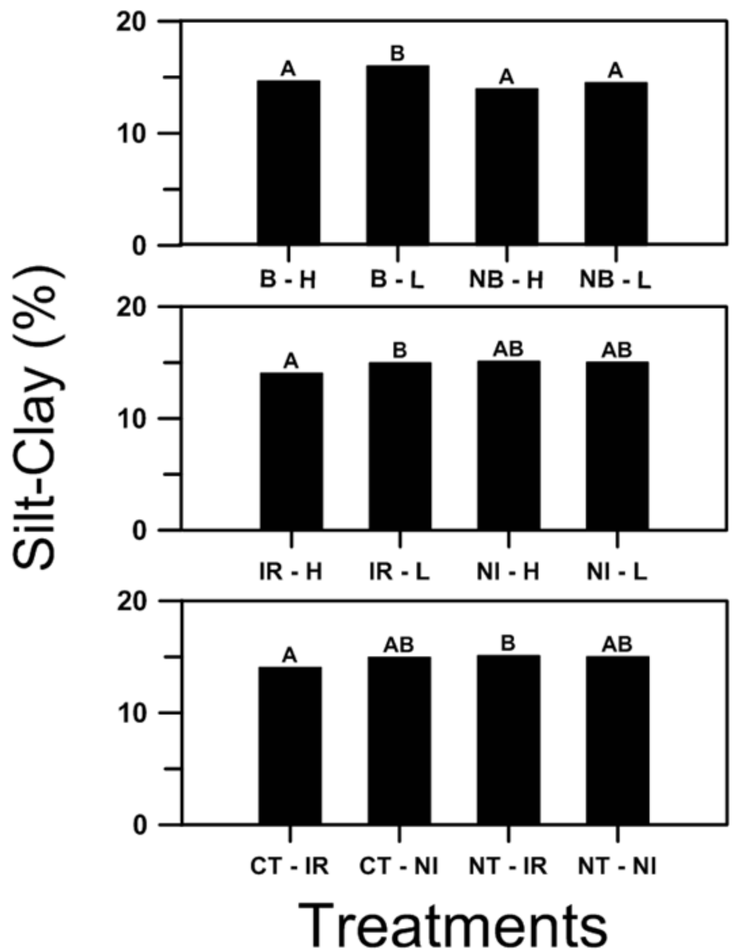

Fig. 2. Burn-residue level (top), irrigation-residue level (center), and tillage-irrigation (bottom) management practice combination effects on silt-clay percentage. Bars with different letters are significantly different at the *P* < 0.05 level. Treatment abbreviations are defined as follows: burned (B) and non-burn (NB) residue, high (H) and low (L) residue level, conventional tillage (CT), no-tillage (NT), irrigated (IR), and non-irrigated (NI).

Evaluation of a Rapid, In-Field Method for Assessing Soybean Potassium Nutritional Status

N.A. Slaton[1], D.A. Sites[1], D.D. Cox[1], T. Richmond[1], J. Hardke[2], T.L. Roberts[1], and J. Hedge[3]

Abstract

Assessing plant potassium (K) sufficiency using plant sap may allow growers to examine crop K needs in the field rather than having to use traditional plant analysis to diagnose or monitor plant K sufficiency. The objectives of this experiment were to evaluate weekly petiole sap analysis as a tool for monitoring soybean [Glycine max. (L.) Merr.] K nutrition as compared to traditional tissue analysis. Leaf and petiole tissue K concentrations were compared to petiole-sap K concentrations for samples collected throughout the soybean reproductive growth phase from different K fertilizer rates in four trials. The tissue K concentrations from soybean leaves, petioles, and sap collected showed similarities as each decreased linearly across time, tissue and sap K concentrations were linearly related with one another, and all methods measured increased K concentrations as K fertilizer rate increased. Sap-K concentration as measured on a handheld device appears to be a promising and rapid method that can be used in the field to monitor soybean nutrition.

Introduction

Plant tissue analysis in production agriculture has historically been used to diagnose nutrient-related maladies or eliminate nutrients as a possible cause after plants express symptoms. The now defunct (in Arkansas) cotton (*Gossypium hirsuturm* L.) petiole monitoring program was one of the few examples of a weekly tissue analysis program to monitor a crop for the nutritional status of selected nutrients (NO_3-N, P, K, and S; Sabbe and Zelinski, 1990). Traditional plant tissue analysis methods usually require at least 24 hours for sample preparation, analysis and result reporting with more time needed if samples must be mailed. In-field nutrient assessments are an alternative to traditional plant analysis but these rapid tests have limited application since research has been conducted primarily in vegetable crop production systems (Rosen et al., 1996; Hochmuth, 2015). The rapid, in-field methods require that sap be extracted from plant tissue, usually petioles. After extraction, the sap is placed on a small handheld instrument, with the first instrument used for this purpose known as the 'Cardy meter'. The original Cardy meter is no longer available but Horiba Scientific (Kyoto, Japan) has developed a series of ion-specific, handheld instruments including one for potassium (K). One limitation for the use of in-field sap analysis as a crop nutrition-monitoring tool is that not all crops are well-suited for sap extraction. The objectives of this experiment were to evaluate weekly petiole sap analysis as a tool for monitoring soybean [*Glycine max* (L.) Merr.] K nutrition and to compare petiole-sap K, petiole K, and trifoliolate leaf K concentrations during the growing season.

Procedures

Soybean grown in two long-term K rate trials and two K application timing trials were used to achieve the objectives of this experiment. The long-term trials included a 16-year trial at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark. (PTRS-LTK, Calhoun series) and a 10-year trial at the Rice Research and Extension Center neat Stuttgart, Ark. (RREC-LTK, Dewitt series), which each include annual K rates of 0 to 160 lb K_2O/acre and are cropped to a rice-soybean rotation. The RREC-LTK trial was drill seeded (7.5-inch row spacing) into a no-till seedbed on 17 May with Armor 47-R13 soybean. The PTRS-LTK trial was drill seeded (15-inch spacing) into a no-till seedbed on 11 May with Pioneer 49T09 soybean. The two K timing trials were both located at the PTRS in fields that will be referred to as I-10 (Calloway series, Pioneer 47T36R) and F3 (Calhoun series, Armor 47-R70). Only two treatments in each trial were used for the objectives of this report and included preplant applications of 0 and 180 lb K_2O/acre. A summary of soil chemical properties including pH (1:2 soil-water mixture) and selected Mehlich-3 extractable nutrients before fertilizer treatment application is listed in Table 1. Selected data from these four trials will be used in this report.

No yield data from these trials is reported here since we were interested only in examining the trends in sap-K concentration among the different levels of K nutrition and comparing sap-K concentration (mg K/L) as determined with the Horiba B-731 LAQUAtwin Compact K Ion Meter with leaf-K and petiole-K concentrations determined via traditional analytical methods.

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[2]Rice Extension Agronomist, Rice Research and Extension Center, Stuttgart.
[3]Program Technician III, Pine Tree Research Station, near Colt.

Tissue samples consisting of two sets of petioles and trifoliolate leaves were collected on five or six different weeks from each trial (Table 2). The first set of tissue was digested with concentrated HNO_3 and 30% H_2O_2, and analyzed for K by inductively coupled plasma spectroscopy. The second set of tissue was used for sap extraction from petioles following the removal of trifoliolate leaves. The petioles were cut into 0.5-inch long pieces, placed in a handheld garlic press to extract the sap into a 3-mL plastic vial, and the vials were frozen until the analysis was conducted in the lab. This procedure generally extracted 0.50 to 0.75 mL sap.

The replicate K concentration data (n = 54) from petiole sap, petiole analysis, and leaf analysis from PTRS-LTK were regressed against the number of days after planting (DAP) using a model that initially included linear and quadratic terms of DAP which were allowed to depend on fertilizer-K rate. The relationship was refined by sequentially removing the most complex non-significant ($P > 0.15$) model terms and running the new model until a final model was reached. The relationships among the three K concentrations (petiole sap, petiole, and leaf) were determined using linear and quadratic models using data from all four trials (n = 81 or 96) that were available at the time this report was prepared.

Results and Discussion

The tissue K concentrations from soybean leaves, petioles, and sap collected from the PTRS-LTK trial showed some similarities as each decreased linearly across time (Figs. 1-3). Petiole-sap K (Fig. 1) and petiole-K (Fig. 2) concentrations each decreased at a uniform rate across time and depended on K fertilizer rate. Leaf-K concentration (Fig. 3) also decreased linearly across time but both the intercepts and slopes depended on K application rate. The R^2 of the three relationships was greatest for petiole-K ($R^2 = 0.89$, CV = 14.2%), intermediate for leaf-K ($R^2 = 0.74$, CV = 15.8%), and lowest for petiole-sap K ($R^2 = 0.60$, CV = 30.8%). The results indicate that sap-K is the most variable of the three measurements, which is not surprising since this is the first time we have extracted sap from tissue. The sap extraction process yielded different volumes of sap among sample times and may be related to soil moisture and plant hydration differences and the fact that the size of petioles changes during the season. A more efficient tool for extracting sap may improve the relationship and increase the speed and ease of sap extraction from petioles.

Data from all sample times and all four K trials were used to evaluate the relationships among sap-K, trifoliolate-leaf K, and petiole-K concentrations (not shown). The relationship between trifoliolate-leaf K and petiole-K concentrations was the strongest with an R^2 value of 0.79 and described by a linear relationship of petiole-K% = $2.45x - 0.68$ where x is %K in the trifoliolate leaves. Petiole-K concentration was approximately two times greater than the K concentration in the upper leaves. Predictions were least accurate when K concentrations were very low, such as late (R5.5 stage) in the growing season. Petiole-K concentration ($R^2 = 0.45$; mg sap-K $L^{-1} = 0.067x + 0.020$ where x is % petiole-K) was a slightly better predictor of sap-K concentration than trifoliolate-leaf K concentration ($R^2 = 0.42$; mg sap-K $L^{-1} = 0.15x - 00.014$ where x is % leaf-K). Although the linear relationships involving sap-K were significant, the strength of the relationships was relatively weak. Further statistical analysis with more data, partitioning data into crop growth stages, and/or examining alternative methods of measuring the sap K are needed before sap can be used to assess soybean K nutrition. Rosen et al. (1996) reported that diluted sap provided stronger relationships for K concentration than undiluted sap. However, the need to dilute sap increases the complexity of the measurement and opportunity for error, especially for making in-field measurements.

Practical Applications

Preliminary information regarding a rapid method of assessing soybean K nutritional status using a handheld instrument was successful in showing the general trend for sap-K to decline across time and differences among K rates. Undiluted petiole-sap K concentrations were more variable than the traditional plant tissue analysis methods but it has the potential advantage of being done in the field and providing a rapid and economical indication of the plant's K status. Additional research will show whether the rate of petiole-sap K concentration decline across time is predictable and uniform across research locations. Despite the greater variability in petiole-sap K concentrations, the method shows.

Acknowledgements

Research was funded by the Soybean Check-off Program administered by the Arkansas Soybean Promotion Board, Rice Check-off Program administered by the Arkansas Rice Research and Promotion Board, Fertilizer Tonnage Fees, and the University of Arkansas System Division of Agriculture. A similar report was published in Research Series 642: Wayne E. Sabbe Arkansas Soil Fertility Studies 2016 (http://arkansas-ag-news.uark.edu/pdf/642.pdf).

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Table 1. Selected soil test information for four sites used for evaluating petiole-sap K trends across time.

Site [a]	Trial[b]	K Rate	pH	P	K	Ca	Mg
		lb K_2O/acre			----------------ppm----------------		
Pine Tree	PTRS-LTK	0	8.0	35	60	2720	544
		40	7.9	35	64	2586	545
		80	7.9	33	85	2322	511
		120	8.0	33	92	2616	541
		160	7.9	31	111	2352	515
Pine Tree	PTRS-I10	0	7.6	13	64	1664	298
Pine Tree	PTRS-F3	0	8.1	10	46	2022	324
Rice Research	RREC-LTK	0	5.4	44	85	998	109
		40	5.5	41	97	987	108
		80	5.3	43	111	928	103
		120	5.3	41	123	898	97
		160	5.4	44	148	920	99

[a] The University of Arkansas System Division of Agriculture's Pine Tree Research Station, PTRS; Rice Research and Extension Center, RREC.
[b] LTK, Long-term potassium, and I-10 and F3 are abbreviations for field names.

Table 2. Planting date, sample dates and average soybean growth stage when tissue samples were collected for petiole-sap K extraction at four fields in 2016.

Event	Growth Stage [a]	Field			
		PTRS-LTK	PTRS-I10	PTRS-F3	RREC_LTK
		------------------------------Month / day ------------------------------			
Plant date	--	May 11	May 7	May 5	May 17
Sample 1	R2	July 12	--	--	July 12
Sample 2	R2-3	July 19	July 19	July 19	July 20
Sample 3	R2-4	July 26	July 27	July 26	July 26
Sample 4	R4-5	Aug 2	Aug 2	Aug 2	Aug 3
Sample 5	R5	Aug 10	Aug 10	Aug 10	Aug 10
Sample 6	R5.5	Aug 17	Aug 17	Aug 17	Aug 18

[a] The listed growth stage represents the stage range for all four sites.

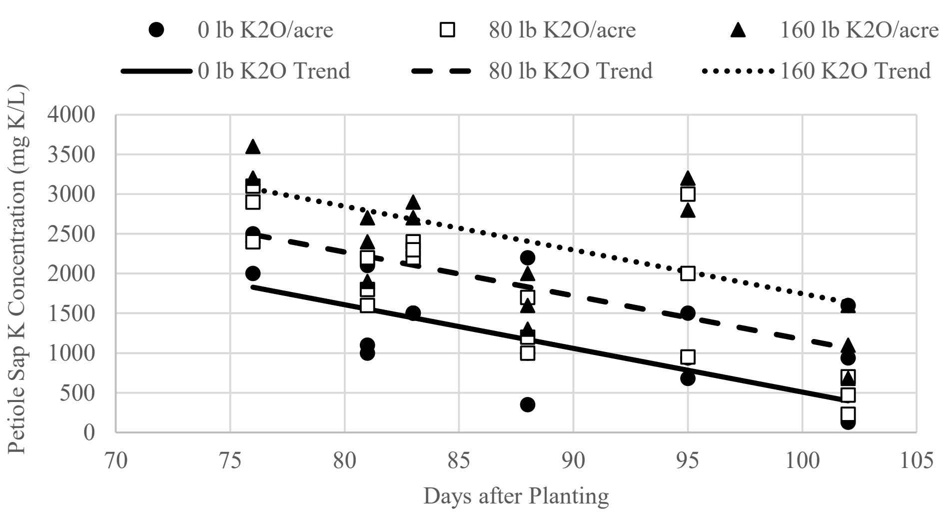

Fig. 1. Petiole-sap K concentration during reproductive growth of soybean receiving three different annual fertilizer-K rates from a long-term trial at the University of Arkansas System Division of Agriculture's Pine Tree Research Station in 2016.

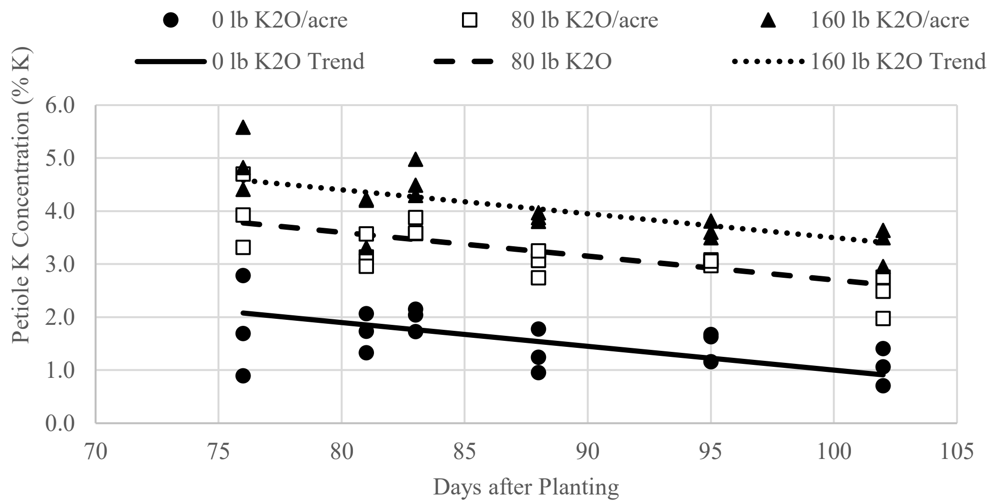

Fig. 2. Petiole-K concentration, as determined by traditional digestion and lab analysis, during reproductive growth of soybean receiving three different annual fertilizer-K rates from a long-term trial at the University of Arkansas System Division of Agriculture's Pine Tree Research Station in 2016.

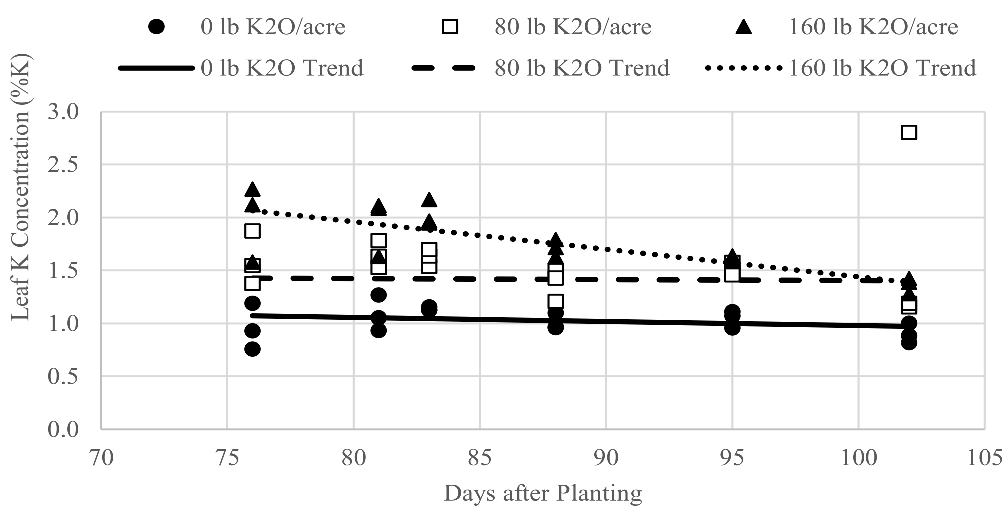

Fig. 3. Leaf-K, as determined by traditional digestion and lab analysis, concentration during reproductive growth of soybean receiving three different annual fertilizer-K rates from a long-term trial at the University of Arkansas System Division of Agriculture's Pine Tree Research Station in 2016.

Why Does Variability Exist among Variety Soybean Chloride Ratings?

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Abstract

Research is conducted annually to rate commercial soybean cultivars for their tolerance to chloride (Cl). The research objective was to examine the leaf-Cl concentration of a population of individual plants from several varieties to determine whether individual plants exhibit consistent Cl uptake (Cl inclusion or exclusion). Leaf tissue from 48 individual plants of eleven varieties representing maturity groups 4.7 to 5.3 were sampled and analyzed for Cl concentration. Leaf-Cl concentration means for each variety ranged from 221 to 3309 ppm Cl with standard deviations of 55 to 2092 ppm Cl indicating large differences in individual plant Cl concentrations for some varieties. Results show that many soybean varieties may be a mixture of plants with either the includer or excluder trait, which partially explains why Cl ratings from five-plant greenhouse assays are sometimes inconsistent.

Introduction

Research is conducted annually to assign a chloride (Cl) trait rating of includer or excluder to commercial soybean varieties. The soybean variety screening program in Arkansas assigns a rating to soybean varieties based on the leaf-Cl concentration of five individual plants grown in the greenhouse that are subjected to relatively high Cl concentrations and compared to known Cl-includer and Cl-excluder check varieties (Green and Conatser, 2014). The information from this screening method sometimes produces inconsistent annual ratings, which is frustrating and sometimes costly for growers that may need a Cl-excluding variety.

Arkansas soybean growers possess limited tools for dealing with Cl toxicity, which highlights the importance of accurate Cl-trait ratings. Our research objective was to examine the leaf-Cl concentration of a population of individual plants from several varieties to better understand whether individual plants within each variety exhibit consistent Cl uptake (Cl inclusion or exclusion). We anticipated that most soybean varieties would be a population of Cl includer and excluder plants rather than a pure population of plants that had similar leaf-Cl concentrations.

Procedures

A field trail was established at the University of Arkansas System Division of Agriculture's Pine Tree Research Station during 2016 on a Calloway silt loam. Selected mean soil chemical properties from composite soil samples (0- to 4-in depth) included 6.3 pH, 88 µmhos/cm for soil electrical conductivity (1:2 soil weight to water volume mixture), 22 ppm Mehlich-3 P, 106 ppm Mehlich-3 K, 256 ppm Mehlich-3 Mg, 1161 ppm Mehlich-3 Ca, and 15.8 ppm water-soluble Cl. No fertilizers or soil amendments were added to the field prior to or during the growing season. The field had been fallow for at least two years.

The eleven varieties listed in Table 1 were selected for this study to represent maturity groups (4.7 to 5.3) commonly grown in Arkansas with some of the varieties having inconsistent Cl ratings (Table 1). From the most recent Cl ratings available for each variety, three varieties were rated as Cl-excluders, three were rated as mixed, and five were rated as Cl-includers. The Cl-ratings for the selected varieties may not be consistent with company ratings or ratings given in previous years of the Arkansas Cl screening trial.

Each variety was planted (130,000 seed/acre) in an 8-row strip that was 500 ft long with rows on the top center of beds spaced 30 inches apart. Beginning 100-ft inside the west border of the field, where polypipe was positioned for irrigation, three 50-ft blocks spaced 50-ft apart were established. Within each block at the V6 growth stage, 16 individual plants (48 plants/variety) from the two middle rows of each strip were identified with a flag and plants on either side of the flagged plant were pulled to avoid confusion about which plant was selected for the study. Soybean management in regard to pest control and irrigation closely followed the University of Arkansas System Division of Agriculture Cooperative Extension Service production guidelines. Soybean was furrow irrigated with surface-water from a nearby pond (61 mg Cl/L when sampled on 2 Aug. 2016).

At the R2-R3 growth stage, trifoliate leaf samples (leaf and petiole) were collected by removing the top four fully matured leaves and petioles from each plant. The sampled tissue was oven-dried, weighed, ground, extracted with water (Kalra, 1998), and extracts were analyzed for Cl concentration using inductively coupled plasma spectroscopy (Spectro Analytical Instruments Inc., Mahwah, N.J.).

The experiment was a strip trial design containing 11 varieties. The mean and standard deviation of leaf-Cl concentration were calculated for each variety using the MEANS procedure of SAS (v. 9.4, SAS Inst., Cary, N.C.). The MIXED procedure was used to determine if location in the field (block) had a significant effect on leaf-Cl concentra-

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tion to address the potential for spatial variability. For this analysis, variety and block were treated as fixed effects and significance was interpreted at the 0.10 level.

Leaf-Cl concentrations were allocated into six categories including low (<500 ppm), moderately low (501-1000 ppm), moderate (1001-2000 ppm), moderately high (2001-3000 ppm), high (3001-4000 ppm), and very high (>4000 ppm Cl) to represent the range of leaf-Cl concentrations. The Cl concentrations that define each category in this research are somewhat subjective (i.e., dependent on site and environment) and different Cl concentration ranges might be needed for an environment with different amounts of Cl. The percentage of plants within each Cl concentration category was summarized across all varieties and then by variety. Linear regression analysis was performed to evaluate the relationship between mean leaf-Cl concentration and individual leaf-Cl concentrations of each variety.

Results and Discussion

This study aimed to answer two questions; do individual, field-grown plants of a single variety have similar leaf-Cl concentrations, and, more comprehensively, why are variety Cl ratings inconsistent among years or screening times? The block main effect addressing leaf Cl spatial variability was not statistically significant ($P = 0.33$) indicating that numerical differences in mean leaf-Cl concentration among blocks were due to the different behavior of individual plants (n =16) in each variety to accumulate Cl and not on the location in the field, Cl movement with irrigation water, or soil properties.

Leaf-Cl concentrations averaged across plants within a single variety ranged from 221 to 3309 ppm Cl (Table 1). Across the 11 varieties in our trial, the leaf Cl categories in decreasing order of percentage of the total plant population followed the order of low, moderate, moderately high, moderately low, high and very high (Table 2). The distribution of plants among Cl concentration categories was clearly variety dependent (Table 2). The all-variety distribution does not likely represent that of all commercially available varieties since many of these 11 varieties were picked for specific reasons.

Pioneer 49T80R, rated as a Cl-excluder, had 100% of its plants with low leaf-Cl concentrations, which is behavior expected from a true Cl-excluding variety in this environment. Armor 47-R70 had over 90% of plants with leaf-Cl concentrations >1000 ppm Cl, which is consistent with the Cl-includer variety. Varieties labeled as mixed (Asgrow 5233, Progeny 4900RY, and Progeny 5333RY) had 43%, 85%, and 79% of plants with low leaf-Cl concentrations (<500 ppm) and 47%, 8%, and 17% of plants with leaf-Cl concentrations >1000 ppm, respectively. The remaining includer varieties (Armor 47-R13, Asgrow 4934, Dynagro S52RY75, and Pioneer 49T09BR) had no plants with low leaf-Cl concentrations (<500 ppm) and all, except Asgrow 4934, had >90% of the plants with leaf-Cl concentrations >1000 ppm. The two remaining excluder varieties (GoSoy 4914GTS and NK S48-D9) produced 13% and 50% of plants with leaf-Cl concentrations <500 ppm and 15% and 44% with >1000 ppm, respectively. The majority of the GoSoy 491GTS plants had moderately low Cl concentrations suggesting it behaved as a Cl excluder.

A preliminary configuration for a new rating system was examined using plant mean leaf-Cl concentrations and Cl distribution data. We summarized the 11 varieties into two categories including the percentage of plants with low Cl (< 500 ppm Cl) and plants having moderate and greater Cl concentrations (>1000 ppm Cl, Tables 1 and 2). The mean leaf-Cl concentration (dependent variable, Table 1) regressed against the percentage of plants having low leaf-Cl concentrations (independent variable, Table 2) showed a relatively weak relationship ($R^2 = 0.57$, not shown). However, the relationship between mean leaf-Cl concentration and the percentage of plants having moderate and higher leaf-Cl concentrations was positive, linear, and relatively strong (Fig. 1).

Based on the relationship in Fig.1, a preliminary rating system on a 1-10 scale could possibly be developed using composite leaf samples from field-grown variety trials. For example, varieties having less than 10% of its plants with leaf-Cl concentrations >1000 ppm for this field environment would be assigned a rating of 1 and represent a strong Cl-excluder (e.g., 2 = 11-20%, 3 = 21-30%, 4 = 31-40%, etc…). Additional research is needed to confirm the consistency of these results using more varieties and different locations.

Practical Applications

The results of our study showed that many soybean varieties may be a mixture of plants with either the includer or excluder trait and explains why Cl ratings are sometimes inconsistent. The ratio of includer to excluder plants in the population of a single variety likely influences the overall performance of the variety in the presence of high Cl concentrations and the mean leaf Cl concentration of field grown plants appears to be well correlated with the percentage of Cl-including plants in the population. Our trial did not fully examine whether plants have a range of abilities to include or exclude Cl, but a wide range of leaf-Cl concentrations were measured. The fact that most varieties likely contain a mixture of includer and excluder plants may be the primary reason for a single variety having different Cl-trait ratings from the annual five-plant greenhouse screening. Research to characterize the ratio of includer and excluder plants of more varieties with different maturity groups and herbicide tolerance technologies is warranted and needed to develop a more robust and accurate Cl-trait rating system. The data from this trial will also provide insight as to how many plants of each Cl rating (includer, excluder and mixed) varieties are needed to provide reasonably accurate assessments of the population.

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Table 1. Varieties, Cl-rating category, leaf Cl means and standard deviations, and percentage of plants in two categories for each variety from the field trial conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station in 2016.

	Cl Rating (Cl Screening Trials)			Leaf-Cl Concentration		Percentage of Plants	
Variety	2013	2014	2015	Mean	SD[a]	<500 ppm	>1000 ppm
				------ppm Cl----		--------------%-------------	
Pioneer P49T80R	Excluder	Mixed	Excluder	221	55	100	0
Progeny P4900RY	-	Excluder	Mixed	400	670	85	8
Progeny P5333RY	Excluder	Excluder	Mixed	437	522	17	17
GoSoy 4914GTS	Mixed	Excluder	Excluder	759	253	13	15
NK S48-D9	-	Includer	Excluder	875	837	50	44
Asgrow AG5233	Mixed	Mixed	Mixed	1045	906	43	47
Asgrow AG4934	Includer	Includer	Includer	1319	456	0	66
Armor 47-R70	-	-	Includer	1693	513	0	96
Armor 47-R13	Includer	Includer	-	2225	1124	0	94
Pioneer P49T09BR	-	-	Includer	2350	1397	0	100
Dynagro S52RY75	-	Mixed	Includer	3309	2092	0	100

[a] SD, Standard deviation

Table 2. Distribution of leaf-Cl concentration using all varieties from the 2016 soybean chloride population trial conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station in 2016.

	Leaf Cl Concentration Range					
Variety	Low 0-500 ppm	Moderately Low 501-1000 ppm	Moderate 1001-2000 ppm	Moderately High 2001-3000 ppm	High 3001-4000 ppm	Very High >4000 ppm
	--% of plants--					
Pioneer 49T80R	100	0	0	0	0	0
Progeny 4900 RY	85	7	0	6	2	0
Progeny 5333RY	79	4	15	2	0	0
GoSoy4914GTS	13	72	15	0	0	0
NK S48-D9	50	6	33	11	0	0
Asgrow AG5233	43	11	32	13	2	0
Asgrow AG4934	0	34	62	4	0	0
Armor 47-R70	0	4	71	23	2	0
Armor 47-R13	0	6	50	27	8	8
Pioneer 49T09BR	0	0	44	48	4	4
Dyna-Gro S52RY75	0	0	21	44	17	18
All Varieties	34	13	31	16	3	3

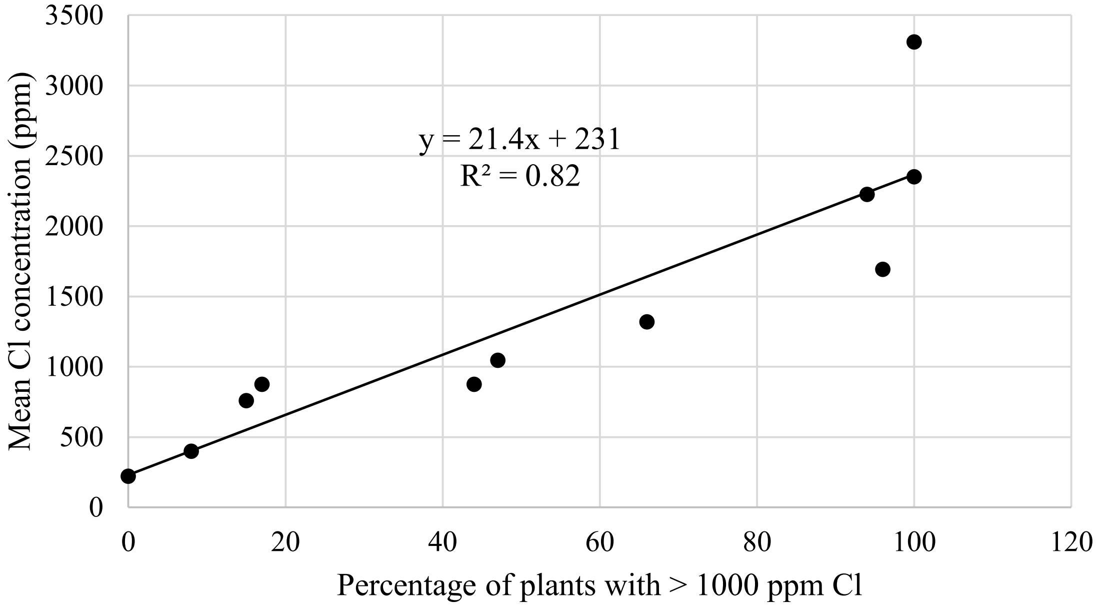

Fig. 1. Mean leaf chloride (Cl) concentration (n = 48) regressed across percentage of plants with leaf Cl concentrations greater than 1000 ppm Cl. Data taken from soybean Cl population trial conducted at the University of Arkansas System Division of Agriculture's Pine Tree Research Station in 2016.

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