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Corn and Grain Sorghum Research Studies 2022

Victor Ford, Jason Kelley, and Nathan McKinney II, editors

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ARKANSAS
CORN AND GRAIN SORGHUM
RESEARCH STUDIES
– 2022 –

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University of Arkansas System Division of Agriculture,
Little Rock and Fayetteville, Arkansas

Arkansas Agricultural Experiment Station
University of Arkansas System
Division of Agriculture
Fayetteville, Arkansas 72704

INTRODUCTION

The 2022 edition of the Arkansas Corn and Grain Sorghum Research Studies Series includes research results on topics pertaining to corn and grain sorghum production, including weed, disease, and insect management; economics; sustainability; irrigation; post-harvest drying; soil fertility; mycotoxins; cover crop management; and research verification program results.

Our objective is to capture and broadly distribute the results of research projects funded by the Arkansas Corn and Grain Sorghum Board. The intended audience includes producers and their advisors, current investigators, and future researchers. The Series serves as a citable archive of research results.

Reports in this publication are 2–3 year summaries. The reports inform and guide our long-term recommendations but should not be taken solely as our recommended practices. Some reports may appear in other University of Arkansas System Division of Agriculture's Arkansas Agricultural Experiment Station publications. This duplication results from the overlap between disciplines and our effort to broadly inform Arkansas corn and grain sorghum producers of the research conducted with funds from the Corn and Grain Sorghum Check-off Program. This publication may also incorporate research partially funded by industry, federal, and state agencies.

The use of products and trade names in any of the research reports does not constitute a guarantee or warranty of the products named and does not signify that these products are endorsed or 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, Agricultural Research Service.

We extend thanks to the staff at the state and county extension offices and the research centers and stations; producers and cooperators; and industry personnel who assisted with the planning and execution of the programs. A special thanks to Dr. Victor Ford for his time, effort, and support of the Series. This publication is available as a research series online at: https://aaes.uada.edu/communications/publications/

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2022 Corn and Grain Sorghum Research Verification Program

C. Capps,[1] J.P. Kelley,[2] B. Deaton,[3] and C.R. Stark Jr.[3]

Abstract

During 2022, the Corn and Grain Sorghum Research Verification Program (CGSRVP) was conducted on 9 irrigated corn fields. Counties participating included Desha (2), Faulkner, Independence, Jefferson, Lonoke, Monroe, Poinsett, and Prairie. Corn grain yields averaged 195 bu./ac across the 9 fields. The Arkansas state average corn grain yield for 2022 was 173 bu./ac (USDA-NASS, 2023). Fields were planted between 28 March and 12 May with an average planting date of 21 April. Final plant populations ranged from 29,900 to 35,000 plants/ac and averaged 33,982 plants/ac. Fields were furrow irrigated 3 to 7 times depending on the field, and soil moisture sensors were used to assist with irrigation scheduling. Preplant fertilizer applied averaged 42-41-53-12-1 lb/ac of nitrogen, phosphorus, potassium, sulfur, and zinc, respectively. The average total in-season fertilizer applied across all fields was 224-41-63-26-1 lb/ac of nitrogen, phosphorus, potassium, sulfur, and zinc, respectively. The resulting nitrogen fertilization program achieved 1.0 bu. of corn grain for every 1.14 lb/ac of nitrogen fertilizer applied. Economic returns to total costs/acre were $739.18 when no land charges were applied. Fertilizer/nutrients were the largest input costs at $205.98 and $129.46/ac, respectively, and accounted for 22% and 35% of total expenses.

Introduction

The Arkansas Corn and Grain Sorghum Research Verification Program (CGSRVP) represents a public demonstration of research-based Extension recommendations on actual working farms in a field-scale farming environment. The programs stress intensive management with timely inputs and integrated pest management to maximize yields and net returns. The overall goal is to verify that crop management using the University of Arkansas System Division of Agriculture recommendations can result in high-yielding and profitable corn and grain sorghum with current technology. The objectives of the programs are: 1) to educate producers on the benefits of utilizing University of Arkansas System Division of Agriculture recommendations for improved yields and/or net returns; 2) to conduct on-farm field trials to verify research-based recommendations; 3) to aid researchers in identifying areas of production that require further study; 4) to improve or refine existing recommendations which contribute to more profitable production; 5) to incorporate data into Extension educational programs at the county and state level; and 6) to provide in-field training to county agents, consultants, and producers on current production recommendations.

The CGSRVP started in 2000 after the initiation of a statewide checkoff program for corn and grain sorghum, which is distributed by the Arkansas Corn and Grain Sorghum Promotion Board. Since the inception of the program, there have been 176 corn or grain sorghum fields enrolled in the program in thirty-five counties.

Procedures

In the fall of each year, the CGSRVP program coordinator sends out requests to county extension agents for program enrollment. County extension agents find cooperators who want to be part of the program and agree to pay production expenses, provide crop expense information for economic analysis, and implement recommended production practices in a timely manner throughout the growing season. During the winter months, the program coordinator and county extension agent meet with the producer to discuss field expectations; review soil fertility, weed control, irrigation, insect control, and hybrid recommendations; and provide details of the program. As the planting season begins, the program coordinator, along with the county agent and cooperator, scout each field weekly and discuss management decisions that are needed that week and the upcoming week. The program coordinator provides the county extension agent and producer with an electronic crop scouting report that outlines recommendations for the week and future expectations.

An on-site weather station provides in-field rainfall data as well as high- and low-temperature data, which is used to calculate accumulated growing degree days for each week. When applicable, irrigation well flow meters are installed prior to initiation of irrigation to document the amount of irrigation water used during the year. Soil moisture sensors are installed in representative areas of the field early in the growing season to provide soil moisture information and are used as a tool to determine initiation frequency and termination of irrigation.

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Results and Discussions

Overall corn yields during the 2022 growing season ranged from 160 bu./ac in Faulkner County to a high of 249 bu./ac in Desha County 2 (Table 1). The overall average yield of the 9 fields in the program was 195 bu./ac. The state average corn yield for 2023 was 173 bu./ac (USDA-NASS, 2022). All corn fields were planted within recommended planting date ranges. The average planting date for all fields was 21 April, with an average harvest date of 8 September. Plant populations averaged 33,982 plants/ac, which would be at a recommended level for most irrigated fields and hybrids.

Fertilizers applied to fields closely followed current University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) recommendations and were based on soil analysis and yield goals (Table 2). Preplant fertilizer applied to corn fields averaged 42-41-53-12-1 lb/ac of nitrogen-phosphorus-potassium-sulfur-zinc, where nitrogen applied preplant or at planting totaled approximately 19% of the total nitrogen applied during the season. Side-dressed nitrogen applied at the V4–V8 growth stage averaged 117 lb of nitrogen/ac with a nitrogen source of urea, ammonium sulfate, urea-ammonium nitrate, or a combination of those sources. A pre-tassel application of nitrogen, typically 100–125 lb of urea fertilizer/ac, was made between the V12 to R1 growth stage and is a common and recommended nitrogen management practice in Arkansas. Total nitrogen applied to corn fields was 224 lb/ac when averaged across all fields. Applied nitrogen fertilizer resulted in an average yield of 195 bu./ac, which led to 1 bushel of corn grain for every 1.14 lb of nitrogen fertilizer applied.

Pest management practices followed current CES recommendations. None of the corn fields met thresholds requiring an insecticide application during the season, and no fields were sprayed with a foliar fungicide. Herbicides applied to corn fields varied, but most commonly consisted of a combination of glyphosate, metolachlor, atrazine, and mesotrione that was applied in a one- or two-pass program.

Irrigation is an important management practice for Arkansas corn. Statewide approximately 95% of the corn grown in the state is irrigated (USDA-FSA 2023). Irrigation initiation, frequency, and termination were scheduled with the help of the Arkansas Irrigation Scheduler program and the use of soil moisture sensors to determine soil moisture content. During 2022, overall irrigation requirements for corn were about average for most fields compared to previous years and on average each field was irrigated 5.6 times (Table 3). Each furrow irrigation was estimated to provide two acre-inches of irrigation water. Average rainfall on corn fields in 2022 from planting to maturity was 16.39 inches demonstrating that total rainfall may be adequate for corn production, but the poor distribution of rainfall during the growing season is the reason such a high percentage of Arkansas corn is irrigated.

On-site weather stations provided high- and low-temperature data to allow for accurate measurement of Growing Degree Days (GDD). The formula used to determine GDDs for corn is as follows:

$$\text{GDDs} = \frac{(\text{Daily Maximum Air Temperature} + \text{Daily Minimum Temperature})}{2} - 50$$

with a maximum air temperature set at 86 °F and a minimum temperature for growth set at 50 °F. During weekly field visits, corn growth stages were recorded and compared to accumulated GDDs. Table 4 shows the 2022 average GDDs accumulated by each growth stage listed. These values align closely with reported GDDs needed to reach maturity for full-season hybrids (110–120 days) that we typically grow in Arkansas. GDDs can accurately predict corn growth stages and assist in management decisions such as irrigation termination.

Economic Analysis

Records of field operations on each field that were compiled by the CGSRVP coordinator, county extension agent, and producer serve as the basis for estimating costs and economic returns that are discussed in this section. Production data from the nine irrigated corn fields were applied to determine costs and returns above operating costs, as well as total specified costs. Operating costs and total costs per bushel indicate the commodity price needed to meet each cost type.

Production expenses are expenditures that would require annual cash outlays and would be included in an annual operating loan application. Actual quantities of all production inputs, as reported by the cooperators, are used in this analysis. Input prices are determined by data from the 2022 Crop Enterprise Budgets published by the Cooperative Extension Service and information provided by the producer cooperators. Fuel and repair costs for machinery are calculated using a budget calculator based on parameters and standards established by the American Society of Agricultural and Biological Engineers. Machinery repair costs should be regarded as estimated values for full-service repairs, and actual cash outlays could differ as producers utilize employee labor or provide unpaid labor for equipment maintenance.

Operating expenses include production expenses, as well as interest paid on operating capital and all post-harvest expenses. Post-harvest expenses include, as applicable for each crop, hauling, drying, check-off fees, and other expenses typically incurred after harvest. Post-harvest expenses increase or decrease with yield.

Ownership costs of machinery are determined by a 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. Machinery costs are estimated by applying engineering formulas to represent the prices of new equipment. This measure differs from typical depreciation methods, as well as actual annual cash expenses for machinery, but establishes a benchmark that estimates farm profitability.

Operating costs, total costs, costs per bushel, and returns are presented in Tables 5 and 6. Costs in this report do not include land costs, management, or other expenses and fees not associated with production. The corn grain price used for economic calculations was $7.23/bu. and was the three-week average for the most active weeks of the harvest period each year. The average corn yield from the irrigated corn verification fields was 195 bu./ac.

The production expenses for irrigated corn fields harvested for grain were $584.00/ac in 2022. On average, fertilizers and nutrients were the largest expense category at $205.98/ac, or 35% of production expenses for irrigated corn fields. Seed costs averaged $129.46/ac which was 22% of production expenses on irrigated corn fields.

With an average corn yield of 195 bu./ac for all irrigated fields, operating costs were $584.00/ac for 2022. Return to operating costs for all irrigated corn fields for 2022 was $826.04/ac. Fixed costs for irrigated fields were $86.91/ac. Returns to total cost for irrigated fields was $739.18/ac. Total specified costs for all irrigated corn fields during 2022 averaged $3.06/bu.

Practical Applications

The corn and grain sorghum research verification program continues to serve as a field-scale demonstration of all CES recommendations for growing corn and grain sorghum in Arkansas. It serves as a method to evaluate recommendations and adjust or define areas that may need more research in the future. The program results are assembled into a database to allow long-term monitoring of agronomic and economic trends of Arkansas corn and grain sorghum production. The program also aids in educating new county agents, consultants, and producers who are less familiar with current production recommendations.

Areas of ongoing research that are being evaluated in the corn and grain sorghum research verification program fields include the use of foliar tissue testing during the season to evaluate whether current fertilizer recommendations for corn provide adequate levels of nutrients in the plants. Tissue samples were taken during the V10-tassel stage to determine whether nitrogen levels in the plant were adequate and if a pre-tassel nitrogen application was needed. End-of-season corn stalk nitrate samples were also collected to determine if nitrogen was adequate during the season and to evaluate overall nitrogen efficiency. Soil moisture sensors were used in all corn fields to track soil moisture levels and will help serve as a testing program for using soil moisture sensors for irrigation timing. The verification fields also serve as a pest management monitoring program for foliar diseases in corn, such as southern rust, to alert growers of potential pest problems.

The corn research verification has annually demonstrated that corn can be a profitable crop for Arkansas growers and that the published research-based recommendations for corn production are dependable for profitable, high yielding, and provide sustainable production. The CES recommendations will be revised according to new findings and used in the verification program to ensure continued success for Arkansas corn growers.

Acknowledgments

The authors appreciate the support provided by Arkansas corn and grain sorghum producers through check-off funds administered by the Arkansas Corn and Grain Sorghum Promotion Board. In addition, we appreciate the cooperation of participating producers and County Extension agents who enrolled in the program. Support was also provided by the University of Arkansas System Division of Agriculture.

Literature Cited

USDA-NASS. 2023. United States Department of Agriculture National Agricultural Statistics Service. Accessed 1 April 2023. Available at: https://quickstats.nass.usda.gov/

USDA-FSA. 2023. United States Department of Agriculture Farm Service Agency. Accessed 1 April 2023. Available at: https://www.fsa.usda.gov/news-room/efoia/electronic-reading-room/frequently-requested-information/crop-acreage-data/index

Table 1. 2022 Corn Research Verification Program locations, hybrid planted, field size, row spacing, previous crop, plants per acre, plant date, harvest date, and yield.

County	Hybrid	Field Size	Row Space	Previous Crop	Plants Per Acre	Plant Date	Harvest Date	Yield
		(ac)	(in.)					(bu./ac)
Desha 1	DeKalb DKC 67-94TRE	121	38	soybean	35,500	3/28	8/27	211
Desha 2	AgriGold 6544VT2P	39	38	soybean	33,750	3/29	8/30	249
Faulkner	Revere 1987VT2P	31	30	soybean	29,900	5/1	8/19	160
Independence	Dyna-Gro 57CC51	40	30	soybean	34,833	4/30	9/20	167
Jefferson	Progeny 9117VT2P	65	38	soybean	34,500	4/23	9/1	215
Lonoke	DeKalb DKC 65-95VT2P	44	30	soybean	32,437	4/29	9/24	188
Monroe	BH Genetics 8721VT2P	28	30	soybean	35,000	5/12	9/3	174
Poinsett	Pioneer 1847Conv	80	30	soybean	34,916	4/30	9/25	196
Prairie	DeKalb DKC 70-27	53	30	soybean	35,000	4/10	9/14	194
Mean	---	**71.1**	**---**	**---**	**33,982**	**4/21**	**9/8**	**195**

Table 2. 2022 Corn Research Verification Program locations, preplant, sidedress, pretassel, total fertilizer applied, and soil type.

County	Preplant Fertilizer	Sidedress	Pretassel[a]	Total Fertilizer	Soil Type
	--------------------------------Applied Fertilizer lb/ac of N-P-K-S-Zn-------------------------------				
Desha 1	49-23-18-4-2	98-0-50-7-0	69-0-0-0-0	216-23-68-11-2	Rilla Silt Loam
Desha 2[b]	40-0-30-20-1	93-0-0-17-0	93-0-0-17-0	226-0-30-54-1	Hebert Silt Loam
Faulkner	44-60-100-24-0	131-0-0-18-0	46-0-0-0-0	221-60-100-42-0	Gallion Silt Loam
Independence	39-91-32-24-0	161-0-0-0-0	58-0-0-0-0	258-91-32-24-0	Egam Silt Loam
Jefferson	37-0-40-0-0	126-0-39-12-0	57-0-0-0-0	220-0-79-12-0	Rilla Silt Loam
Lonoke	46-0-60-0-0	113-0-0-21-0	58-0-0-0-0	217-0-0-21-0	DeWitt Silt Loam
Monroe	35-70-50-0-3	113-0-0-21-3	69-0-0-0-0	217-70-50-21-3	Grenada Silt Loam
Poinsett	41-60-60-12-5	102-0-0-12-0	78-0-0-0-0	221-60-60-24-5	Dundee Silt Loam
Prairie	50-69-90-24-0	126-0-0-12-0	46-0-0-0-0	219-80-120-32-2	Calhoun Silt Loam
Mean	**42-41-53-12-1**	**117-0-10-14-0**	**65-0-0-0-0**	**224-41-63-26-1**	**---**

[a] Applied between V12 to R1 (silking) corn growth stages.
[b] One ton per acre of chicken litter applied.

Table 3. 2022 Corn Research Verification Program locations, irrigation type, number of irrigations, and rainfall from planting to maturity.

County	Irrigation Type	Irrigation Frequency[a]	Rainfall from planting to maturity
		(irrigations/season)	**(in.)**
Desha 1	Furrow	5	17.51
Desha 2	Furrow	3	23.11
Faulkner	Furrow	6	14.47
Independence	Furrow	6	15.56
Jefferson	Furrow	5	17.98
Lonoke	Furrow	6	13.31
Monroe	Furrow	6	10.20
Poinsett	Furrow	6	13.04
Prairie	Furrow	7	22.36
Mean	**-**	**5.6**	**16.39**

[a] Each furrow irrigation supplied approximately 2 ac-in. of irrigation water.

Table 4. Corn growth stage and corresponding average accumulated growing degree days determined by weekly field visits in all corn fields in 2022.

Corn Growth Stage	Accumulated Growing Degree Days From Planting
VE – Emergence	145
V2	274
V4	443
V6	613
V8	782
V10	961
V12	1094
V14	1205
V16	1327
R1 – Silking	1500
R2 – Blister	1671
R3 – Milk	1841
R4 – Dough	2030
R5 – Dent	2247
R6 – Physiological Maturity (Black Layer)	2887

Table 5. Operating costs, total costs, and returns for corn research verification program fields, 2022.

County	Operating Costs	Operating Costs	Returns to Operating	Fixed Costs	Total Costs	Returns to Total Costs	Total Costs per Bushel
	($/ac)	($/bu.)	($/ac)	($/ac)	($/ac)	($/ac)	($/bu.)
Desha 1	562.90	2.67	962.63	92.7	655.6	869.93	3.11
Desha 2	558.81	2.24	1241.46	84.59	643.4	1156.87	2.58
Faulkner	605.65	3.76	558.38	87.61	693.26	470.77	4.31
Independence	581.23	3.48	626.18	89.78	671.01	536.4	4.02
Jefferson	522.26	2.43	1032.19	80.18	602.43	952.02	2.80
Lonoke	556.10	2.96	803.14	74.00	630.1	729.14	3.35
Monroe	611.37	3.51	648.82	81.47	692.84	567.35	3.97
Poinsett	657.88	3.36	759.20	94.88	752.76	664.32	3.84
Prairie	599.82	3.09	802.80	97.00	696.82	705.8	3.59
Mean	**584.00**	**3.06**	**826.09**	**86.91**	**670.91**	**739.18**	**3.51**

Table 6. Summary of operating costs, total costs, and returns for corn research verification program fields, 2022.

	Desha 1	Desha 2	Faulkner	Independence	Jefferson
Yield (bu./ac)	211.00	249.00	160.00	167.00	215.00
Price ($/bu.)	7.23	7.23	7.23	7.23	7.23
Total Crop Revenue	**1525.53**	**1800.27**	**1164.03**	**1207.41**	**1554.45**
Production Expenses	---------------------------------------$/ac---------------------------------------				
Seed	137.93	130.13	125.63	131.25	131.25
Fertilizers & Nutrients	162.57	183.39	268.28	216.64	156.07
Herbicides	53.60	49.59	22.65	28.30	39.59
Fungicide	0.00	0.00	0.00	0.00	0.00
Custom Application	11.25	0.00	14.50	16.88	7.50
Diesel Fuel, Field Activities	19.15	12.48	15.37	11.95	11.80
Irrigation Energy Costs	17.56	11.54	23.08	36.85	19.24
Other Inputs, Pre-harvest	3.88	3.88	3.88	3.88	3.88
Input Costs					
Fees	6.00	6.00	6.00	6.00	6.00
Crop Insurance	16.15	16.15	16.15	16.15	16.15
Repairs & Maint.	19.25	16.75	18.29	19.50	17.66
Labor, Field Activities	10.43	7.12	7.76	7.67	7.11

Continued

Table 6. Continued.

	Lonoke	Monroe	Poinsett	Prairie	Mean
Yield (bu./ac)	188.00	174.00	196.00	194.00	**195.00**
Price ($/bu.)	7.23	7.23	7.23	7.23	7.23
Total Crop Revenue	**1359.24**	**1260.19**	**1417.08**	**1402.62**	**1410.91**
Production Expenses	---------------------------------------$/ac---				
Seed	131.25	135.00	102.08	140.63	**129.46**
Fertilizers & Nutrients	161.09	236.89	243.73	225.14	**205.98**
Herbicides	46.26	35.11	79.06	42.61	**44.09**
Fungicide	0.00	0.00	0.00	0.00	**0.00**
Custom Application	37.38	25.25	27.75	16.00	**17.39**
Diesel Fuel, Field Activities	12.32	13.86	13.86	16.10	**14.10**
Irrigation Energy Costs	23.08	23.08	36.85	4.86	**21.80**
Other Inputs, Pre-harvest	3.88	3.88	3.88	3.88	**3.88**
Input Costs					
Fees	6.00	6.00	6.00	6.00	**6.00**
Crop Insurance	16.15	16.15	16.15	16.15	**16.15**
Repairs & Maint.	16.86	18.63	20.75	21.58	**18.81**
Labor, Field Activities	6.98	7.49	7.18	8.43	**7.80**

Continued

Table 6. Continued.

	Desha 1	Desha 2	Faulkner	Independence	Jefferson
Expenses	-------------------	-------------------	$/ac	-------------------	-------------------
Interest	10.19	9.72	11.61	11.02	9.26
Post-harvest Expenses	94.95	112.05	72.45	75.15	96.75
Total Operating Expenses	**562.90**	**558.81**	**605.65**	**581.23**	**522.26**
Returns to Operating Expenses	**962.63**	**1241.46**	**558.38**	**626.18**	**1032.19**
Capital Recovery & Fixed Costs	92.70	84.59	87.61	89.78	80.18
Total Specified Expenses	**655.60**	**643.40**	**693.26**	**671.01**	**602.43**
Returns to Specified Expenses	**869.93**	**1156.87**	**470.77**	**536.40**	**952.02**
Operating Expenses Per bu.	2.67	2.24	3.76	3.48	2.43
Total Specified Expenses Per bu.	3.11	2.58	4.31	4.02	2.80

Continued

Table 6. Continued.

	Lonoke	Monroe	Poinsett	Prairie	Mean
Expenses	---$/ac---				
Interest	10.26	11.60	12.40	11.16	**10.80**
Post-harvest Expenses	84.60	78.44	88.20	87.30	**87.77**
Total Operating Expenses	**556.10**	**611.37**	**657.88**	**599.82**	**584.00**
Returns to Operating Expenses	**803.14**	**648.82**	**759.20**	**802.80**	**826.04**
Capital Recovery & Fixed Costs	74.00	81.47	94.88	97.00	**86.91**
Total Specified Expenses	**630.10**	**692.84**	**752.76**	**696.82**	**670.91**
Returns to Specified Expenses	**729.14**	**567.35**	**664.32**	**705.80**	**739.18**
Operating Expenses Per bu.	2.96	3.51	3.36	3.09	**3.06**
Total Specified Expenses Per bu.	3.35	3.97	3.84	3.59	**3.51**

Economic Analysis of the 2022 Arkansas Corn and Grain Sorghum Research Verification Program

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

Abstract

The economic results of a statewide corn and grain sorghum research verification program can be a useful tool for producers making production management decisions prior to and within a crop-growing season. The 2022 season results provide additional economic insights between conventional and stacked herbicide systems. All of the 2022 fields were furrow irrigated. The conventional herbicide system field had a yield that was slightly more than 1 bu./ac higher than the average yield of the stacked fields. The stacked fields, however, had an average of $84.22/ac more return to land and management than the conventional field because of higher costs incurred on the conventional field.

Introduction

The Arkansas Corn and Grain Sorghum Research Verification Program (CGSRVP) originated in 2000, and records have been compiled each succeeding year from the fields of participating cooperators until 178 individual fields now comprise the state data set. Among other goals, the program seeks to validate University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) standard corn and grain sorghum production recommendations and demonstrate their benefits to state producers. Cooperating producers in each yearly cohort are identified by their County Extension Agent for Agriculture. Each producer receives timely management guidance from state CGSRVP coordinators on a regular basis and from state extension specialists as needed. CGSRVP coordinators record input rates and production practices throughout the growing season including official yield measures at harvest. A state extension economist compiles the data into the spreadsheet used for annual cost of production budget development. Measures of profitability and production efficiency are calculated for each cooperator's field and then grouped by production system.

Procedures

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

Results and Discussion

The 9 fields included in the 2022 Arkansas Corn and Grain Sorghum Research Verification Program report (Capps et al., 2022) had an average yield of 195.03 bushels per acre generating an average revenue of $1,410.09 per acre. Producers required $584.00 per acre of variable costs, $86.91 per acre fixed costs, or a total cost per acre of $670.91 per acre resulting in a return to land & management of $739.18 per acre. All 9 fields used furrow irrigation. Eight fields used stacked herbicide technology, and 1 field used conventional herbicide technology. All economic comparisons were developed from corn daily forward booking and cash market prices for the 2022 crop reported by Deaton in weekly market reports (Deaton, 2022). The corn forward booking and cash market price for the 2022 crop averaged $7.23 per bushel over the period of 1 January through 31 August 2022. Market price multiplied by yield gave field revenues. No grade reductions or premiums were included. All yields were standardized to 15.5% moisture content. Readers should note that the small number of fields in total and the numbers within groups of fields represented in this study do not permit standard statistical analysis. Yield and economic results are presented by grouping for discussion purposes only. Economic comparisons are drawn solely across herbicide technology since all of the fields used the same type of irrigation (Table 1). The values for yield, revenue, total variable cost, total fixed cost, total cost, and return to land and management are discussed.

Herbicide Comparisons

The stacked herbicide system was used in 8 fields while the conventional herbicide system was used in only 1 field (Table 1). Yield comparisons by herbicide system show that the conven-

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tional herbicide field had only about a 1 bu./ac advantage over the stacked fields. The conventional field had $7.86/ac higher revenue, $83.11/ac higher total variable costs, $8.96/ac higher total fixed costs, and $92.08/ac higher total costs. The stacked fields, however, had an average of $84.22/ac more return to land and management because of the higher costs incurred on the conventional field.

The higher costs for the conventional field occur in the following categories. Compared to the average costs of the stacked fields, the conventional field had $42.47/ac higher fertilizer and nutrient costs, $24.65/ac higher herbicide costs, $16.94/ac higher irrigation energy costs, and $11.66/ac higher custom application costs. The one input that was cheaper for the conventional field was seed, which was $30.80/ac less than the average stacked field seed cost. The other costs differences between the conventional and stacked fields are negligible. For further details, see the 2022 Arkansas Corn and Grain Sorghum Research Verification Program report (Capps et al., 2022).

Overall Comparisons

The 2022 Arkansas Corn and Grain Sorghum Research Verification Program fields had a 195.03 bu./ac statewide average yield. This was 30.93 bushels less than in 2021 but more than 22 bushels above the 2022 Arkansas state average yield of 173 bu./ac (USDA-NASS, 2023). Revenue averaged $1410.09 from this production and a historically high market price. The revenue mark represents an increase of more than $194/ac compared to 2021. Total variable costs averaged $584.00, a $60.59 increase, and total fixed costs averaged $86.91, an $8.41 decrease, for an average total cost per acre of $670.91, a $52.20 increase over 2021. These revenue and cost averages left producers with an average per acre return to land and management of $739.18 across all production systems, an increase per acre of $142.27 compared to 2021.

Practical Applications

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

Acknowledgments

The authors wish to thank the Arkansas Corn and Grain Sorghum Board for the support provided by Arkansas corn producers through check-off funds administered by the board. Appreciation is given to the University of Arkansas System Division of Agriculture and the University of Arkansas at Monticello College of Forestry, Agriculture, and Natural Resources, both of which provided funding and other support for this research project. Appreciation is especially extended to Chuck Capps, Arkansas Corn and Grain Sorghum Research Verification Program Coordinator, and Jason Kelly, Arkansas Corn and Grain Sorghum Research Verification Program Director, without whom this research would not have been possible.

Literature Cited

Capps, C., J.P. Kelley, B.J. Watkins, B.D. Deaton, and C.R. Stark Jr. 2022. University of Arkansas System Division of Agriculture's Corn and Grain Sorghum Research Verification Program. Available at: https://www.uaex.uada.edu/farm-ranch/crops-commercial-horticulture/verification/corn-grain-sorghum-verification.aspx

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

Deaton, B.D. 2023. Arkansas Corn and Grain Sorghum Market Reports (various dates). Arkansas Row Crops Blog. Accessed 31 March 2023. Available at: https://arkansas-crops.uada.edu/

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

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

Table 1. Economic Results by Herbicide System for the 2022 Corn and Grain Sorghum Research Verification Program.

Herbicide Production System	Stacked	Conventional	All Fields
# Fields	**8**	**1**	**9**
Yield (bu./ac)	194.91	196.00	195.03
Revenue ($/ac)	1409.22	1417.08	1410.09
Total Variable Costs ($/ac)	574.77	657.88	584.00
Total Fixed Costs ($/ac)	85.92	94.88	86.91
Total Costs ($/ac)	660.68	752.76	670.91
Returns to Land and Management ($/ac)	748.54	664.32	739.18

Source: 2022 Arkansas Corn and Grain Sorghum Research Verification Program Report.

Field Efficacy of Soil-Applied Fluopyram in Corn

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

Abstract

The field efficacy of three soil-applied nematicides was evaluated in a field naturally infested with stubby-root nematodes (*Paratrichodorus* sp.), lesion nematodes (*Pratylenchus* spp.), and southern root-knot nematodes (*Meloidogyne incognita* (Kofoid and White) Chitwood) in Pulaski County. All nematodes were observed at low densities, below the damage threshold, and at similar densities between shallow (0- to 6.0-in. deep) and deep (6.1- to 12.0-in. deep) soil samples during the cropping season. None of the soil-applied nematicides had a significant impact on nematode reproduction or grain yield protection. Regardless, a greater grain yield trend was observed with Velum (fluopyram), Propulse (fluopyram + prothioconazole) and Counter (terbufos) compared to the nontreated control. Overall, these data suggest these soil-applied nematicides provide little nematode suppression and grain yield protection when nematode densities are low in a silt loam soil in Arkansas.

Introduction

Several genera of plant-parasitic nematodes are common in corn (*Zea mays* L.) fields in Arkansas. The most frequent genera include stubby-root nematodes (*Paratrichodorus* sp.), lesion nematodes (*Pratylenchus* spp.), and root-knot nematodes (*Meloidogyne* spp.). Though plant-parasitic nematode rank among the ten most destructive diseases of corn in the southern U.S. (Mueller et al., 2020), there is little information on vertical distribution of corn nematodes and their damage to corn in Arkansas.

The vertical distribution of stubby-root nematode, *Paratrichodorus minor* (Colbran) Siddiqi and the southern root-knot nematode, *M. incognita* has been reported to change dramatically during the cropping season on corn in Florida (McSorley and Dickson, 1990). Furthermore, the greatest density of lesion nematode, *P. brachyurus* (Godfrey) Filipjev & Stekhoven was reported to remain primarily at 6- to 12-in. soil depth on corn in Florida. In one study in Arkansas, a greater proportion of stubby-root nematodes remain at 0- to 6-in. soil depth, while most root-knot nematodes remain at 6.1- to 12.0-in. soil depth in loamy sand soil (Faske et al., 2022). Further studies are needed to understand the vertical distribution of corn nematodes across other soil texture classes in Arkansas.

Fluopyram, a succinate dehydrogenase inhibitor fungicide (SDHI), was registered as an in-furrow nematicide in 2015 in cotton (*Gossypium hirsutum* L.). Fluopyram selectively inhibits Complex II of the mitochondrial respiratory chain in the mitochondria of fungi and nematodes. Currently, fluopyram is marketed as a corn nematicide under the trade names Velum (fluopyram) and Propulse (fluopyram + prothioconazole (De-Methylation inhibitor fungicide)). These liquid formulations are applied in-furrow at planting to suppress early season corn nematodes' impact on the developing seedling root system. Currently, there is little information on the benefit of Velum as a nematicide in Arkansas corn. Thus, the objectives of this study were to: (i) evaluate the field efficacy of fluopyram to suppress corn nematodes and protect grain yield potential, and (ii) evaluate the vertical distribution of corn nematodes during a cropping season.

Procedures

The field efficacy of fluopyram was evaluated in a field experiment in 2022 in Pulaski County, Ark. (Table 1). The soil texture was a silt loam soil with 30% sand, 57% silt and 13% clay. The corn hybrid, Local Seed 'LC1577' (Local Seed Co, LLC, Memphis, TN; 115-day maturity) was planted on 10 May at a seeding rate of 32,000 seed/ac. The previous crop was soybean (*Glycine max*), and the field was furrow irrigated. Weeds were controlled per recommendations by University of Arkansas System Division of Agriculture's Cooperative Extension Service. Plots consisted of four, 30-ft long rows spaced 30-in. apart. The experimental design was a randomized complete block design with six replications separated by a 5-ft fallow alley. All seed were treated with a base fungicide, Vibrance Cinco at 1.2 fl oz/cwt (Syngenta Crop Protection, Greensboro, N.C.; the active ingredients are azoxystrobin, mefenoxam, fludioxonil, sedaxane, and thiabendazole at 0.077 mg ai/seed) and insecticide, Cruiser 5FS at 0.25 mg ai/seed (Syngenta Crop Protection; the active ingredient is thiamethoxam). Velum and Propulse were applied in-furrow through a 0.07-in.-diam. poly tubing using a pressurized sprayer to deliver a total volume of 6.5 gal/ac. Counter was applied in-furrow through 0.5-in.-diameter poly-tubing using a variable rate AMVAC SmartBox meter. Soil samples were a composite of 8 core samples taken 6- to 8-in. deep, within 3 in. of the plant stalk with a 0.75-in.-diameter soil probe. Nematodes were collected with a modified Baermann funnel system and enumerated using a stereoscope. Soil samples were collected at planting (10 May), mid-season

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13 June; 34 days after planting (DAP) and V4 growth stage). To determine the changes in nematode distribution at two soil depths, 6 cores samples were collected at two depths: 0–6.0 in. and 6.1–12 in. from the same hole in three of the six nontreated control plots at the same sample times with one additional time at harvest. Stand counts, number of plants per ten-row feet, were determined at 14 and 28 DAP. A vigor rating was given for the entire plot at 14 and 28 DAP, where 1 = poor growth and 5 = best growth. The two center rows of each plot were harvested on 16 September with an ALMACO SPC40 plot combine (ALMACO, Nevada, Iowa) equipped with a HarvestMaster Single BDS HiCap HM800 weigh system (HarvestMaster Logan, Utah).

Nematode data were subjected to repeated measures analysis and grain yield to analysis of variance using SPSS 27.0 (International Business Machines Corporation, Armonk, N.Y.) and mean separation when appropriate at $P = 0.05$ according to Tukey's honestly significant difference procedure. Nematode data at different sampling depths were subjected to a mixed model analysis with sample depth and sample timing as fixed variables and replications as random variables using the same statistical software and means separation procedure. All data were transformed ($\log_{10} +1$) to normalize for analysis, and reverse transformed data are reported.

Results and Discussion

There was an interaction ($P \leq 0.05$) between the two sample depths and sample time for southern root-knot nematode densities, so data are separated by depth and time (Table 2). The densities of the three corn nematodes were similar between the shallow (0 to 6.0 in.) and deeper (6.1 to 12 in.) soil sample depth at each sample time. A similar number of all corn nematodes were detected at the shallow depth than at deeper depth across all sample times. A greater density of southern root-knot nematode was observed at harvest compared to density at planting or mid-season, while stubby-root and lesion nematode densities were similar across sample times. These data contrast with the erratic densities of stubby-root nematode and southern root-knot nematode in a study in Florida (McSorley and Dickson, 1990). In a similar study in 2021, a greater percentage of stubby-root nematodes remained at 0- to 6-in. soil depth, while most root-knot nematodes remained at 6.1- to 12-in. depth in a loamy sand field (Faske et al., 2022). In the current study, there was no difference in nematode density at either soil depth, which may be due to less-than-favorable soil textures for nematode mobility and reproduction.

No soil-applied nematicide had a significant effect at 28 days after planting on seedling emergence or vigor. The average plant density was 17.0 plants per ten feet of row and the average vigor rating was 4.6. No significant ($P > 0.46$) suppression of stubby-root nematode, lesion nematode, or southern root-knot nematode densities was observed by any soil-applied nematicide (Fig. 1). Furthermore, these nematicides had no ($P = 0.39$) impact on corn grain yield (Fig. 2). A greater grain yield trend was observed with Velum, Propulse, and Counter compared to the non-treated control. In other studies, there were numerically greater grain yields with soil-applied nematicides compared to the non-treated control when corn nematodes were at low to moderate damage thresholds in loamy sand and silt loam fields (Faske et al., 2021, Faske et al., 2022). The working fall damage threshold for stubby-root nematode, lesion nematode, and root-knot nematode is 40, 500, and 500 individuals/100 cm^3 soil, respectively. Collectively, these data support the inconsistency in yield protection with these non-fumigant, soil-applied nematicides in corn.

Practical Applications

Soil-applied nematicides were inconsistent in nematode suppression and grain yield protection when nematode densities were low in silt loam soil. Thus, suggesting that the impact of these corn nematodes in silt loam soils at low population densities does not warrant the use of a nematicide.

Acknowledgments

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Literature Cited

Faske, T.R., M. Emerson, and J. Kelly. 2021. Evaluation of seed- and soil-applied nematicides for management of corn nematodes in Arkansas, 2020. Plant Dis. Mgmt. Reports 15:N041.

Faske, T.R., M. Emerson, and J. Kelly. 2022. Field efficacy of seed- and soil-applied nematicides in hybrid corn. Corn and Grain Sorghum Research Studies 2021. Arkansas Agricultural Experiment Station Research Series 687:17-20. Fayetteville.

McSorley R. and D.W. Dickson. 1990. Vertical distribution of plant-parasitic nematodes in sandy soil under maize. J. Nematol. 22:90-96.

Mueller, D.S., K.A. Wise, A.J. Sisson, T.W. Allen, G.C. Bergstrom, K.M. Bissonnette, C.A. Bradley, E. Byamukama, M.I. Chilvers, A.A. Collins, P.D. Esker, T.R. Faske, A.J. Friskop, A.K. Hagan, R.W. Heiniger, C.A. Hollier, T. Isakeit, T.A. Jackson-Ziems, D.J. Jardine, H.M. Kelly, N.M. Kleczewski, A.M. Koehler, S.R. Koenning, D.K. Malvick, H.L. Mehl, R.F. Meyer, P.A. Paul, A.J. Peltier, P.P. Price, A.E. Robertson, G.W. Roth, E.J. Sikora, D.L. Smith, C.A. Tande, D.E.P. Telenko, A.U. Tenuta, L.D. Thiessen, and W.J. Wiebold. 2020. Corn Yield Loss Estimates Due to Diseases in the United States and Ontario, Canada, from 2016 to 2019. Plant Health Prog. 21:238-247.

Table 1. Trade names, rates, and active ingredients for nematicides used in a corn nematicide experiment in 2022 in Pulaski County.

Trade name and formulation	Rate	App[a]	Active ingredient
Velum 4.16 SC[b]	6.5 fl oz/ac	IF	fluopyram
Propulse 3.34 SC	8.0 fl oz/ac	IF	fluopyram + prothioconazole
Counter 20G	6.5 lb/ac	IF	terbufos

[a] App = application method; IF = in-furrow.
[b] The Velum label from September 2020 has rate range of 6.5 to 6.84 fl oz/ac, while the label from July 2022 has a rate range of 3.0 to 5.0 fl oz/ac.

Table 2. Population density of three corn nematodes at three sample times and two sample depths in a corn nematicide experiment in 2022 in Pulaski County.

Sample time (DAP)†	Sample depth	Stubby-root nematode	Lesion nematode	Southern root-knot nematode
	(in.)	-----------------------(nematodes/100 cm³ soil)	------------------------	
0	0.0–6.0	1.9	10.0 ab‡	63.4 ab
0	6.1–12	1.4	3.1 a	38.0 ab
34	0.0–6.0	1.0	3.4 a	12.8 a
34	6.1–12	1.3	1.7 a	40.0 ab
129	0.0–6.0	1.5	60.1 b	270.5 d
129	6.1–12	1.0	7.1 ab	170.5 cd

† DAP = days after planting
‡ Means with different letters indicate a significant difference at α = 0.05 according to Tukey's honestly significant difference procedure.

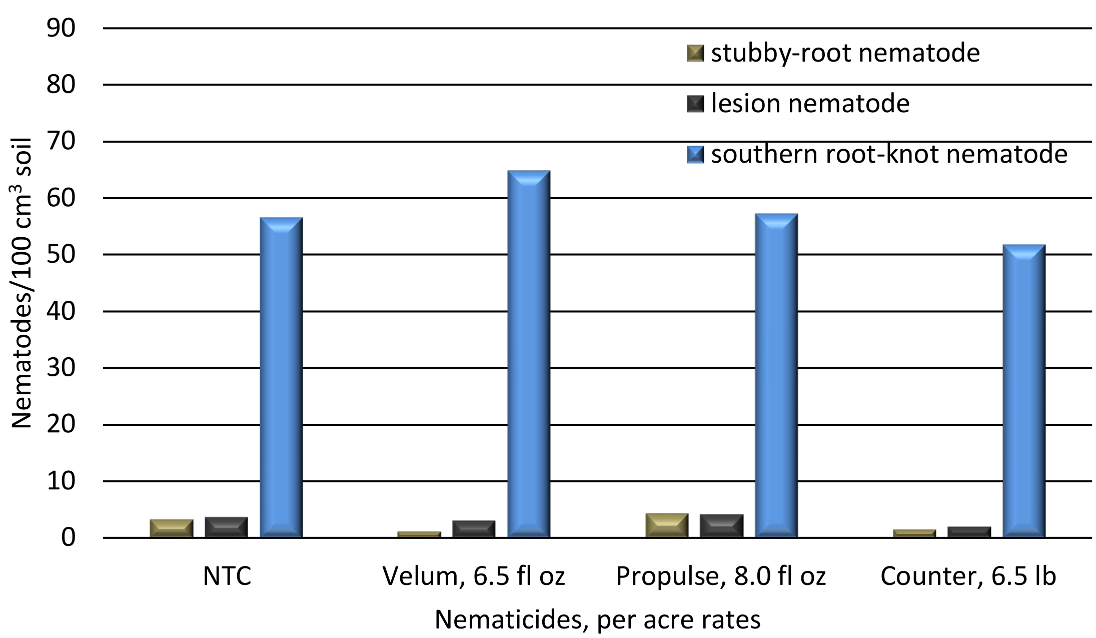

Fig. 1. Suppression of three corn nematodes by three nematicides in 2022 in a field experiment in Pulaski County. Each bar represents the average nematode density from six replicates collected at planting and 34 days after planting.

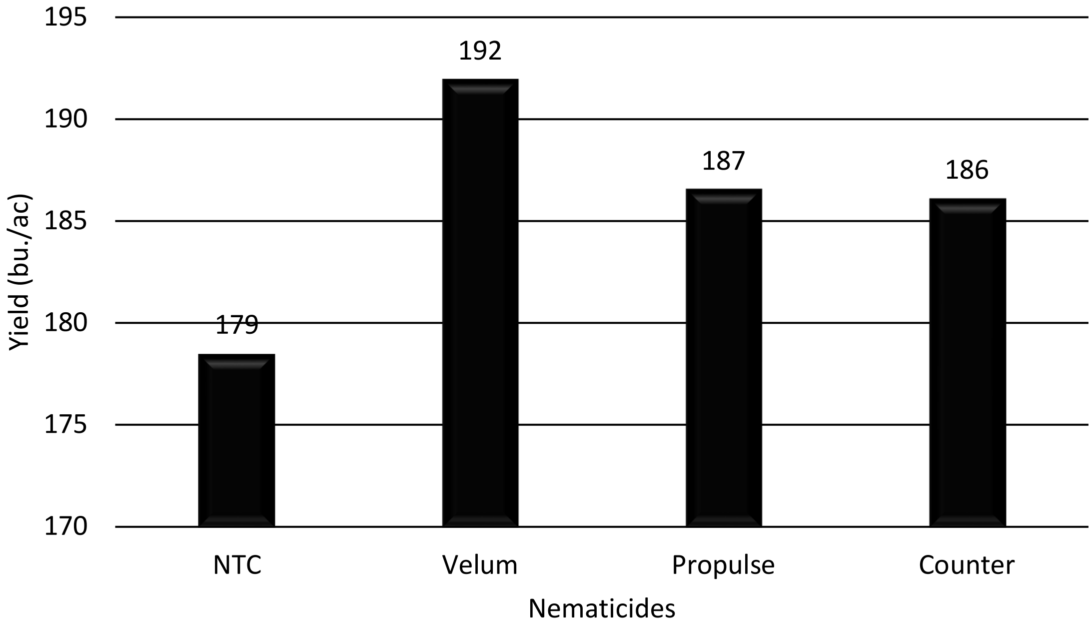

Fig. 2. Yield protection by three nematicides in a field with stubby-root nematode, lesion nematode, and southern root-knot nematode in Pulaski County. Grain yield was adjusted to 15.5% moisture.

Evaluation of In-furrow Fungicides on Corn, 2022

T.N. Spurlock,[1] J.P. Kelley,[2] T.D. Keene,[2] R.C. Hoyle,[1] A.C. Tolbert,[1] and J.A. Davis[3]

Abstract

In-furrow and foliar fungicide trials on corn were planted at the University of Arkansas System Division of Agriculture's Rohwer Research Station and at the Lon Mann Cotton Research Station in 2022. At Rohwer, fungicides were applied at planting, 2 x 2, outside of the seed furrow or as a foliar application at R3. At Lon Mann, fungicides were applied in the seed furrow at planting or as a foliar application at R3. Stands were not different across treatments at either location. At Rohwer, foliar disease levels were below average due to atypically warmer and drier conditions. At Lon Mann, southern rust levels increased later in the season and were significantly different by treatment as both foliar fungicides applied, Trivapro and Veltyma, provided adequate control. Southern rust levels were not significantly different than the nontreated, where fertilizer alone or in-furrow fungicides Xyway or Quadris were applied. Yields were not significantly different by treatment at either location.

Introduction

Each year, corn fields are planted into cool and wet soil and suffer reduced stand, plant vigor, and yield losses due to of lack of available nutrition and attack by soil-borne pathogens such as *Rhizoctonia* and *Pythium* spp. Root growth is often slowed or shallow, increasing the likelihood of drought stress later in the season (often prior to initiation of irrigation). While delaying planting would alleviate or eliminate these early season issues, simply by planting into relatively warmer and dryer soil, the delayed planting may result in increased susceptibility to southern rust as the likelihood of its movement into the state would have an increased chance of infecting fields at growth stages R4 or earlier, when yield losses from the disease would be most likely to occur (Kelley and Capps, 2020). The objective of this work is to determine if fungicide applied at planting increases early season plant health and lessens foliar disease pressure later in the growing season.

Procedures

A trial was planted at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station 11 May in a randomized complete block design with three in-furrow treatments applied at 5 gal/ac, Agroliquid Pro-germinator 9-24-3 (pop-up starter), pop-up starter + Quadris at 13.8 fl oz/ac, and pop-up starter + Xyway LFR at 12 fl oz/ac. Two foliar fungicide treatments, Veltyma and Trivapro, were also included in the trial and applied at R3 at 7 and 13.7 fl oz/ac, respectively, in 10 gal/ac of water volume using a backpack sprayer. The 2 center rows were sprayed using TeeJet XR 110015-VS tips, propelled with carbon dioxide at 4 mph. Stand and vigor data (0–9 scale) were collected on 26 May. Southern rust levels were determined at the time of foliar fungicide application and again at R5.5 on 24 August. Grain was harvested with a small plot combine equipped with a research weigh system on 14 September. All data were subjected to analysis of variance (ANOVA) and means separation of fixed effects using Fisher's least significant difference test at $P = 0.05$.

A trial was planted at the University of Arkansas System Division of Agriculture's Rohwer Research Station near Kelso, Ark. on 29 April. The trial consisted of 3 in-furrow treatments applied at planting in 10 gal/ac water volume with and without a fungicide application, 2 x 2, and an untreated check in a randomized complete block design with 3 replications. Plots were 4-rows wide on 38 in. beds and 40 ft. long. In-furrow treatments included Headline 11.4 fl oz/acre, Quadris 13.8 fl oz/ac and Xyway LFR 12 fl oz/ac. Trivapro 13.7 fl oz/acre was applied at R3 (beginning pod) on 14 June in 10 gal/ac of water volume using a backpack sprayer. The 2 center rows were sprayed using TeeJet XR 110015-VS tips, propelled with carbon dioxide at 4 mph. Plant stands were collected on 9 May, and plots were harvested on 16 September with a plot combine equipped with a weigh system. All data were subjected to ANOVA and means separation of fixed effects using Tukey's honestly significant difference test at $P = 0.05$.

Results and Discussion

Stands, vigor, and yields were not significantly different at the trial planted at Lon Mann. Southern rust developed later in the season and was significantly less where foliar fungicides Veltyma and Trivapro were applied. The fungicides applied at planting did not impact southern rust levels when compared to the nontreated control (Table 1).

The trial planted at Rohwer did not have disease levels that were high enough to quantify prior to maturity. Stands were low overall but were not significantly different by treatment. Yields were also not different by treatment (Table 2).

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Practical Applications

Fungicides applied at planting did not reduce the later season impacts of foliar disease sufficiently to add value to the crop (by increasing yield) above any application costs. Based on these results, the benefit of in-furrow fungicide application in Arkansas is still unclear. As of 2022, the supplemental Xyway LFR label indicates it should no longer be applied to the seed furrow, especially in cooler soils. At the trial at Lon Mann, no impacts to stand or emergence were seen when planted into the seed furrow mid-May. However, it was not beneficial to yield nor control of southern rust when compared to the nontreated controls or foliar-applied fungicides. In addition to Veltyma and Trivapro, numerous other foliar fungicides are labelled for control of southern rust and are effective when applied properly. These products and their relative efficacy ratings on several diseases can be found in MP154 (Faske and Spurlock, 2022).

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Literature Cited

Faske, T.R. and T.N. Spurlock. 2022. Arkansas plant disease control products guide. MP 154, University of Arkansas System Division of Agriculture Cooperative Extension Service, Little Rock. pp. 7-8.

Kelley, J.P. and C. Capps. 2020. Arkansas Corn Quick Facts. University of Arkansas System Division of Agriculture Cooperative Extension Service, Little Rock. Accessed 1 April 2022. Available at: https://www.uaex.uada.edu/farm-ranch/crops-commercial-horticulture/corn/2020%20Arkansas%20Corn%20Quick%20Facts.pdf

Table 1. Plant stands and yield data from a corn in-furrow fungicide trial at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, 2022.

Treatment and rate/acre	Growth stage at application	Stand	Vigor (V7)†	Southern rust (R5.5)‡	Yield
		(plants per acre)			(bu./ac)
Nontreated	--	28,856	6.5	3.8 a§	181.4
Fertilizer only	Plant	29,715	6.8	2.5 ab	186.1
Fertilizer + Quadris 13.8 fl oz	Plant	27,310	6.5	3.5 a	169.7
Fertilizer + Xyway 12 fl oz	Plant	28,341	6.0	3.8 a	171.1
Trivapro 13.6 fl oz	R3	29,200	6.5	0.3 c	183.1
Veltyma 7 fl oz	R3	28,856	7.3	1.0 bc	187.5

† Vigor is determined on a 0–9 scale by visual estimation of the single most healthy plot and estimating plant health of other plots in comparison to the "healthiest" plot.

‡ Southern rust severity was determined on a 0–9 scale where 9 is the most severe southern rust from the ear leaf and those leaves above the ear leaf.

§ Means followed by the same letter are not significantly different using Fisher's least significant difference test at $P = 0.05$.

Table 2. Plant stands and yield data from a corn in-furrow fungicide trial at the University of Arkansas System Division of Agriculture's Rohwer Research Station, 2022.

Treatment and rate/acre	Growth stage at application	Stand	Yield
		(plants/acre)	(bu./ac)
Headline 11.4 fl oz	Plant	25,937	170.0
Headline 11.4 fl oz +	Plant	25,009	168.6
Trivapro 13.7 fl oz	R3		
Untreated	--	27,345	192.0
Untreated +	--	26,040	191.7
Trivapro 13.7 fl oz	R3		
Quadris 13.8 fl oz	Plant	26,864	184.9
Quadris 13.8 fl oz +	Plant	26,349	187.7
Trivapro 13.7 fl oz	R3		
Xyway LFR 12 fl oz	Plant	25,421	174.9
Xyway LFR 12 fl oz +	Plant	24,975	174.3
Trivapro 13.7 fl oz	R3		

Assessing Susceptibility of Insect Pests of Corn in Storage to Selected Insecticides

G.E. Studebaker,[1] A. Twaibu,[2] N.K. Joshi,[2] N.R. Bateman,[3] and B. Thrash[4]

Abstract

The susceptibility of sawtoothed grain beetle, *Oryzaephilus surinamensis*, to pirimiphos-methyl, spinosad, deltamethrin, silicone dioxide and s-methoprene was evaluated utilizing 55-gallon barrels of stored corn. Spinosad provided protection to grain for 298 days. Pirimiphos-methyl protected grain for up to 329 days. Bioassays were conducted measuring the mortality of the red flour beetle, *Tribolium castaneum*, and the rice weevil, *Sitophilus oryzae*, to pirimiphos-methyl and deltamethrin in the laboratory. The LC_{50} for deltamethrin was 9.11 for *S. oryzae* and 0.026 for *T. castaneum*. The LC_{50} values for pirimiphos-methyl were 0.74 for *S. oryzae* and 13.44 for *T. castaneum*.

Introduction

Several insect pests are known to attack corn in storage (Rees, 2004). Among them, internal feeders, such as the rice weevil and maize weevil are economically most important. If not managed effectively, these insect pests have the potential to cause a total loss in stored grain. Numerous other pests, such as the Indian meal moth larva, confused flour beetle, red flour beetle etc., are also known to infest stored corn. Recent studies have indicated that the red flour beetle is the most common insect detected in stored corn grain in Arkansas. Rice weevil, saw-toothed grain beetle, confused flour beetle, and Angoumais grain moth were also detected to a lesser extent. Red flour beetle has been shown to be resistant to some of the insecticides (spinosad, malathion, and phosphine) commonly used to protect stored grains (Bajracharya et al., 2013; Zettler and Cuperus, 1990). Chlorpyrifos-methyl has been shown to still be an effective means of control of stored pests in stored corn and other grains. However, the EPA has recently revoked all tolerances for chlorpyrifos on food crops and this product is no longer available to growers (EPA, 2022). It is important to determine what insecticides and rates are most effective at preventing infestations of these insect pests in stored corn. Due to the prevalence of insecticide resistance in some of these pest species, it is important to determine the susceptibility of the most commonly encountered stored grain pests in Arkansas.

Procedures

This study was conducted in two parts. In the first part, the insecticides listed in Table 1 were applied to 55-gallon barrels of freshly harvested field corn at the University of Arkansas System Division of Agriculture's Northeast Research and Extension Center, Keiser, Ark., in the fall of 2021. Treatments were replicated four times with an individual barrel equal to one replication. Treatments were arranged in a randomized complete block design and kept in a small covered shed throughout the study. Individual barrels were covered with ¼-inch hardware cloth to discourage rodents and other animal pests from feeding on the corn, while allowing naturally occurring stored grain insects to infest the treatments.

Once each month, 1-pint samples of grain were collected from each barrel and examined for the presence of stored grain insects. Insect pests were identified as species with numbers of each recorded. Data were analyzed using Agricultural Research Manager with mean separation at the $P = 0.05$ alpha level.

The second part of the study was conducted at the Laboratory of Entomology, Department of Entomology and Plant Pathology, University of Arkansas and consisted of two laboratory experiments. The first laboratory study aimed to evaluate the effectiveness of two insecticide formulations, pirimiphos-methyl (Actellic 5 EC, WinField United, Saint Paul, Minn.) and deltamethrin (Centynal 0.41 EC, Central Life Sciences, Schaumburg, Ill.), against *Sitophilus oryzae* (rice weevil) infesting corn grains. The insects used in the study were reared in whole kernels of corn. The two insecticides were tested at various concentrations - 0.4, 0.8, 1.6, 2.4, and 3.2 ppm for pirimiphos-methyl and 1.5, 3, 6, 12, and 24 ppm for deltamethrin. Each dose was replicated three times, with 15 adult *S. oryzae* individuals per replication, totaling 45 individuals per dose. Both insecticide formulations were applied topically using filter paper as substrate in small plastic jars containing the test insects. The control treatment consisted of distilled water application. The mortality of *S. oryzae* adults was recorded every 24 hours after exposure until 96 hours.

In the second laboratory study, the toxicity of pirimiphos-methyl and deltamethrin was tested against *Tribolium castaneum* (red flour beetle), a common stored grain pest infesting storage corn grains. The doses tested in this study ranged from

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8 to 32 ppm for pirimiphos-methyl and from 0.005 to 1 ppm for deltamethrin. Each dose was replicated three times, with 15 red flour beetle adult individuals per replication, resulting in a total of 45 individuals per dose. To expose the insects to the insecticides, a spray tower was used, and each insect was placed in a Petri dish. Distilled water was used as the control treatment. The study used a laboratory population of *T. castaneum*, which was initially collected from corn grain bins from different farms in Arkansas. Likewise, in the previous experiment, insect mortality was recorded every 24 hours after exposure until 96 hours. The datasets from both laboratory studies were analyzed using probit analysis, and the toxicity of each insecticide was determined in terms of LC_{50}, which is the concentration required to kill 50% of the test population.

Results and Discussion

Samples collected throughout the winter months did not yield any insect pests. No insect pests were detected until May 2022 (Fig. 1). Sawtoothed grain beetle, *Oryzaephilus surinamensis*, was the predominant pest detected throughout the study. Maize weevils were also detected, but at extremely low numbers and were not included in the analysis.

Sawtoothed grain beetles numbers were low in the May collection (238 days, Fig. 1) and no significant differences were observed. Numbers were higher at 298 days with over 40 beetles in the untreated (Fig. 2). Only the Sensat and Actellic treatments were significantly lower than the untreated with less than 5 beetles per sample. At 329 days after treatment, sawtoothed grain beetles were at levels above 170 per 1 pint of sample and causing significant damage to the grain (Fig. 3). Although the Sensat, Diacon IGR, and Centynal treatments were significantly lower than the untreated check, they still had infestations of sawtoothed grain beetles. Throughout the course of the study, only the Actellic treatment kept grain free of sawtoothed grain beetles.

The preliminary results of the laboratory studies showed that the 50% lethal concentration of deltamethrin against *S. oryzae* was higher than that of pirimiphos-methyl (Figs. 4 and 5). On the other hand, the 50% lethal concentration of pirimiphos-methyl against *T. castaneum* was higher than that of deltamethrin (Figs. 6 and 7). These preliminary findings indicate that the two insecticide chemicals have different toxicities and may be more effective against specific species. The results of these studies also showed that the mortality rate of both stored grain pest species increased with the concentration of the insecticides and the duration of exposure. The highest mortality rates in both species were recorded at the highest concentrations of the insecticides and 96 hours of exposure.

It is important to note that the population of insect pests used in the study were field populations but reared in the laboratory, and that the results may vary depending on the local insect populations. Therefore, further studies are needed to assess the effectiveness of these insecticides against *S. oryzae* and *T. castaneum* populations collected from different corn-growing regions in Arkansas and to determine the risk of resistance development, and such laboratory and field studies will be valuable in ensuring the continued efficacy of these insecticide chemistries in controlling stored-grain pests infesting corn and other grains in Arkansas.

Practical Applications

These data indicate that all of the products tested provided some level of protection to stored corn against sawtoothed grain beetle. Silicone dioxide appeared to be the least effective, while Actellic gave the longest level of protection keeping grain free of insect pests for nearly one year after treatment. Actellic appears to be the product of choice for growers wishing to store harvested corn for long periods of time. Overall, the laboratory study provides valuable information for the development of effective pest management strategies for *S. oryzae* and *T. castaneum* in stored corn grain facilities. The preliminary results suggest that deltamethrin and pirimiphos-methyl may be more suitable options for controlling *T. castaneum* and *S. oryzae*, respectively. However, further research is needed to confirm these findings.

Acknowledgments

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Literature Cited

Bajracharya, N., G. Opit, J. Talley, and C. Jones. 2013. Efficacies of Spinosad and a Combination of Chlorpyrifos-Methyl and Deltamethrin Against Phosphine-Resistant *Rhyzopertha dominica* (Coleoptera: Bostrichidae) and *Tribolium castaneum* (Coleoptera: Tenebrionidae) on Wheat. J. Econ. Entomol. 106: 2208-2215.

USEPA. 2022. United States Environmental Protection Agency. Chlorpyrifos. www.epa.gov/ingredients-used-pesticide-products/chlorpyrifos

Rees, D. 2004. Insects of Stored Products. Csiro Publishing. 181 pages.

Zettler, L. and G. Cuperus. 1990. Pesticide Resistance in *Tribolium castaneum* (Coleoptera: Tenebrionidae) and *Rhyzopertha dominica* (Coleoptera: Bostrichidae) in Wheat. J. Econ. Entomol. 83:1677-1681.

Table 1. Stored grain insecticide rates and method of application applied to freshly harvested field corn in 55-gallon barrels.

Insecticide	Rate	Method of Application
Actellic 5 E (pirimiphos-methyl)	12.3 oz/1,071 bu	incorporated
Centynal 0.42 SC (deltamethrin)	18 oz/1,000 bu	incorporated
Sensat 0.73 SC (spinosad)	9.8 oz/1,000 bu	incorporated
Diacon 2.5 EC (s-methoprene)	7 oz/1,000 bu	incorporated
Silicon Dioxide Dust	2 lb/1,000 bu	incorporated
Untreated		

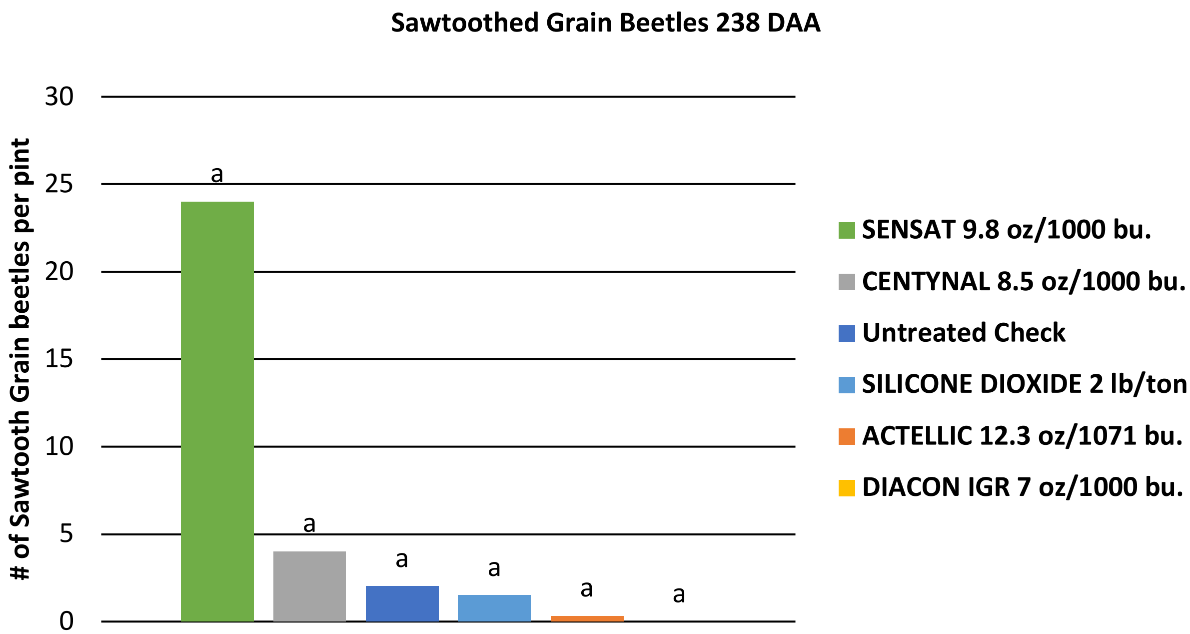

Fig. 1. Sawtoothed grain beetles per 1 pint of grain sample at 238 days after insecticide application (DAA) in 55-gallon barrels. Bars with the same letter above are not significantly different at the *P* = 0.05 alpha level.

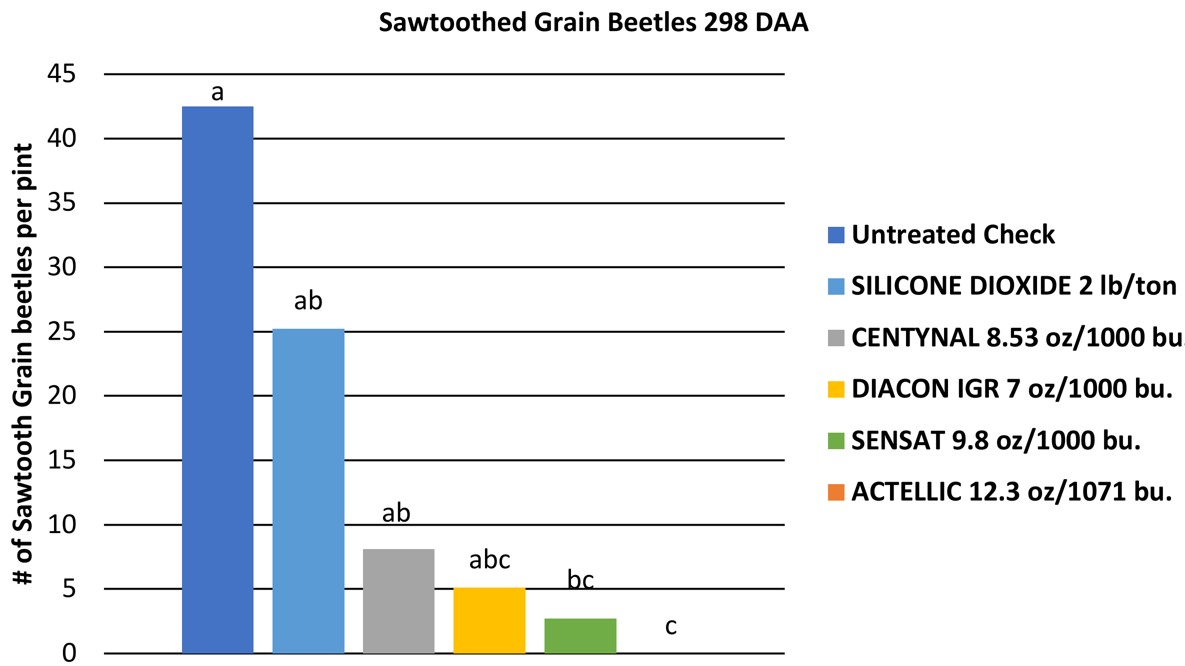

Fig. 2. Sawtoothed grain beetles per 1 pint of grain sample at 298 days after insecticide application in 55-gallon barrels. Bars with the same letter above are not significantly different at the *P* = 0.05 alpha level.

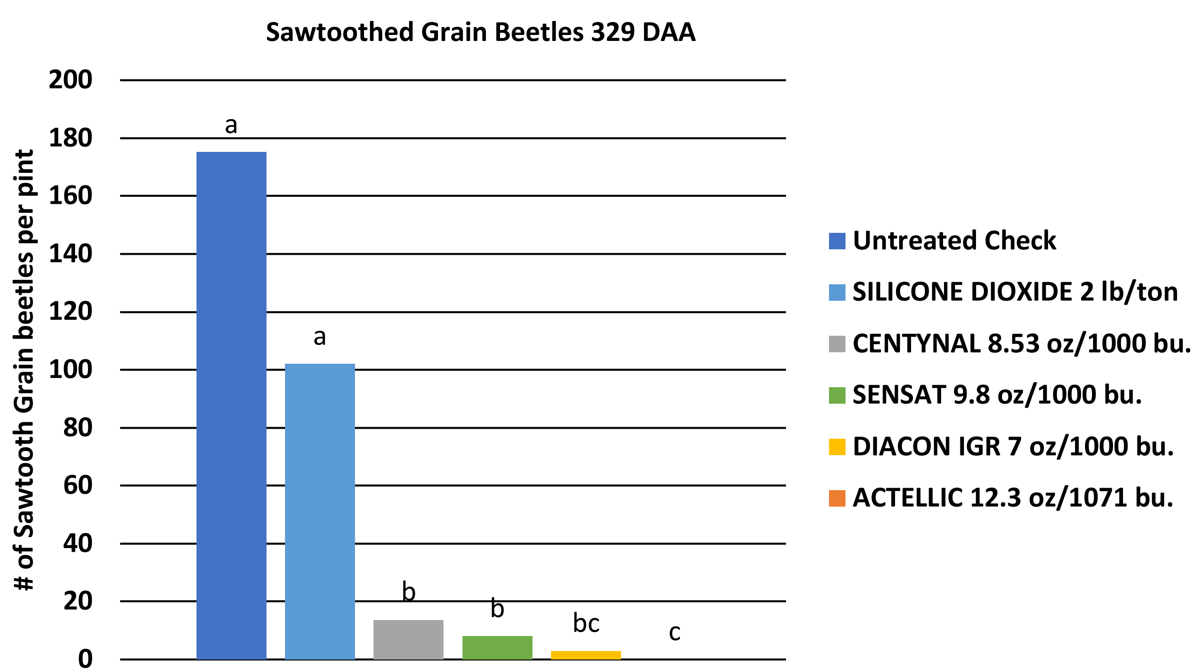

Fig. 3. Sawtoothed grain beetles per 1 pint of grain sample at 329 days after insecticide application in 55-gallon barrels. Bars with the same letter above are not significantly different at the *P* = 0.05 alpha level.

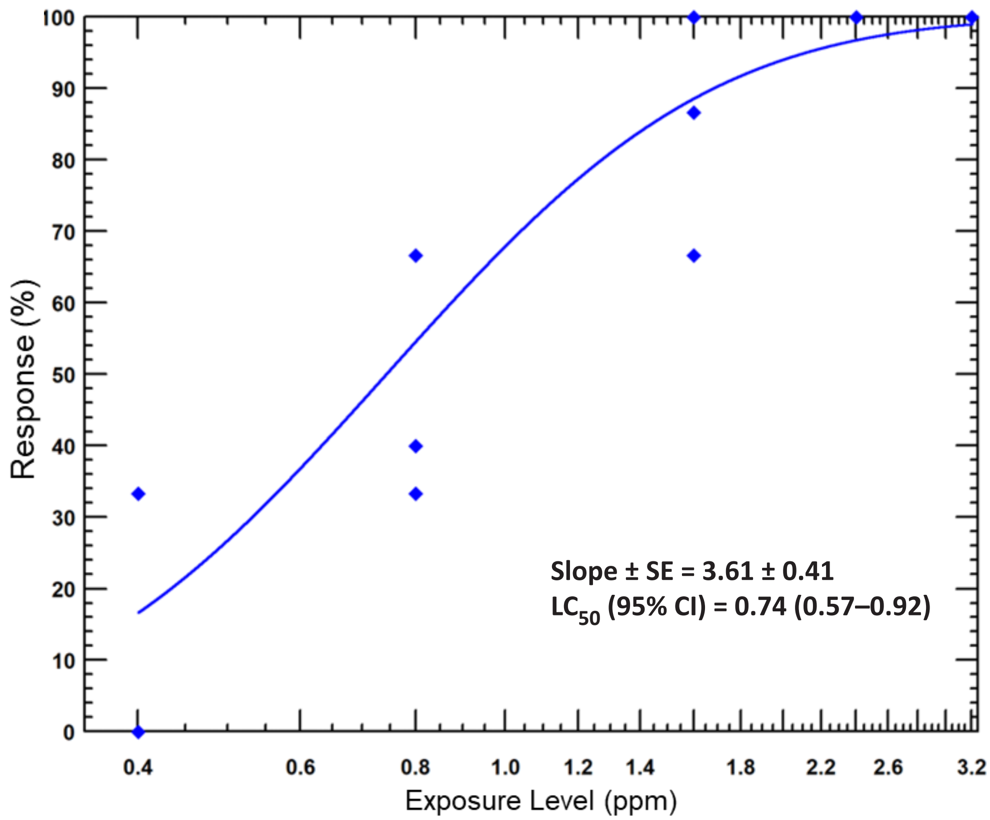

Fig. 4. Mortality of *Sitophilus oryzae* to pirimiphos-methyl at 48 hours post-treatment.

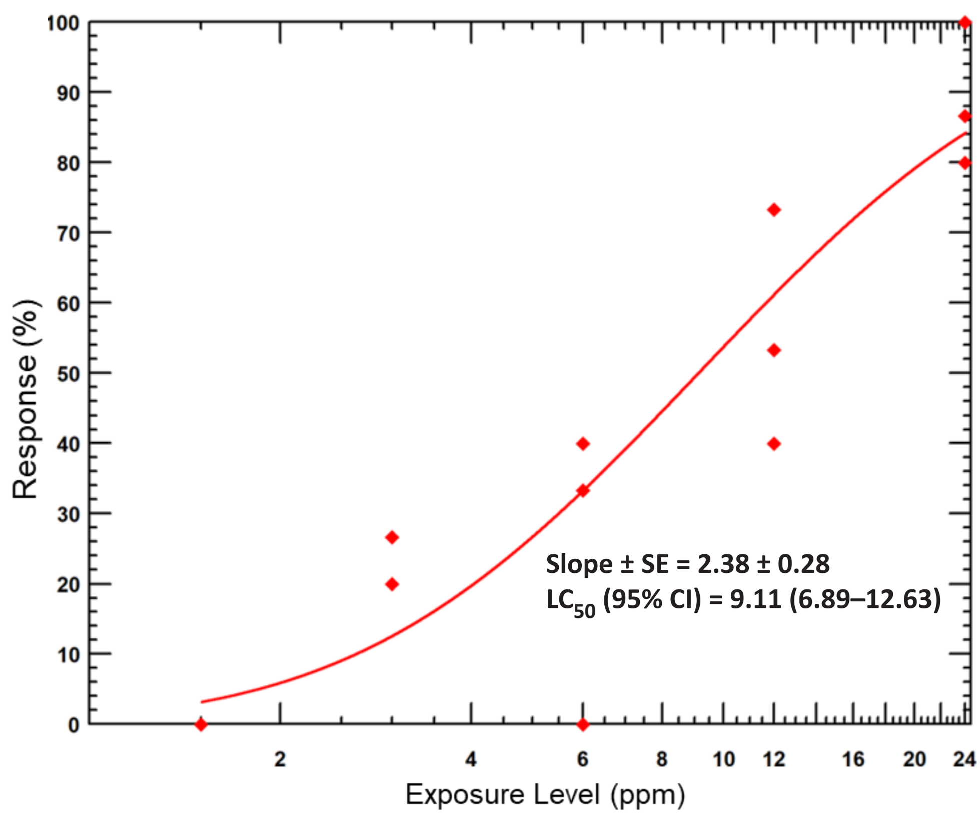

Fig. 5. Mortality of *Sitophilus oryzae* to deltamethrin at 48 hours post-treatment.

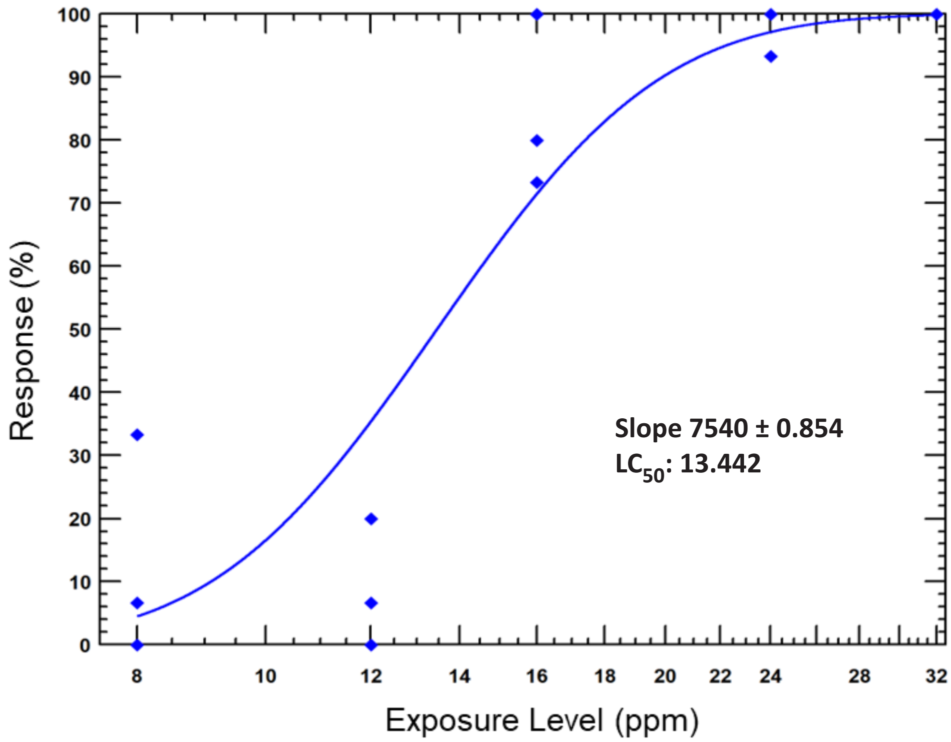

Fig. 6. Mortality of *Tribolium castaneum* to pirimiphos-methyl at 48 hours post-treatment.

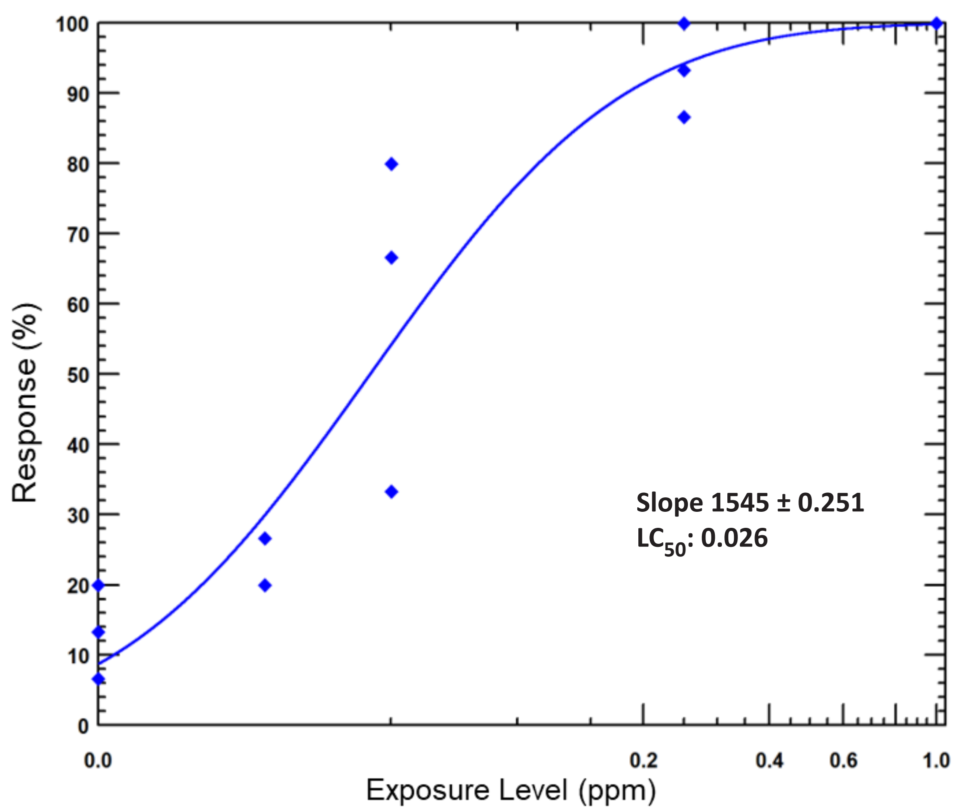

Fig. 7. Mortality of *Tribolium castaneum* to deltamethrin at 48 hours post-treatment.

Optimum Cereal Rye Termination Timing in Corn

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Abstract

Cereal rye (*Secale cereale* L.) is one of the most used cover crops for soybean [*Glycine max* (L.) Merr.] production across the United States. Its use is limited in corn (*Zea mays* L.), and data regarding the best timing to terminate cereal rye to avoid negative affects to the crop are scarce. Therefore, the objective of this study was to determine the most appropriate cereal rye termination timing in corn. Treatments consisted of cereal rye terminated at 21, 14, and 7 days prior to or after planting and at planting. A conventional tillage treatment with no cover crop was also included. The cover crop in all treatments was terminated by applying glyphosate plus *S*-metolachlor plus atrazine. These herbicides were also sprayed at planting in the conventional tillage treatment. At 30 days after planting, corn stand count in two 40-in. row sections, the height of five plants per treatment, and yellow nutsedge (*Cyperus esculentus* L.) suppression were collected. The highest yellow nutsedge suppression was observed in the treatment where there was conventional till (77%) and when the cover crop was terminated 7 days after planting the corn (63%). Corn stand was not different among the treatments. Additionally, corn plants from the treatment with cereal rye terminated 7 days after planting corn had an average height of 27 in., significantly higher than the other termination timings. The lowest heights were observed in the treatment with cereal rye terminated 21 days after planting with an average of 19 in. Based on these initial findings, cereal rye should be terminated 7 days before or after corn planting to avoid negative growth interference that may cause delay or reduction in yield without losing its desired weed suppression capacity. This study will be repeated and data from additional years will be used to support further or refute these preliminary findings.

Introduction

In Arkansas, the exponential increase in herbicide-resistant weeds coupled with the low number of new active ingredients being introduced to the market yearly has resulted in the necessity of using alternative weed control practices along with chemical control in cultivated row crops. The cultivation of cover crops between cash crops can be an effective weed management partner. Cover crops will compete and suppress weeds physically or through allelopathy (Heap, 2023; Lu et al., 2000; Mohler et al., 2021). Among winter cover crops, cereal rye has shown higher uptake and immobilization of nitrogen than other winter cover crops (Shipley et al., 1992).

Cereal rye (*Secale cereale* L.) is widely used as a winter cover crop in corn (*Zea mays* L.)-soybean [*Glycine max* (L.) Merr.] rotations and can release inhibitory substances (allelochemicals) that can reduce the initial growth of grass weeds (Dhima et al., 2006; Snapp et al., 2005). Cereal rye cover crop mulch can delay soil warming, decrease available nitrate-nitrogen, and reduce soil moisture which might suppress the yield of the following corn crop (Kaspar and Bakker, 2015; Krueger et al., 2011). Ideal cover crop termination ensures complete control of the cover crop species with little to no disturbance for the cash crop. Little information is available regarding the best timing to terminate cereal rye in corn to avoid crop damage while maintaining desirable weed suppression, and additional data is needed. Therefore, this study was designed to determine the most appropriate cereal rye termination timing in corn to avoid negative affects to the corn crop such as reduced stand or stunting with weed suppression.

Procedures

A field experiment was conducted at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center, Fayetteville, Arkansas, in 2022. The cereal variety Wrens Abruzzi was drill planted at 60 lb/ac at the end of the previous crop season (October 2021).

The study had 8 treatments organized in a randomized complete block design with 4 replications. Treatments consisted of cereal rye terminated at 21, 14, and 7 days prior to planting corn, at planting, and 21, 14, and 7 days after planting corn, and a conventional till treatment with no cover crop. Plots were 12 by 22 ft with 4 corn rows per bed. The cultivar DK62-69 was planted on 26 April at 35,000 seeds/ac with 36-in. row spacing.

The cover crop in all treatments was terminated early in the heading stage with 90% ground cover. The termination was obtained with the application of glyphosate (1.4 lb ae/ac) plus *S*-metolachlor (1.24 lb ai/ac) plus atrazine (1 lb ai/ac). These

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herbicides were also sprayed at planting in the conventional till treatment. To limit the weed competition level, the whole area was sprayed with glyphosate (1.05 lb ae/ac), *S*-metolachlor (1.05 lb ai/ac), mesotrione (0.10 lb ai/ac), and atrazine (1 lb ai/ac) when corn plants reached V4 (fourth-leaf collar visible). Herbicide applications were applied using a CO_2-pressurized backpack equipped with TTI 110015 nozzles and calibrated to deliver 15 gal/ac at 40 psi.

At 30 days after planting, corn stand count in two 40-in. rows, the height of five plants per treatment, and yellow nutsedge (*Cyperus esculentus* L.) suppression (%) were collected. The collected data were subjected to analysis of variance using JMP Pro v. 17. Means were separated using Fisher's protected least significance difference ($\alpha = 0.05$).

Results and Discussion

Corn stand was not different among the treatments (Fig. 1). Similarly, Dhima et al. (2006), working with three rye populations, did not observe a reduction in corn emergence. In a different study by Johnson et al. (1993), corn germination and emergence were reduced in cereal rye treatment. Regarding height, corn plants from the treatment with cereal rye terminated 7 days before or after planting corn had an average height of 27 in., significantly higher than the other termination timings (Fig. 2). The lowest heights were observed in the treatment with cereal rye terminated 21 days after planting with an average of 19 in. Corn height was also reduced in a previous study (Johnson et al., 1993). The reduction observed in the present and previous studies was likely a consequence of the cereal rye-corn competition. In corn, the critical period of plant interference is between V2 and V7, and cereal rye will compete with corn if not wholly terminated, which may cause a decrease in production (Kozlowski, 2002; Moschler et al., 1967).

Yellow nutsedge suppression differed with the different cover crop termination timings (Fig. 3). The highest yellow nutsedge suppression was observed in the treatment where conventional till (77%) was used and when the cover crop was terminated 7 days after planting the corn (63%). The results suggest that suppression was obtained by the action of the herbicide program used to terminate the rye along with the mulch or tillage. Cereal rye is widely recognized for its weed suppression potential. However, this response widely varies. Ormeño-Núñez et al. (2008) observed an inhibition above 80% for yellow nutsedge when a mulch of cereal rye cover crop was present. In a different study, cereal rye mulch or management timing did not impact yellow nutsedge emergence or development (Mirsky et al., 2011). Additional years are necessary to support further or refute these preliminary findings.

Practical Applications

Cover crops are a valuable weed management tool that can alleviate herbicide selection pressure by chemically or physically suppressing weeds that may escape chemical control. Ensuring that cover crops are terminated at an ideal time is crucial to avoid competition with the selected cash crop. Based on these initial findings, cereal rye should be terminated 7 days after corn planting to avoid crop damage that may cause development delays which might negatively impact yield without losing its desired weed suppression capacity. This is a long-term study, and data from additional years will be used to support further or refute these preliminary findings. Yield data will be provided in future publication.

Acknowledgments

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Literature Cited

Dhima, K.V., I.B. Vasilakoglou, I.G. Eleftherohorinos, and A.S. Lithourgidis. 2006. Allelopathic potential of winter cereals and their cover crop mulch effect on grass weed suppression and corn development. Crop Sci. 46:345-352S.

Heap, I. 2023. The international herbicide-resistant weed database. Accessed: 30 March 2023. Available at: http://roadsideweeds.com/default.aspx

Johnson, G.A., M.S. DeFelice, and Z.R. Helsel. 1993. Cover crop management and weed control in corn (*Zea mays*). Weed Technol. 7:425-430.

Kaspar, T.C., and M.G. Bakker. 2015. Biomass production of 12 winter cereal cover crop cultivars and their effect on subsequent no-till corn yield. J. Soil Water Conserv. 70:353–364.

Kozlowski, L.A. 2002. Periodo critico de interferencia das plantas daninhas na cultura do milho baseado na fenologia da cultura. Planta Daninha 20:365-372.

Krueger, E. S., T.E. Ochsner, P.M. Porter, and J.M. Baker. 2011. Winter rye cover crop management influences on soil water, soil nitrate, and corn development. Agron. J. 103:316-323.

Lu, Y.C., K.B. Watkins, J.R. Teasdale, and A.A. Abdul-Baki. 2000. Cover crops in sustainable food production. Food Rev. Int. 16:121-157.

Mirsky, S., W. Curran, D. Mortenseny, M. Ryany, and D. Shumway. 2011. Timing of cover-crop management effects on weed suppression in no-till planted soybean using a roller-crimper. Weed Sci. 59:380-389.

Mohler, C.L., J.R. Teasdale, and A. DiTommaso. 2021. Manage weeds on your farm: a guide to ecological strategies. College Park, MD: Sustainable Agriculture Research and Education, handbook 16.

Moschler, W.W., G.M. Shear, D.L. Hallock, R.D. Sears, G.D. Jones. 1967. Winter cover crops for sod-planted corn: their selection and management. Agron. J. 59: 547-551.

Ormeño-Núñez, J., G. Pino-Rojas, and F. Garfe-Vergara. 2008. Inhibition of yellow nutsedge (*Cyperus esculentus* L.) and bermudagrass (*Cynodon dactylon* (L.) Pers.) by a mulch derived from rye (*Secale cereale* L.) in grapevines. Chil. J. Agric. Res. 68:238-247.

Shipley, P.R., J.J. Meisinger, and A.M. Decker. 1992. Conserving residual corn fertilizer nitrogen with winter cover crops. Agron. J. 84:869-876.

Snapp, S.S., S.M. Swinton, R. Labarta, D. Mutch, J.R. Black, R. Leep, J. Nyiraneza, and K. O'Neil. 2005. Evaluating cover crops for benefits, costs and performance within cropping system niches. Agron. J. 97:322–332.

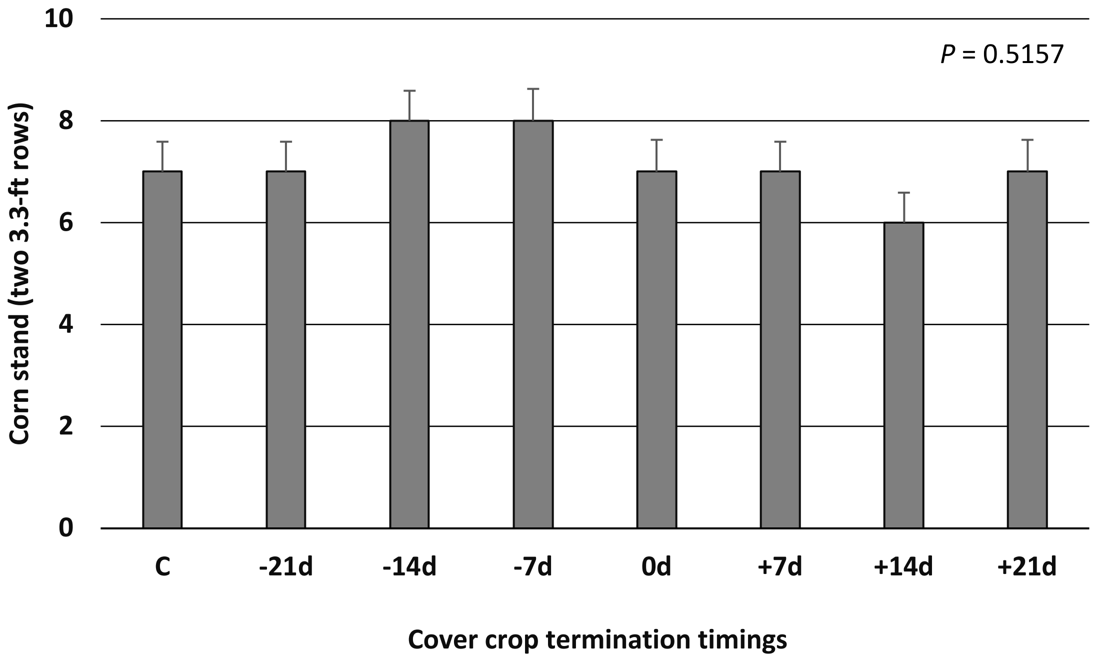

Fig. 1. Corn stand count 30 days after planting. The letter C represents conventional treatment.

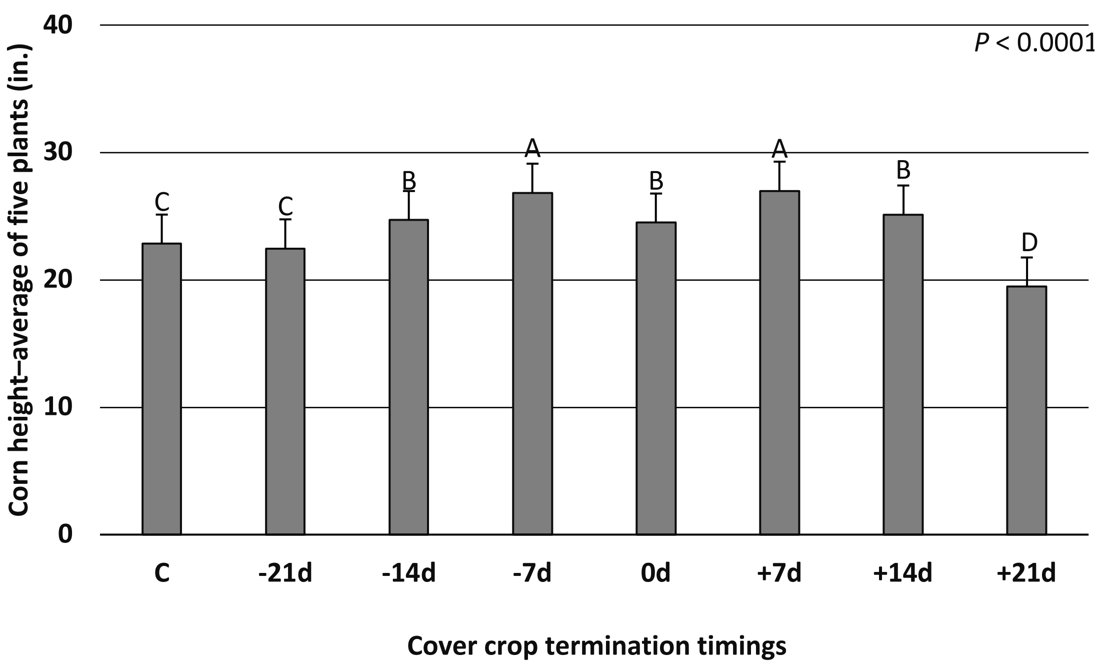

Fig. 2. Average height of five corn plants per plot 30 days after planting. Treatments with the same uppercase letter are not different according to Fisher's protected least significant difference at α = 0.05. The letter C represents conventional treatment.

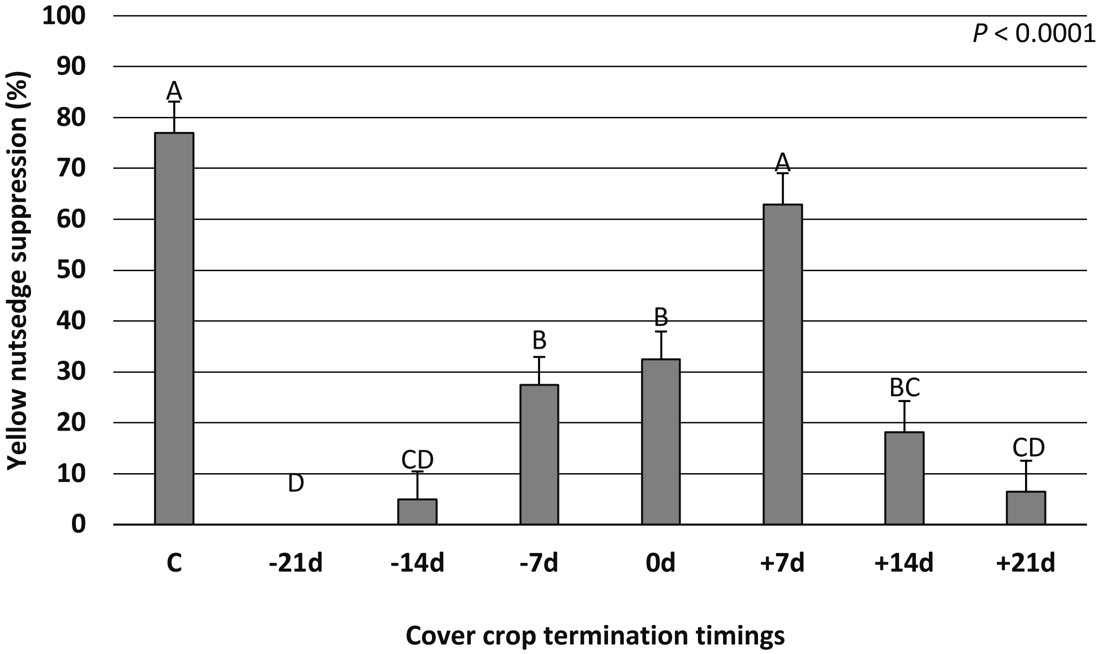

Fig. 3. Yellow nutsedge suppression (%) 30 days after planting. Treatments with the same uppercase letter are not different according to Fisher's protected least significant difference at α = 0.05. The letter C represents conventional treatment.

Enlist™ Corn Tolerance to Preemergence Applications of Synthetic Auxin and Acetyl-CoA Carboxylase-Inhibiting Herbicides

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Abstract

Enlist^{TM} corn represents an innovation in the ongoing development of herbicide-resistant crops since the 1990s and enables the use of herbicides from two additional modes of action (MOA): synthetic auxin and acetyl-CoA carboxylase (ACCase)-inhibitors. At the Fayetteville (2021 and 2022) and Tillar (2020 and 2021) sites in Arkansas, four site-year field experiments were carried out to evaluate the response of Enlist corn to preemergence application of both labeled and non-labeled synthetic auxin or ACCase-inhibiting herbicides. A non-Enlist corn hybrid was used along with the Enlist corn for each herbicide treatment to establish differential tolerance. Injury response 5 weeks after treatment application varied among site-years, where clethodim was the only herbicide that occasionally caused significant (7% at Tillar in 2021 and 17% at Fayetteville in 2021) injury to Enlist corn. Although fluazifop-P-butyl and quizalofop-P-ethyl caused injury to non-Enlist corn, Enlist corn did not experience any significant injury from those herbicides. Compared to non-treated plots, none of the treatments, except clethodim at Fayetteville in 2021, affected the yield of Enlist corn. In summary, Enlist corn can tolerate preemergence application of or exposure to those labeled as well as most non-labeled herbicides from the same MOAs. Some injury from preemergence exposure to this herbicide is a risk with Clethodim being a highly grass-active herbicide and lacking the tolerance trait in Enlist corn.

Introduction

Enlist^{TM} corn provides additional tolerance to herbicides from two modes of action (MOA), one herbicide from each of the acetyl-CoA carboxylase (ACCase)-inhibitor (quizalofop-P-ethyl) and synthetic auxin (2,4-D) MOAs. This technology offers highly differentiated weed management solutions in corn production systems compared to the previously available herbicide-tolerant crop technologies. Recently developed by Corteva Agriscience, Enlist corn allows use of quizalofop-P-ethyl (a FOP herbicide) to control volunteer, non-Enlist corn in Enlist corn and also provides an effective alternative to glyphosate for control of glyphosate-resistant grass species such as johnsongrass. This opportunity for selective in-season management of volunteer (non-Enlist) corn in corn is an unprecedented use case for ACCase-inhibiting herbicides in the grass crop. In addition, robust resistance to 2,4-D offers much greater flexibility in its use in Enlist corn compared to non-Enlist corn (Wright et al., 2010; Ruen et al., 2017).

Several other herbicides from these MOAs, including some newly developed ones, are commonly used in the Midsouthern cropping systems. Fluazifop-P-butyl (a FOP), clethodim, sethoxydim (DIMs), and halauxifen-methyl (synthetic auxins) are used in cotton, soybean, and/or rice in the region. Enlist being the first ever commercialized herbicide-tolerance trait in corn, conferring resistance to herbicides from synthetic auxins and ACCase-inhibiting MOAs, means it must be assessed for its safety for prospective herbicide use or exposure scenarios. The objective of this research was to evaluate the injury and yield response of Enlist corn in comparison with glyphosate-resistant (non-Enlist) corn to preemergence application of labeled as well as non-labeled synthetic auxins and ACCase-inhibiting herbicides.

Procedures

Four field experiments were conducted in Arkansas at two sites over two years. The experiments were established as a randomized complete block design with four replications. Plot sizes were 4-row wide and 30 ft long. Corn hybrids (Mycogen UNI 14D38 Enlist corn and 6252RIB non-Enlist corn at Fayetteville, and Mycogen UNI 14D38 or B10Z78SXE Enlist corn and Pioneer P1197YHR non-Enlist corn at Tillar site) were planted 1 to 1.2 in. deep at a seeding rate of 28,00 to 35000 seeds/ac with a 30- to 38-in. wide row spacing, depending on location. Date of planting, site-specific soil texture, and general weather conditions are presented in Table 1. Herbicides were applied to two center rows of corn in four-row plots at planting. A list of herbicides along with relevant information is given in Table 2. A non-treated control was included for each corn hybrid. Herbicide treatments were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 15 GPA at 32 psi fitted with AIXR 110015 flat-fan nozzles (TeeJet®, Spraying Systems Co., Wheaton, Ill.).

At Fayetteville, weeds in plots were controlled with application of glyphosate (Roundup PowerMAX®, Bayer CropScience LP) at 1.12 lb ae/ac plus halosulfuron-methyl at 0.06 lb ai/ac (Permit®, Gowan Company LLC) at three-leaf

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corn, followed by a premix of *S*-metolachlor + mesotrione + bicyclopyrone + atrazine (Acuron®, Syngenta Crop Protection, LLC) at 1.33 + 0.15 + 0.04 + 0.62 lb ai/ac.

Corn injury on a scale of 0 (no injury, non-treated control) to 100% (complete plant death) at 5 weeks after application (WAA) and crop yield (except for Tillar in 2021) at maturity were taken, and the data were fit to generalized linear mixed-effect models using the glmmTMB function (Brooks et al., 2017) using R statistical software v. 4.2.2 (R Core Team, 2022). Analysis of variance was conducted with Type III Wald chi-square tests, and treatment estimated marginal means were separated using the emmeans package (Length, 2022) and multcomp package (Hothorn et al., 2008).

Results and Discussions

Corn planting for the Fayetteville site in 2021 was earlier than the other site years (Table 1). The weather conditions (temperature or precipitation) following application varied among the sites (Table 1), which may have caused some variability in corn response to the herbicide treatments.

By 5 WAA, non-Enlist corn injury across sites was generally more pronounced with most herbicides that had caused injury at 3 WAA (data not shown). Enlist corn at Fayetteville showed >15% injury with clethodim and at least 10% injury with sethoxydim in 2021 (Fig. 1A), whereas corn had recovered from initial injuries from halauxifen-methyl and sethoxydim (>10%, data not shown) by 5 WAA in 2022 (Fig. 1B). For all herbicides at Tillar in 2020, injury was nonsignificant at 5 WAA (Fig. 2C), similar to the results at 3 WAA (data not shown); nevertheless, >5% injury was visible with quizalofop-P-ethyl or clethodim for Enlist corn in 2021 (Fig. 2D). Across sites, the FOP herbicides frequently caused injury on non-Enlist corn (Fig. 1A-D). The discrepancies in corn injury response to these herbicides at different sites are likely the result of weather conditions following the applications. Soil moisture content has long been known to affect herbicide fate and modulate herbicide transport within the soil-plant system, resulting in differential injury to plants (Green and Objen, 1996). A high amount of rainfall that coincided with the crop emergence time at Fayetteville in 2022 may have contributed to an overall greater injury at 3 WAA, while relatively dry conditions at Tillar may have safeguarded emerging corn plants from exposure to herbicides in the soil solution.

Yield data for Tillar (2021) were not collected. Besides occasional injury from the DIM family of ACCase-inhibiting herbicides (clethodim and sethoxydim), Enlist corn yields were not affected by any of the herbicides from the two MOAs used in this study. Non-Enlist corn usually showed a similar response as Enlist corn, with instances of yield discrepancies such as with clethodim and halauxifen-methyl.

For the labeled herbicides, Enlist corn invariably showed no injury in contrast to non-Enlist corn, which showed frequent injury, especially with the FOP herbicides, indicating that the tolerance mechanism in Enlist corn is operative early in the growth stage.

Practical Applications

This two-site, two-year field study evaluated Enlist corn response to preemergence application of synthetic auxin and ACCase-inhibiting herbicides that are relevant in Midsouthern crop production systems. Results showed that injury and the subsequent yield loss are not a concern for Enlist corn from preemergence exposure to these herbicides. These results provide baseline information on outcomes from the prospective, both intended and accidental, preemergence exposure of Enlist corn to these herbicides.

Acknowledgments

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Literature Cited

Brooks, M.E., K. Kristensen, K.J. van Benthem, A. Magnusson, C.W. Berg, A. Nielsen, H.J. Skaug, M. Mächler, and B.M. Bolker. 2017. glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. R. J. 9:378-400.

Green, R. and S. Obien. 1969. Herbicide equilibrium in soils in relation to soil water content. Weed Sci. 17:514-519.

Hothorn, T., F. Bretz, and P. Westfall. 2022. multcomp: Simultaneous inference in general parametric models. Accessed 25 March 2023. Available at: https://CRAN.R-project.org/package=multcomp

Length, R.V. 2022. emmeans: Estimated marginal means, aka least-squares means. Accessed 25 March 2023. Available at: https://CRAN.R-project.org/package=emmeans

R Core Team. 2022. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN: 3-900051-07-0. Available at https://www.R-project.org/

Ruen, D., E. Scherder, S. Ditmarsen, P. Prasifka, J. Ellis, D. Simpson, P. Gallup, and B. Hopkins. 2017. Tolerance of corn with glyphosate resistance and the aryloxyalkanoate dioxygenase trait (AAD-1) to 2,4-D choline and glyphosate. Weed Technol. 31:217-224.

Wright, T.R., G. Shan, T.A. Walsh, J.M. Lira, C. Cui, P. Song, M. Zhuang, N.L. Arnold, G. Lin, K. Yau, S.M. Russell, R.M. Cicchillo, M.A. Peterson, D.M. Simpson, N. Zhou, J. Ponsamuel, and Z. Zhang. 2010. Robust crop resistance to broadleaf and grass herbicides provided by aryloxyalkanoate dioxygenase transgenes. PNAS USA 107:20240-20245.

Table 1. Site description, planting and application time, and weather conditions at Fayetteville and Tillar study sites in Arkansas.

Site, year	Soil type	Date of treatment application[a]	Precipitation[b]	Weather conditions following treatment application[c]
			in	
Fayetteville, 2021	Captina silt loam	8 April	26.4	Moist, cool
Fayetteville, 2022	Captina silt loam	27 April	27.5	Wet, moderate
Tillar, 2020	Hebert silt loam	12 May	31.9	Dry, moderate
Tillar, 2021	Hebert silt loam	8 May	39.9	Moderate, moderate

[a] Corn planted on the same day.
[b] Cumulative of daily amount beginning 1 April through 30 September.
[c] Represents duration 15 days following application; cool < avg. temperature 50–60 °F = moderate > warm; dry < cumulative precipitation 2–4 in. = moist > wet.

Table 2. List of synthetic auxin and ACCase-inhibiting herbicides applied preemergence on Enlist and non-Enlist corn in Arkansas (2020–2022), along with other relevant information.

Herbicide	Trade name	Manufacturer	Rates[a]	Is the herbicide labeled for use in Enlist corn?	Rotation/replant interval for non-Enlist corn
			(lb ai/ac)		(days)
Synthetic auxins					
2,4-D choline	Enlist One®	Corteva Agriscience LLC	0.95	Yes	0
Halauxifen-methyl	Elevore™	Corteva Agriscience LLC	0.01	No	15
ACCase-inhibitors -FOPs					
Fluazifop-P-butyl	Fullisade®DX	Syngenta Crop Protection, LLC	0.19	No	60
Quizalofop-P-ethyl	Provisia®	BASF Corporation	0.1	Yes	120
ACCase-inhibitors -DIMs					
Clethodim	Select Max®	Valent U.S.A. LLC	0.12	No	6
Sethoxydim	Poast Plus®	BASF Corporation	0.19	No	30

[a] All herbicides applied with 1% v/v crop oil concentrate.
ai = active ingredient.

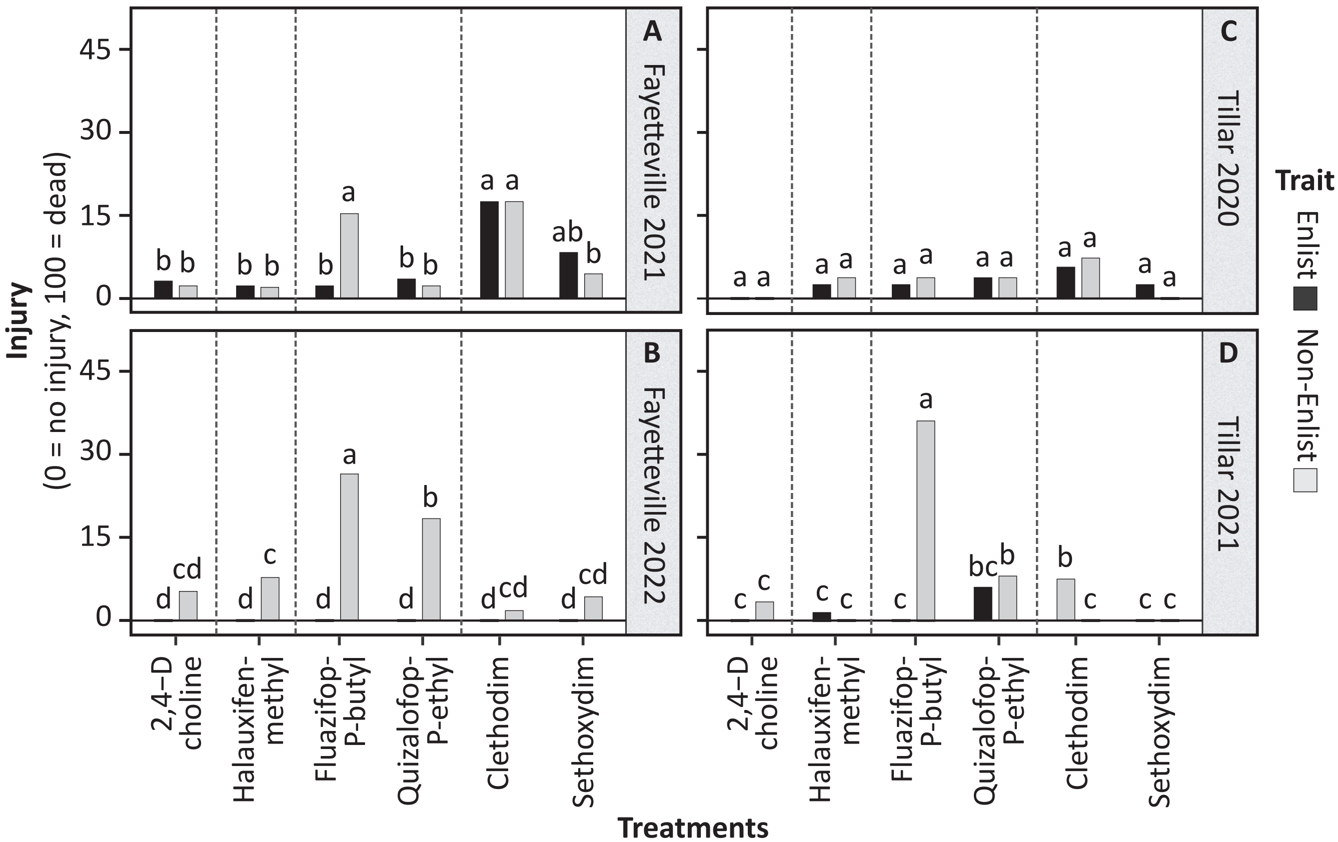

Fig. 1. Injury response of Enlist corn in comparison to non-Enlist corn to preemergence application of synthetic auxin and ACCase-inhibiting herbicides 5 weeks after application at (A) Fayetteville 2021, (B) Fayetteville 2022, (C) Tillar 2020, and (D) Tillar 2021, Arkansas. Means with the same letter within a plot are not significantly different (*P* = 0.05, Tukey's honestly significant difference).

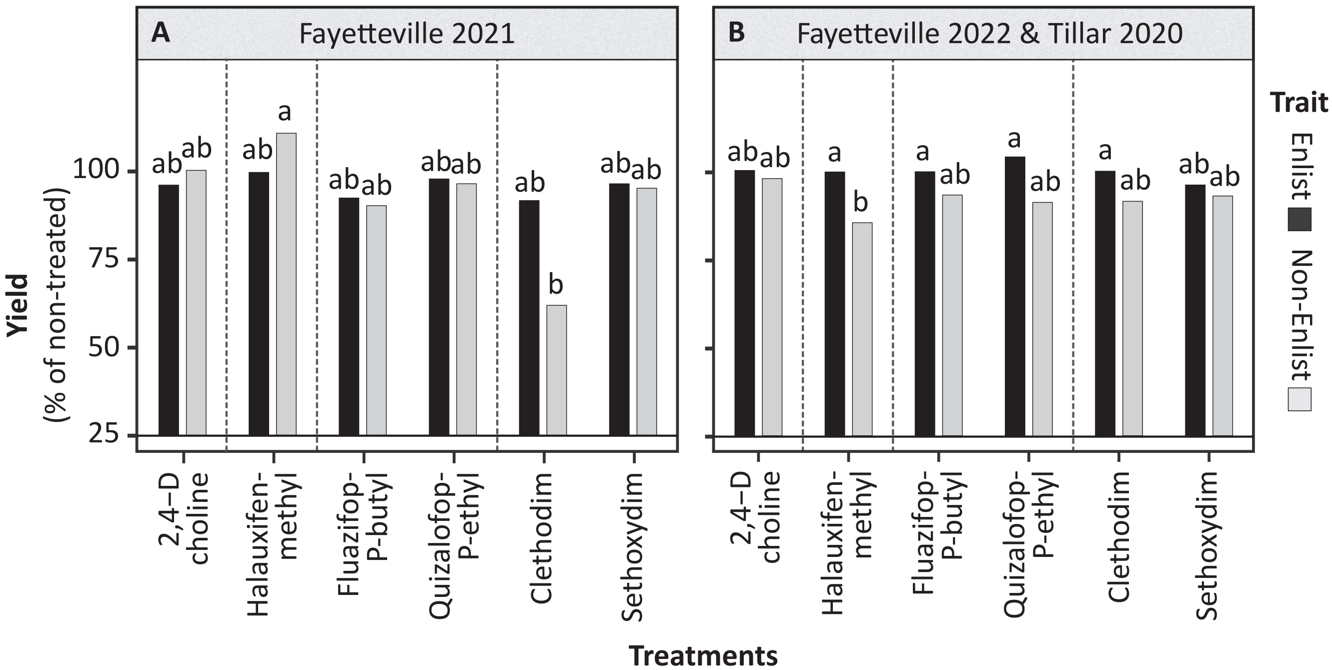

Fig. 2. Yield of Enlist corn in comparison to non-Enlist corn as affected by preemergence application of synthetic auxin and ACCase-inhibiting herbicides at (A) Fayetteville (2021) and (B) Fayetteville (2022), Tillar (2020), Arkansas. Means with the same letter within each plot are not significantly different (*P* = 0.05, Tukey's honestly significant difference).

Evaluation of Enlist™ Corn Tolerance to Postemergence Applications of Synthetic Auxin and Acetyl-CoA Carboxylase-inhibiting Herbicides

A.S. Godar,[1] J.K. Norsworthy,[1] and L.T. Barber[2]

Abstract

Enlist™ corn is a newly commercialized hybrid allowing the use of 2,4-D and quizalofop-methyl herbicides. Knowledge of Enlist corn tolerance to these labeled herbicides as well as other herbicides within the same mode of action (MOA) is not well established. Four site-year field experiments were conducted at Fayetteville (2021 and 2022) and Tillar (2020 and 2021) sites, in Arkansas, to evaluate Enlist corn response to postemergence applications of herbicides from two MOAs, synthetic auxin or acetyl-CoA carboxylase (ACCase)-inhibitors, that are common in Midsouthern crop production systems. A non-Enlist corn hybrid was used along with the Enlist corn for each herbicide treatment for comparison. Enlist corn showed injury to applications of florpyrauxifen-benzyl (>10%), fluazifop-P-butyl and quizalofop-P-ethyl (>5%), and clethodim and sethoxydim (>75%) 1 week after application (WAA). These initial injury responses to clethodim and sethoxydim were generally reflected in Enlist corn yield; however, the minimal injury from fluazifop-P-butyl and quizalofop-P-ethyl did not affect yield. Injury on non-Enlist corn with ACCase-inhibiting herbicides 1 or 2 WAA was >80%, resulting in a proportionate yield reduction. Florpyrauxifen-benzyl caused more initial injury in non-Enlist corn; however, yield reduction in non-Enlist corn was occasionally less than in Enlist corn, with both hybrids experiencing >75% yield reduction. In summary, Enlist corn may occasionally show transient injury even to labeled herbicides, and injury from florpyrauxifen-benzyl may result in serious yield loss.

Introduction

The herbicide resistance trait in Enlist™ corn provides tolerance to specific chemical classes of the herbicides; the aryloxyphenoxypropionate (AOPP, a.k.a. FOPs) class of acetyl-CoA carboxylase (ACCase)-inhibiting and the phenoxycarboxylic class of synthetic auxins (Wright et al., 2010). Quizalofop-P-ethyl and 2,4-D, one from each mode of action (MOA), respectively, are the only herbicides that are labeled for use with Enlist technology. While Enlist corn offers selective in-season management of volunteer (non-Enlist) corn in corn and much greater flexibility of 2,4-D use in Enlist corn (Wright et al., 2010; Ruen et al., 2017), information regarding its response to various other herbicides from the same MOAs is lacking. Commonly used ACCase-inhibiting and synthetic auxin herbicides, including some newly developed ones, in the Midsouthern cropping systems are fluazifop-P-butyl (a FOP), clethodim and sethoxydim (DIMs), and florpyrauxifen-benzyl and halauxifen-methyl (synthetic auxins, pyridine carboxylate family, different than 2,4-D). The objective of this research was to evaluate the response of Enlist corn in comparison with glyphosate-resistant (non-Enlist) corn to postemergence applications of synthetic auxins and ACCase-inhibiting herbicides for potential implications for Enlist corn safety under normal and replanting situations, and volunteer corn control.

Procedures

Field experiments were conducted at the Fayetteville and Tillar sites in Arkansas in 2020, 2021, or 2022. Corn hybrids (Mycogen UNI 14D38 Enlist corn and 6252RIB non-Enlist corn at Fayetteville, and Mycogen UNI 14D38 or B10Z78SXE Enlist corn and Pioneer P1197YHR non-Enlist corn at the Tillar site) were planted 1 to 1.2 in. deep at a seeding rate of 28,00 to 35000 seeds/ac with a 30- to 38-in. wide row spacing, depending on location. Plot sizes were 4-row wide and 30 ft long. Date of planting, site-specific soil texture, and general weather conditions are presented in Table 1. Herbicides were applied to two center rows of corn in four-row plots to 2-to-3-leaf corn. A list of herbicides along with relevant information is given in Table 2. A non-treated control was included for each corn hybrid. Herbicide treatments were applied using a CO_2-pressurized backpack sprayer calibrated to deliver 15 GPA at 32 psi fitted with AIXR 110015 flat-fan nozzles (TeeJet®, Spraying Systems Co., Wheaton, Ill.).

At Fayetteville, weeds in plots were controlled with application of glyphosate (Roundup PowerMAX®, Bayer CropScience LP) at 1.12 lb ae/ac plus halosulfuron-methyl at 0.06 lb ai/ac (Permit®, Gowan Company LLC) at three-leaf corn, followed by a premix of *S*-metolachlor + mesotrione + bicyclopyrone + atrazine (Acuron®, Syngenta Crop Protection, LLC) at 1.33 + 0.15 + 0.04 + 0.62 lb ai/ac.

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Visible injury (a composite assessment of chlorosis, necrosis, and stunting) was rated 1 and 2 weeks after application (WAA). The visible injury ratings were based on a scale of 0 (no injury, non-treated control) to 100% (complete plant death). Two center rows of corn were harvested (except for Tillar in 2021) at crop maturity using a plot combine, and grain yield was adjusted to 15% moisture. Corn was accidentally harvested by the farmer at Tillar in 2021. Yield data were converted to a percentage of respective traits' non-treated controls.

The experiments were established as a randomized complete block design with four replications. Injury and yield data were fit to generalized linear mixed-effect models using the glmmTMB function (Brooks et al., 2017) using R statistical software version 4.2.2 (R Core Team, 2022). Analysis of variance was conducted with Type III Wald chi-square tests, and treatment estimated marginal means were separated using the emmeans package (Length, 2022) and multcomp package (Hothorn et al., 2008).

Results and Discussion

At 1 WAA, all the treatments for both Enlist and non-Enlist corn caused 5% or more crop injury, with clethodim and sethoxydim resulting in >65% injury (Fig. 1A). The responses for fluazifop-P-butyl or quizalofop-P-ethyl were highly differentiated between Enlist and non-Enlist corn (<10% vs. >75%, respectively). Injury to corn from florpyrauxifen-benzyl was at least 25% with the 1X rate and >40% with the 2X rate. Despite instances of injury in some plots, Enlist corn did not show significant injury with 2,4-D. Conversely, non-Enlist corn showed variable injury, ranging from no injury to 30% injury. At 2 WAA, Enlist corn had slightly recovered from the initial injury caused by all herbicides, except for clethodim (Fig. 1B). Non-Enlist corn generally maintained a similar level of injury from synthetic auxin treatments, whereas the injury with fluazifop-P-butyl, quizalofop-P-ethyl, or clethodim was more pronounced (>90% injury). Non-Enlist corn injury was greater compared to Enlist corn with both florpyrauxifen-benzyl rates (averaged across rates, 22 vs. 38% injury, respectively). Corn injury from sethoxydim was not as severe as that from clethodim, especially in non-Enlist corn.

At Fayetteville, except for 2,4-D, fluazifop-P-butyl, or quizalofop-P-ethyl, all other herbicides reduced the grain yield of Enlist corn, ranging from >75% with florpyrauxifen-benzyl to >95% with clethodim or sethoxydim. For Enlist corn, similar yield reductions occurred with all the herbicides, with additional yield loss (complete loss) from fluazifop-P-butyl or quizalofop-P-ethyl. Yield results were generally similar for Tillar, except for florpyrauxifen-benzyl. The grain yield of Enlist corn was >75% of the non-treated, whereas it was at least 50% of the non-treated for non-Enlist corn at a 1X rate of florpyrauxifen-benzyl.

Practical Applications

With direct comparisons to non-Enlist corn, this two-site, two-year field study evaluated Enlist corn response to postemergence applications of synthetic auxin and ACCase-inhibiting herbicides that are relevant in Midsouthern crop production systems. Results from this study indicate that transient injury is possible for Enlist corn even from those labeled herbicides. Florpyrauxifen-benzyl initially caused a mild injury but resulted in serious yield loss in both Enlist and non-Enlist corn, with instances of greater yield loss in Enlist corn than in non-Enlist corn. Injury development with DIM herbicides was rapid in Enlist corn and generally similar to that of non-Enlist corn, implying that DIM herbicides can be successfully used to control volunteer corn in soybean production systems.

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Literature Cited

Brooks, M.E., K. Kristensen, K.J. van Benthem, A. Magnusson, C.W. Berg, A. Nielsen, H.J. Skaug, M. Mächler, and B.M. Bolker. 2017. glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. R. J. 9:378-400.

Hothorn, T., F. Bretz, and P. Westfall. 2022. multcomp: Simultaneous inference in general parametric models. Accessed 25 March 2023. Available at: https://CRAN.R-project.org/package=multcomp

Length, R.V. 2022. emmeans: Estimated marginal means, aka least-squares means. Accessed 25 March 2023. Available at: https://CRAN.R-project.org/package=emmeans

R Core Team. 2022. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN: 3-900051-07-0. Available at: https://www.R-project.org/

Ruen, D., E. Scherder, S. Ditmarsen, P. Prasifka, J. Ellis, D. Simpson, P. Gallup, and B. Hopkins. 2017. Tolerance of corn with glyphosate resistance and the aryloxyalkanoate dioxygenase trait (AAD-1) to 2,4-D choline and glyphosate. Weed Technol. 31:217-224.

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Table 1. Site description, planting and application time, and weather conditions at Fayetteville and Tillar, Arkansas for the study of Enlist corn tolerance to postemergence applications of synthetic auxins and ACCase-inhibiting herbicides.

Site, year	Soil type	Date of planting	Date of treatment application[a]	Precipitation[b]	Weather conditions following treatment application[c]
				(in.)	
Fayetteville, 2021	Captina silt loam	8 April	18 May	26.4	Moist, moderate
Fayetteville, 2022	Captina silt loam	27 April	27 May	27.5	Moderate, warm
Tillar, 2020	Hebert silt loam	12 May	3 June	31.9	Moderate, warm
Tillar, 2021	Hebert silt loam	8 May	4 June	39.9	Wet, warm

[a] Corn planted on the same day.

[b] Cumulative of daily amount beginning 1 April through 30 September.

[c] Represents duration 15 days following application; cool < avg. temperature 50–60 °F = moderate > warm; dry < cumulative precipitation 2–4 in. = moist > wet.

Table 2. List of herbicides applied postemergence on Enlist and non-Enlist corn in study sites in Arkansas (2020–2022), along with other relevant information.

Herbicide	Trade name	Manufacturer	Rates[a]	Is the herbicide labeled for use in Enlist corn?	Rotation/replant interval for non-Enlist corn
			(lb ai/ac)		(days)
Synthetic auxins					
2,4-D choline	Enlist One®	Corteva Agriscience LLC	0.95	Yes	0
Florpyrauxifen-benzyl	Loyant®	Corteva Agriscience LLC	0.01[b]	No	0
ACCase-inhibitors -FOPs					
Fluazifop-P-butyl	Fullisade®DX	Syngenta Crop Protection, LLC	0.19	No	60
Quizalofop-P-ethyl	Provisia®	BASF Corporation	0.1	Yes	120
ACCase-inhibitors -DIMs					
Clethodim	Select Max®	Valent U.S.A. LLC	0.12	No	6
Sethoxydim	Poast Plus®	BASF Corporation	0.19	No	30

[a] All herbicides applied with 1% v/v crop oil concentrate.

[b] 1X rate.

ai = active ingredient.

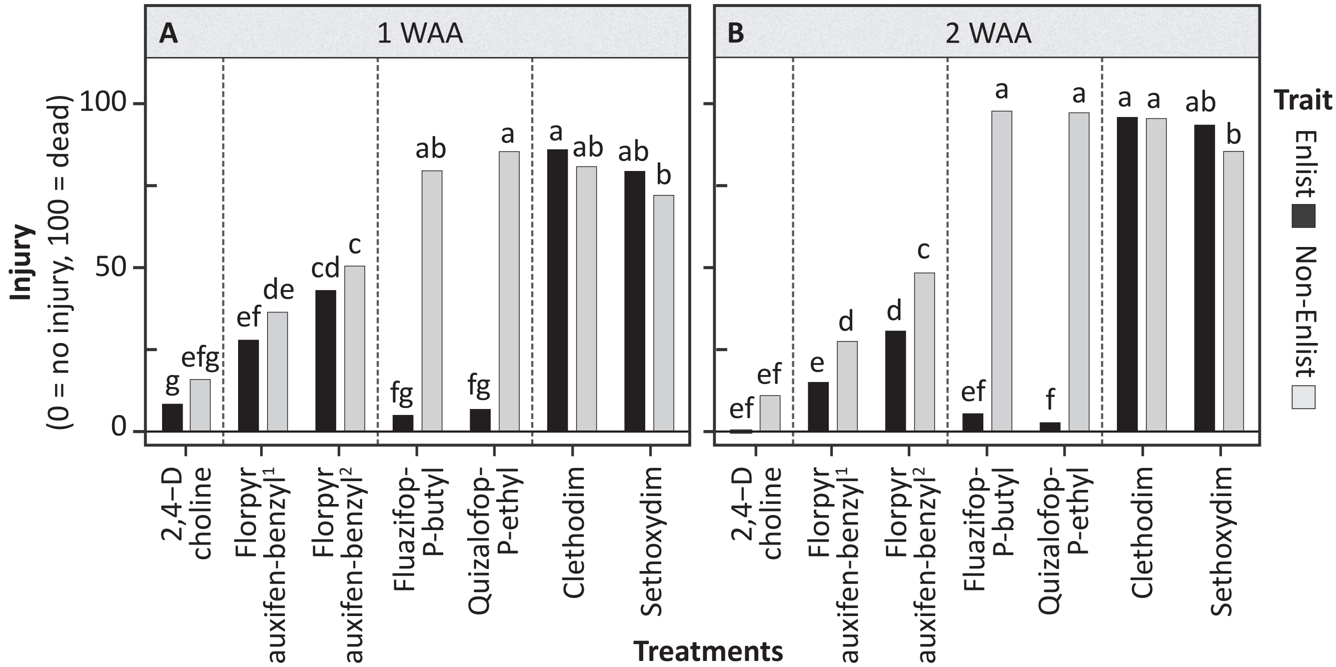

Fig. 1. Injury response of Enlist corn in comparison to non-Enlist corn to postemergence application of synthetic auxin and ACCase-inhibiting herbicides (A) 1 week(s) after application (WAA) and (B) 2 WAA. Data were pooled for four site-year experiments: Fayetteville (2021 and 2022) and Tillar (2020 and 2021), Arkansas. Means with the same letter within a plot are not significantly different (*P* = 0.05, Tukey's honestly significant difference). [1]1X rate; [2]2X rate.

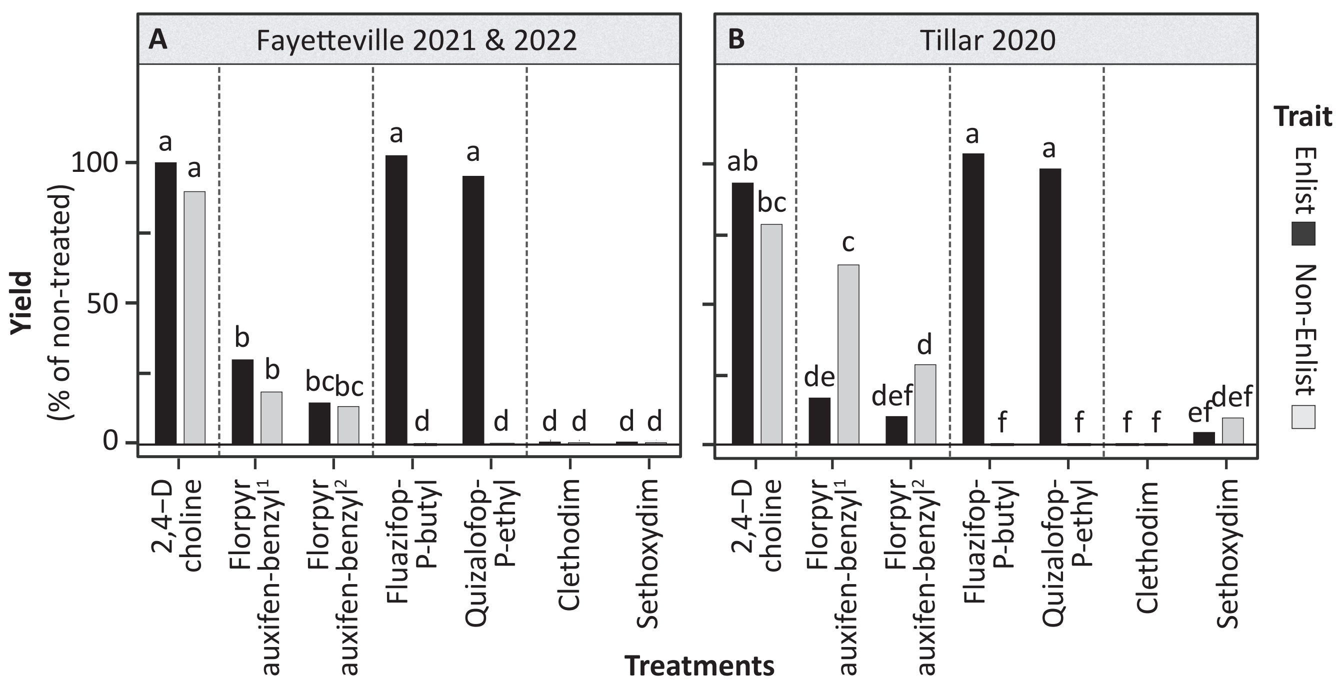

Fig. 2. Yield of Enlist corn in comparison to non-Enlist corn as affected by postemergence application of synthetic auxin and ACCase-inhibiting herbicides at (A) Fayetteville (2021 and 2022) and (B) Tillar (2020), Arkansas. Means with the same letter within each plot are not significantly different (*P* = 0.05, Tukey's honestly significant difference). [1]1X rate; [2]2X rate.

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

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

Abstract

The University of Arkansas System Division of Agriculture Irrigation Yield Contest was conducted between 2018 and 2022. The contest was designed to promote better use of irrigation water as well as to record data on water use and water use efficiency for various crops. Unlike yield contests where winners are decided by yield alone, the irrigation contest results are decided by the highest calculated total water use efficiency (WUE) achieved by a producer.
The contest consists of three categories: corn, rice, and soybeans. All fields entered were required to show a history of irrigation and production on the field. Irrigation water usage was recorded by using 6-, 8-, 10, and 12-in. portable mechanical flow meters. Rainfall totals were calculated using Farmlogs™. The contest average water use efficiency of 2018–2022 for corn was 8.57 bu./in. The winning WUE was 7.47 bu./in. for 2022, 12.53 bu./in. for 2021, 11.59 bu./in. for 2020, 11.36 bu./in. for 2019, and 10.55 bu./in. for 2018. Adoption of irrigation water management practices such as computerized hole selection, surge irrigation, and soil moisture sensors are increasing. Corn contest participants report using on average 9.7 ac-in./ac of irrigation water over the last five years.

Introduction

According to data from 2015 reported by USGS, Arkansas ranks 3rd in the United States for irrigation water use and 2nd for ground water use (Dieter et al., 2018). For comparison, Arkansas ranked 18th in 2017 in total crop production value (USDA-NASS, 2017). Of the ground water used for irrigation, 96% comes from the Mississippi River Alluvial Aquifer (Kresse et al., 2014). One study of the aquifer found that 29% of the wells in the aquifer, that were tested, had dropped in water level between 2009 and 2019 (Arkansas Department of Agriculture Natural Resource Division, 2020).

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

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

Procedures

Rules for the irrigation yield contest were developed in 2018. Influence was taken from already existing yield contests (Arkansas Soybean Association, 2014; National Corn Growers Association, 2015; National Wheat Foundation, 2018; University of California Cooperative Extension, 2018). The rules were designed to be as unobtrusive as possible to normal planting and harvesting operations. Fields must be at least 30 acres in size. A yield minimum of 200 bu./ac must be achieved to qualify.

A portable propeller style mechanical flowmeter was used to record water use. All flow meters were checked for proper installation and sealed using polypipe tape and serialized tamper-proof cables. Rainfall was recorded using Farmlogs™, an online software that provides rainfall data for a given location. Rainfall amounts were totaled from the date of emergence to the date of physiological maturity. Emergence was assumed as 7 days after the planting date provided on the entry form. For physiological maturity, the seed companies published days to maturity is used. Rainfall is adjusted for extreme events outlined in Henry et al (2023) by reducing precipitation events to what the soil profile could contain.

The harvest operations were observed by a third-party observer, often an Extension agent, Natural Resources Conservation

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Service employee, or University of Arkansas System Division of Agriculture staff. For the yield estimate, a minimum of 3 acres was harvested from the contest field.

The equation used for calculating WUE for the contest was:

$$WUE = \frac{Y}{Pe + IRR}$$

where, WUE = water use efficiency in bu./in., Y = yield estimate from harvest in bu./ac, Pe = Effective precipitation in inches, and IRR = Irrigation application in ac-in./ac (Irmak et al., 2011). Statistical analysis was performed using Microsoft Excel and JMP 15 (SAS Institute, Inc., Cary, N.C.).

Results and Discussion

Detailed results are published on the contest website (www.uaex.uada.edu/irrigation) for each year of the contest. Over the five years that the competition has been conducted, there have been 46 fields entered for corn. The average WUE over the 5 years was 8.57 bu./in. By year, the average WUE was 7.19 bu./in. for 2022 with 5 contestants; 10.53 bu./in. for 2021 with 7 contestants; 8.07 bu./in. for 2020 with 14 contestants; 8.06 bu./in. for 2019 with 9 contestants; and 9.36 bu./in. for 2018 with 6 contestants (Table 1). In 2022, participation was low primarily due to the late planting window caused by persistent wet field conditions. Total average water use was the second highest of the five-year contest, and average yield was the lowest to date for the contest. The winning WUE was lower in 2022 than the previous four years. The winning WUE for each year was: 7.47 bu./in. for 2022, 12.53 bu./in. for 2021, 11.59 bu./in. for 2020, 11.36 bu./in. for 2019, and 10.55 bu./in. for 2018. Total water use was higher in 2019, 2020, and 2023, than in 2018 and 2021

There has been no discernable relationship between yield and WUE in corn when analyzed (Henry et al., 2023). Another commonly held belief by contestants is that a higher amount of rainfall will help to increase WUE. By plotting rainfall against WUE, linear regression was used to determine if there was a linear relationship. The coefficient of determination was determined to be $R^2 = 0.02$. There is no discernable relationship between WUE and precipitation. The lack of relationships suggests that neither precipitation nor yield is a factor in achieving high WUE and achieving high WUE is due to irrigation management.

There appears to be a high correlation in the overall contest success with owner management of irrigation timing versus an employee with no direct incentive to promote irrigation efficiency. The 2022 corn winner won the soybean division in 2019. The 2021 corn division winner placed first in the soybean division in 2021 and first in the rice division in 2022. The corn winner from 2019 placed first in the levee rice division in 2022. The rice winner from 2020 won the soybean division in 2022. One corn contestant has placed in the top three for the last 4 years.

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

Contestants are asked about their adoption of IWM tools when they enter the contest. In total, 64% of the participants across all 3 categories included responses in their entry form. The IWM tool that was most widely adopted was CHS. The average use among respondents was 82.7% across all 5 years with 88% in 2018, 72% in 2019, 100% in 2020, 97.5% in 2021, and 79% in 2022. The use of furrow-irrigated rice saw an increase in respondents from 56% and 50% in 2018 and 2019, respectively, to 73% in 2020, 80% in 2021, and 64% in 2022. Adding all years together, 68% of rice contest fields used furrow irrigation. Another water-saving method of rice irrigation is multiple inlet rice irrigation (MIRI). Twenty-one percent of respondents from all 5 years reported using MIRI with 33% in 2018, 17% in 2019, 27% in 2020, 100% in 2021, and 25% in 2022. Sixty percent of respondents from all 5 years said that they used soil moisture sensors on their farm, with 50% in 2018, 40% in 2019, 42% in 2020, 87% in 2021, and 81% in 2022. Surge valves were the least used IWM tool, with a 5-year average use rate of 25%. Those that reported using surge irrigation over the 5 years of the contest were 44% in 2018, 28% in 2019, 16% in 2020, 35% in 2021, and 12% in 2022 (Table 2).

Practical Applications

Irrigation water use efficiency of working farms is not a common metric available in the literature, and it is not a metric familiar to corn farmers. The data recorded from the Arkansas Irrigation Yield Contest provides direct feedback to irrigators about their irrigation performance in maintaining high yields and low irrigation water used. Such direct feedback of Arkansas corn farmers will likely provide many with a competitive advantage when water resources become more scarce. It provides a mechanism for corn farmers to evaluate the potential for water savings by adopting water saving techniques or management changes.

On average, corn growers in the contest across the five years averaged 9.7 ac-in./ac of irrigation water applied and a total water use (irrigation + rainfall) of 26.6 inches. The winning WUE of the contest winners improved over the first four years. However, the reduced yield seen in the contest, and other fields is likely due to unfavorable weather (lower rainfall and higher temperatures) during the growing season that contributed to a lower WUE in 2022.

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Literature Cited

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

Arkansas Soybean Association. 2014. Grow for the Green Soybean Yield Challenge Rules & Entry Form. Accessed 14 January 2021. Available at: https://www.arkansassoybean.com/2014_final_entry_form.pdf

Dieter, C.A., M.A. Maupin, R.R. Caldwell, M.A. Harris, T.I. Ivahnenko, J.K. Lovelace, N.L. Barber, and K.S. Linsey. 2018. Estimated use of water in the United States in 2015: U.S. Geological Survey Circular 1441, 65 p., https://doi.org/10.3133/cir1441

Henry, C.G., R. Parker, T. Clark, R. Goodson, and R. Mane. 2023. University of Arkansas System Division of Agriculture Irrigation Yield Contest 2022 Final Report. University of Arkansas System Division of Agriculture, Little Rock, Ark. Accessed 5 May 2023. Available at: https://www.uaex.uada.edu/environment-nature/water/agriculture-irrigation/docs/Arkansas-Irrigation-Yield-Contest-2022-Annual-Report.pdf

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

Kresse, T.M., P.D. Hays, K.R. Merriman, J.A. Gillip, D.T. Fugitt, J.L. Spellman, A.M. Nottmeier, D.A. Westerman, J.M. Blackstock, and J.L. Battreal. 2014, Aquifers of Arkansas-Protection, management, and hydrologic and geochemical characteristics of groundwater resources in Arkansas: U.S. Geological Survey Scientific Investigations Report 2014–5149. http://dx.doi.org/10.3133/sir20145149

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

National Wheat Foundation. 2018. National Wheat Yield Contest Rules. Accessed 14 January 2021. Available at: https://yieldcontest.wheatfoundation.org/Content/RulesPDF/NWYC%20Entry%20Harvest%20Rules.pdf

Spencer, G.D., L.J. Krutz, L.L. Falconer, W.B. Henry, C.G. Henry, E.J. Larson, and R.L. Atwill. 2019. Irrigation water management technologies for furrow-irrigated corn that decrease water use and improve yield and on-farm profitability. Crop Forage Turfgrass Mgmt. 5(1):180100. https://doi.org/10.2134/cftm2018.12.0100

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

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

Table 1. Maximum, average, and minimum for 2018–2022 of various water and yield data points for corn from the Arkansas Irrigation Yield Contest.

Year		Water Use Efficiency	Yield	Adjusted Rainfall	Irrigation Water	Total Water
		(bu./in.)	(bu./ac)	(in.)	(ac-in./ac)	(in.)
2022	Maximum	7.47	212	18.0	18.8	35.2
	Average	7.19	197	14.4	14.0	28.1
	Minimum	5.75	183	9.7	12.0	26.2
2021	Maximum	12.53	279	17.3	9.8	25.7
	Average	10.53	243	15.3	7.9	23.3
	Minimum	9.16	224	14.1	5.6	20.6
2020	Maximum	11.53	252	21.4	19.3	33.5
	Average	8.08	210	16.2	10.3	26.5
	Minimum	5.71	155	12.1	2.8	18.8
2019	Maximum	11.36	280	32.6	14.3	43.6
	Average	8.06	233	24.6	6.0	30.6
	Minimum	4.10	179	18.0	1.5	19.5
2018	Maximum	10.55	265	13.1	16.9	29.2
	Average	9.36	216	11.2	12.2	23.4
	Minimum	6.27	160	9.0	8.4	20.3
5 Yr.	Average	8.76	223	17.3	9.1	26.4

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

Year	Computerized Hole Selection	Furrow Irrigated Rice	Multiple Inlet Rice Irrigation	Moisture Sensors	Surge Valve
	(%)	(%)	(%)	(%)	(%)
2022	79	64	25	81	12
2021	97.5	80	100	87	35
2020	100	73	27	100	25
2019	72	50	17	40	28
2018	88	56	33	50	44

Corn Response to Potassium Fertilizer Applications

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Abstract

Corn (*Zea mays* L.) grain yield is tightly linked to potassium (K) fertilization practices, but so is producer profitability. Work sponsored by the Arkansas Corn and Grain Sorghum Board has been ongoing to verify the current K fertilization rates based on soil test K concentrations and develop leaf tissue correlation and concentration data to diagnose in season K deficiencies. Potassium response trials were established at four research stations across Arkansas in 2022 and included the Milo J. Shult Agricultural Research and Extension Center (SAREC), the Lon Mann Cotton Research Station (LMCRS), the Pine Tree Research Station (PTRS), and the Rohwer Research Station (RRS). Six K fertilizer rates ranging from 0–200 lb K_2O/ac were applied preplant and incorporated prior to corn establishment. At the VT growth stage earleaf (leaf immediately subtending the ear) samples were collected, dried, ground and analyzed to determine tissue-K concentration. At maturity corn grain yield was determined using a small plot combine. Preplant soil samples suggested that the PTRS location should be highly responsive to K fertilizer applications, that LMCRS would have little to no response to K fertilization and that SAREC and RRS should not respond to K fertilization. Yield results indicated a significant yield increase from K fertilization at the LMCRS and the PTRS with yield increases of 14 and 83 bu./ac, respectively. Corn earleaf tissue-K concentrations ranged from 0.79% to 2.67 % K and were not statistically different than one another at the SAREC or RRS locations but were influenced by K fertilizer rate at LMCRS and PTRS. The results of this trial suggest that corn response to K fertilization in Arkansas can be significant and that earleaf tissue-K concentrations can be a good indicator of K nutritional status.

Introduction

Corn continues to be an important rotational crop in Arkansas production systems and although acreage fluctuates from year to year there seems to be a general trend of increasing acreage over time. Additionally, worldwide demand for K fertilizer has been consistently rising as crop yields are continuing to increase across the globe (Dhillon et al., 2019). One of the largest input costs for corn production is fertilization and K can account for a significant portion of the input costs specifically on silt loam soils. Recent work in Arkansas strengthened the soil test correlation and calibration data for soil test K as a predictor of K fertilizer needs (Drescher et al., 2021). Results of this work indicated a linear relationship between corn relative grain yield and soil test K and suggested that more data was needed in the higher soil test K ranges to help identify the critical soil test K concentration for corn. Corn is highly responsive to fertilizer-K applications and significant yield increases can be realized when responsive sites are identified, and the proper rate of K fertilizer is applied. Research in Iowa also supports the impact of proper K fertilization on corn grain yield and suggests that large yield increases can be expected when soil test K concentrations are low (Mallarino, 1991). Work by Oliver and others (2022) assessed the economics of proper K fertilization and developed the economic potash rate calculator to aid producers in identifying the most profitable K fertilization rate based on their soil test K values.

To better predict the need for in-season nitrogen (N) applications in corn, dos Santos et al. (2021) identified leaf N concentration sufficiency ranges for corn across the V10–VT growth stages. The summary of their results suggested that maintaining a leaf N concentration above 3% for all growth stages from V10–R1 would optimize corn grain yield as influenced by N fertilizer applications. The previous work in N suggests that similar research could be completed in K to aid producers in confirming K deficiency symptoms or helping to identify potential hidden hunger. The primary objectives of this research project were to 1) increase the database of corn grain yield response to K fertilization on a range of soil test K concentrations and 2) begin the collection of data to assess the ability of leaf tissue-K concentration as a predictor of corn grain yield and K nutritional status.

Procedures

Potassium fertilization trials were established at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center (SAREC), Fayetteville, Ark., Lon Mann Cotton Research Station (LMCRS), Marianna, Ark., Pine Tree Research Station (PTRS), Colt, Ark., and Rohwer Research Station (RRS), Rohwer, Ark., during the 2022 cropping season. The study areas varied for each location and followed soybean (*Glycine max* L.) at the SAREC, RRS and PTRS locations and corn at the LMCRS. Preplant soil samples were taken and analyzed at the Agricultural Diagnostic Laboratory (Fayetteville, Ark.) for soil pH and routine soil analysis. All nutrients (K, P, and

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Zn) other than nitrogen (N) were applied preplant onto flat ground prior to pulling beds. Nitrogen fertilizer was applied in a two-way split application with 30 lb N/ac applied preplant incorporated and 190 lb N/ac applied at sidedress (V4–V8) as NBPT-treated urea (46%N). The K rate structure for this trial consisted of preplant K rates of 0, 40, 80, 120, 160, and 200 lb K_2O/ac.

Raised beds spaced 36 in. apart (SAREC), 38 in. apart (LMCRS and RRS) or 30 in. apart (PTRS) were established following preplant fertilizer application. At each location, the corn hybrid P1718VYHR was planted on 30 May, 12 May and 13 May 2022 at approximately 35,000 seed/ac for the SAREC, LMCRS, and PTRS locations, respectively. Plot dimensions for this trial were 4 rows wide by 30 ft long, and, therefore, plot width varied by location. Irrigation and pest management were conducted based on current University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) guidelines, and corn was furrow irrigated as needed based on the Arkansas irrigation scheduler set to a 1.5-in. deficit.

At the VT growth stage, five earleaves (leaf immediately subtending the ear) were sampled from the middle two rows of each plot. Leaf samples were oven dried at 70 °C until a constant weight, ground to pass through a 1-mm sieve, mixed, digested with 1 mol L^{-1} HNO_3, and analyzed using inductively coupled plasma atomic emission spectroscopy to determine elemental concentrations (Jones and Case, 1990). The inside two rows of each plot were harvested and adjusted to 15.5% moisture to determine grain yield.

The experiment was arranged in a randomized complete block design with four blocks. The corn grain yield and tissue-K concentration were analyzed using a simple one-way analysis of variance to compare the preplant K fertilizer treatments. Fisher's protected least significant difference ($\alpha = 0.05$) was used to separate yield and tissue-K concentration means. The statistical analysis was completed using JMP Pro 16.

Results and Discussions

Corn grain yield can be impacted by several factors, but research has consistently shown that K fertilizer can influence the yield and profitability of irrigated corn production systems especially where soil test K values are categorized as Low or Very Low. Mean (n = 4) soil test K concentrations were 163, 107, 56, and 132 ppm for the SAREC, LMCRS, PTRS, and RRS, respectively. Based on the current CES soil test guidelines, the SAREC (163 ppm) and RRS (132 ppm) fields would fall in the Optimum category and there would not be an expected yield increase due to K fertilization. The soil test K at the PTRS location (56 ppm) would place it in the Very Low category and the soil test K at the LMCRS (107 ppm) would place it in the Medium category, suggesting that both sites should exhibit a yield response to K fertilization.

Corn grain yield at the SAREC location ranged from 193–203 bu./ac and was maximized when 160 lb K_2O/ac was applied (Table 1). However, the corn grain yield at 0 lb K_2O/ac and 160 lb K_2O/ac were not statistically different than one another indicating no yield response to K fertilization. Results from the RRS followed a similar pattern with a range of 197–225 bu./ac, but with no statistical differences amongst the lowest or highest rates indicating no significant yield response to K fertilization. The lack of yield response at the SAREC and RRS stations is supported by the soil test K levels and was expected. Significant responses to K fertilization are expected ~50% of the time for soils testing in the Medium soil test K category. There was a statistical yield response at the LMCRS where the 0 lb K_2O/ac rate resulted in a significantly lower yield than all treatments that received K fertilizer. Corn grain yield at the LMCRS ranged from 192–217 bu./ac, but indicated that a 14 bu./ac yield increase could be achieved with as little as 40 lb K_2O/ac. The PTRS location had the lowest overall soil test K (56 ppm) and fell within the Very Low soil test K category suggesting that significant and large yield increases might be expected following K fertilization. Yields ranged from 106–189 bu./ac at PTRS and followed a linear response suggesting that rates higher than 200 lb K_2O/ac might have increased yields even further. At the PTRS location, an 83 bu./ac yield increase was observed when 200 lb K_2O/ac was applied. The data presented here indicate that irrigated corn in Arkansas is highly responsive to K fertilization and that soil test K appears to be a good indicator of sites that will respond positively to fertilization.

Corn tissue-K concentrations have been used to diagnose K deficiency, but most interpretive guidelines are based on survey data and not replicated K response trial data. Previous work on correlating tissue-K concentration to corn grain yield has primarily occurred in the upper Midwest under non-irrigated conditions. Sufficiency ranges for tissue-K concentrations at the VT growth stage have been reported as 1.75–2.75 %K. These sufficiency ranges suggest that tissue-K concentrations below 1.75 %K were experiencing hidden hunger and tissue-K concentrations below 1.25 %K were deficient. At the SAREC and RRS where there was no significant yield response to K fertilization exhibited, tissue-K concentrations were near or above the 1.75% K threshold (Table 2). At the SAREC location, there were no significant differences in tissue-K concentrations; they ranged from 2.55–2.67 %K, and fell within the range that was considered sufficient. Like SAREC, there were no significant differences in the tissue-K concentrations at the RRS, but one treatment (40 lb K_2O/ac.) did fall slightly outside the sufficiency range (1.67 %K). However, the fertilizer-K treatment with the lowest tissue-K concentration also produced the highest corn grain yield (225 bu./ac) further supporting the notion that these ranges are not as rigid as one might expect. All tissue-K concentrations at the LMCRS (1.83–2.15 %K) fell within the sufficient range even though the tissue-K for the two lowest K fertilization rates was statistically lower than the other fertilizer-K rates. Similar to what was observed in the tissue-K concentrations, there were no visual K deficiency symptoms at the RRS in any of the K rate treatments throughout the season. There was a yield response at the LMCRS suggesting that the 1.75 %K threshold is not exact, but in an alternate direction to what was observed for RRS. At the LMCRS, there were some slight visual K deficiency symptoms in the nontreated control, but no symptoms were identified in any of the treatments that received preplant K. Tissue-K concentrations at the PTRS ranged from 0.79–1.83 %K and all fertilizer-K treatments would have been below the suggested 1.75 %K threshold except the highest K rate of 200 lb K_2O/ac. There were distinct visual K deficiency symptoms on the lower leaves at the PTRS location in the non-treated control and two lowest K fertilizer rates. The increase in corn grain yields at the PTRS location appears to coincide with increasing tissue-K concentrations suggesting that a correlation of tissue-K concentrations with corn grain yields is possible.

Practical Applications

Following a period of record-high fertilizer prices, it is imperative that Arkansas corn producers have ample data to make their K management decisions to maximize yield and profitability. Our data indicate that soil test K is a good indicator of sites that will require K fertilization to maximize corn grain yield and that sites in the Very Low soil test category can see highly significant increases in corn grain yield (83 bu./ac) when the proper rate of K fertilizer is applied. Although our tissue-K dataset is limited, it appears that there is a strong correlation between corn tissue-K concentration and corn grain yield. Further research should focus on correlating leaf tissue-K concentration to corn grain yield to develop a dynamic critical tissue-K concentration for corn similar to what has been developed for irrigated soybean (Slaton et al., 2021).

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Literature Cited

Dhillon, J.S., E.M. Eickhoff, R.W. Mullen, and W.R. Raun. 2019. World potassium use efficiency in cereal crops. Agron. J. 111:889– 896. https://doi.org/10.2134/agronj2018.07.0462

dos Santos, C.L., T.L. Roberts, and L.C. Purcell. 2021. Leaf Nitrogen Sufficiency Level Guidelines for Midseason Fertilization in Corn. Agron. J. 113:1974-1980.

Drescher, G.L., N.A. Slaton, T.L. Roberts, and A.D. Smartt. 2021. Corn yield response to phosphorus and potassium fertilization in Arkansas. Crop, Forage, and Turfgrass Mgmt. 7:e20120. https://doi.org/10.1002/cft2.20120

Jones, J.B. and V.W. Case, 1990. Sampling, handling, and analyzing plant tissue samples. *In:* R. L. Westerman (ed.) Soil Testing and Plant Analysis (3rd ed., pp. 389–428). SSSA.

Mallarino, A.P., J.R. Webb, and A.M. Blackmer. 1991. Soil test values and grain yields during 14 years of potassium fertilization of corn and soybean. J. Produc. Agric. 4:562–566. https://doi.org/10.2134/jpa1991.0560

Oliver, K. M.P. Popp, N.A. Slaton, G.L. Drescher, and T.L. Roberts. 2022. Profit-maximizing potassium fertilizer recommendations for corn and cotton. Agron. J. 114:3358-3376.

Slaton, N.A., Roberts, T.L., and R. Parvej, 2021. Dynamic critical potassium concentrations in soybean leaves and petioles for monitoring potassium nutrition. Agron. J., Accessed 21 March 2023. Available at: https://doi.org/10.1002/agj2.20819

Table 1. Influence of potassium (K) fertilizer rate on the grain yield of corn at four locations during 2022.

K Fertilizer Rates	Locations			
	SAREC†	LMCRS	PTRS	RRS
(lb K_2O/ac)	----------(bu./ac)----------			
0	197 ab‡	192 b	106 e	221 ab
40	196 ab	206 a	131 d	225 a
80	195 ab	217 a	145 c	216 ab
120	197 ab	211 a	153 c	197 b
160	203 a	208 a	176 b	209 ab
200	193 b	215 a	189 a	219 ab

† SAREC = Milo J. Shult Agricultural Research and Extension Center, Fayetteville, Ark.; LMCS = Lon Mann Cotton Research Station, Marianna, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RRS = Rohwer Research Station, Rohwer, Ark.

‡ Means within a column followed by the same letter are not significantly different ($P < 0.05$).

Table 2. Influence of potassium (K) fertilizer rate on the corn earleaf tissue-K concentration at the VT growth stage at four locations during 2022.

	Locations			
K Fertilizer Rates	**SAREC**[†]	**LMCRS**	**PTRS**	**RRS**
(lb K_2O/ac)	--------------------(%K)--------------------			
0	2.55 a[‡]	1.83 b	0.79 d	1.88 a
40	2.54 a	1.86 b	1.08 c	1.67 a
80	2.67 a	2.04 a	1.31 b	1.81 a
120	2.60 a	2.02 a	1.70 a	1.79 a
160	2.60 a	2.10 a	1.68 a	1.98 a
200	2.60 a	2.15 a	1.83 a	1.88 a

[†] SAREC = Milo J. Shult Agricultural Research and Extension Center, Fayetteville, Ark.; LMCS = Lon Mann Cotton Research Station, Marianna, Ark.; PTRS = Pine Tree Research Station, Colt, Ark.; RRS = Rohwer Research Station, Rohwer, Ark.

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

Irrigated Rotational Cropping Systems, 2014–2022 Summary

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

Abstract

A large-plot field trial evaluating the impact of crop rotation on yields of winter wheat (*Triticum aestivum* L.) and irrigated corn (*Zea mays* L.), early planted soybean [*Glycine max* (L.) Merr.], double-crop soybean, full-season grain sorghum [*Sorghum bicolor* (L.) Moench], and double-crop grain sorghum was conducted from 2013–2022 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station near Marianna, Arkansas. Yields of early planted (April) group 4 soybean yields were 5 and 6 bu./ac higher when planted following corn and grain sorghum, respectively, compared to continuous soybean. Crop rotation impacted June-planted, double-crop soybean yield 2 out of 9 years, and average yields were 3 and 4 bu./ac greater when following corn or grain sorghum compared to a previous wheat double-crop soybean crop. Corn yields were impacted by the previous crop 3 out of 9 years, where corn following corn yield was 26, 11, and 20 bu./ac lower than when following early planted soybean in 2016, 2021, and 2022. On average, corn following corn yielded 8 bu./ac less than when following early planted soybean or double-crop soybean, respectively. Wheat yields were impacted by the previous crop in 6 out of 8 years of the trial. Wheat following full-season grain sorghum across all years yielded 10 bu./ac less than when following early planted soybean, and 5 and 4 and 5 bu./ac less than when following corn and double-crop soybean, respectively. Full-season grain sorghum was always planted following early planted soybean or double-crop soybean, and yields averaged 113 bu./ac with no difference in yield between previous crops over 9 years. Double-crop grain sorghum averaged 84 bu./ac across 8 years. This trial was a unique collaborative project funded project by the Arkansas Corn and Grain Sorghum, Soybean, and Wheat Promotion Boards to answer questions pertaining to each commodity.

Introduction

Arkansas crop producers have a wide range of crops that can be successfully grown on their farms, including early planted group 4 soybean (typically planted in April), corn, full-season grain sorghum, wheat, double-crop soybean, double-crop grain sorghum, cotton (*Gossypium hirsutum*), and rice (*Oryza sativa*) depending on soil type. As crop acreages in Arkansas have changed over the years due to grain price fluctuations and changing profitability, more producers are incorporating crop rotation as a way to increase crop yields and farm profitability. Crop rotation has been shown in numerous trials to impact crop yields. In studies near Stoneville, Mississippi, Reddy et al., 2013, found that corn yields following soybean were 15%–31% higher than when corn was continuously grown; however, soybean yields were not statistically greater but trended to higher yields when planted following corn. In Tennessee, Howard et al., 1998, found that soybean following corn yielded 11% higher than compared to continuous soybean and attributed soybean yield increases following corn to reduced levels of soybean-cyst nematodes. As crop acreage continues to shift based on economic decisions, more information is needed for producers on which crop rotation produces the greatest yields and profitability under mid-South irrigated growing conditions. There is a lack of long-term crop rotation research that documents how corn, soybean, wheat, and grain sorghum rotations perform in the mid-South. A comprehensive evaluation of crop rotation systems in the mid-South is needed to provide non-biased and economic information for Arkansas producers.

Procedures

A long-term field trial evaluating yield responses of 8 rotational cropping systems that Arkansas producers may use was initiated at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station near Marianna, Arkansas in April of 2013. The following 8 crop rotations were evaluated:

1. **Corn/Soybean/Corn/Soybean**. Corn is planted in April each year followed by early planted group 4 soybean planted in April the following year.
2. **Corn/Wheat/Double-Crop Soybean/Corn**. Corn is planted in April, followed by wheat planted in October following corn harvest, then double-crop soybean planted in June after wheat harvest, and corn planted the following April.
3. **Wheat/Double-Crop Soybean/Wheat**. Wheat is planted in October, followed by double-crop soybean planted in June, then wheat planted in October.
4. **Full-Season Grain Sorghum/Wheat/Double-Crop Soybean/Full-Season Grain Sorghum**. Full-season grain sorghum is planted in April, followed by wheat planted in October, then double-crop soybean planted in June after

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wheat harvest, then full-season grain sorghum planted the following April.

5. **Continuous Corn**. Corn is planted during April every year.
6. **Continuous Soybean**. Early planted group 4 soybean is planted in April every year.
7. **Full-Season Grain Sorghum/Early Planted Soybean**. Full-season grain sorghum is planted in April, followed by early planted group 4 soybean planted in April the following year.
8. **Early Soybean/Wheat/Double-Crop Grain Sorghum/ Soybean**. Early planted (April) group 4 soybean, followed by wheat, is planted in October, then double-crop grain sorghum is planted in June after wheat harvest, followed by early planted group 4 soybean the following April.

The soil in the trial was a Memphis Silt Loam (Fine-silty, mixed, active, thermic Typic Hapludalf), which is a predominant soil type in the area. Crop rotation treatments were replicated 4 times within a randomized complete block design and all rotation combinations were planted each year. Plot size was 25-ft wide (8 rows wide) by 200-ft long with 38-in. row spacing. Prior to planting summer crops each year, plots were conventionally tilled, which included disking, field cultivation, and bed formation with a roller-bedder so crops could be planted on a raised bed for furrow irrigation. Prior to planting wheat in October, plots that were going to be planted were disked, field cultivated, and rebedded. Wheat was then planted on raised beds with a grain drill with 6-in. row spacing with a seeding rate of 120 lb of seed/ac. Planting wheat on raised beds has become a more common practice in Arkansas on fields that have been precision leveled for furrow irrigation and facilitates timely double-crop soybean establishment.

Soybean varieties planted changed over the duration of the trial. For early planted group 4 soybean, maturity ranged from 4.6 to 4.9 each year. Double-crop soybeans planted each year had a maturity range of 4.6 to 4.9. Corn hybrids planted varied by year, but maturity ranged from 112 to 117 days. Full-season grain sorghum was Pioneer 84P80 from 2014–2018 and DKS51-01 in 2019–2022. Double-crop grain sorghum hybrids that were grown varied over the duration of the trial but included: Sorghum Partners 7715, DKS 37-07, and DKS 44-07, which are sugarcane aphid-tolerant hybrids. The soft red winter wheat variety Pioneer 26R41 was planted each year with the exception of the fall of 2020, and 2021 when the variety Progeny #Bullet was planted.

Summer crops were furrow irrigated as needed according to the University of Arkansas System Division of Agriculture's Cooperative Extension Service (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 2 rows of each 8-row wide plot at crop maturity and remaining standing crops were harvested with a commercial combine and the crop residue deposited back onto the plots. Soil nematode samples were collected at the trial initiation and each subsequent fall after crop harvest and submitted to the University of Arkansas System Division of Agriculture's Nematode Diagnostic Lab at the Southwest Research and Extension Center at Hope, Arkansas, for analysis. Soybean-cyst nematode was the only nematode that was found to be above economic threshold levels during the course of this trial. No root-knot nematodes were found in the trial area.

Results and Discussion

Soybean

Early planted group 4 soybean yields were considered good each year with an average yield of 57 to 63 bu./ac depending on rotation over the 9-year period (Table 1). The yield of early planted group 4 soybean was statistically impacted by previous crops in 4 out of 9 years of the trial. Continuously grown soybean without rotation yielded 57 bu./ac on average, while soybean rotated with corn or full-season grain sorghum the previous year yielded 62 and 63 bu./ac, respectively (Table 1). Similar trends were noted with double-crop soybean yields when following wheat. When double-crop soybeans were following a previous crop of wheat/double-crop soybean, yields on average were only 42 bu./ac, while yields increased to 45 and 46 bu./ac, respectively, when corn or full-season grain sorghum had been grown the previous year. However, double-crop soybean yields were only statistically influenced by the previous crop in 2 out of 9 years (Table 2). Early planted group 4 soybean averaged 60.7 bu./ac averaged across rotations from 2014-2022 and double-crop soybeans averaged 44.4 bu./ac averaged across rotations during the same time. The 16.3 bu./ac difference between April soybean and June-planted double-crop soybean is similar to what many Arkansas soybean producers see on their farms between the early planted production system and double-crop system.

Differences in early-planted and double-crop soybean yields between crop rotations can likely be partially attributed in part to lower soybean cyst nematode (SCN) numbers following corn or grain sorghum. Soybean cyst nematode egg numbers from soil samples collected in October of 2022 after soybean harvest were highest in the double-crop soybean plots. Plots where wheat-double-crop soybean was grown previously each year had the highest level of SCN eggs with 534 eggs/100cc of soil, while plots that had been planted to wheat and corn or grain sorghum the previous year and then planted to double-crop soybean had SCN egg levels of 240 and 477 eggs/100cc of soil, respectively. In comparison, analysis showed plots that had been continuously planted to corn since 2013 resulted in no SCN eggs detected. The general trend of lower SCN egg numbers in the double-crop soybean plots in 2022 indicates that rotation to a non-host for 1 year can reduce numbers temporarily but will not eliminate SCN.

Corn

Corn yields were generally good for Arkansas conditions over the 9-year period and averaged 197–205 bu./ac depending on rotation (Table 3). Yields were statistically influenced by rotation in 3 out of 9 years with corn following corn yielding 26, 11, and 20 bu./ac less than when following early planted group 4 soybean in 2016, 2021, and 2022 respectively. Visually it was not apparent why there was a yield difference between rotations in those 3 years as there were no notable differences in plant stands, foliar disease level, or late season lodging, and all inputs between rotations were constant. Over the 9-yr period, corn following early planted group 4 soybean and double-crop soybean yielded 8 bu./ac more, respectively, than continuously grown corn. These results are similar to other trials in that corn grown in rotation with soybean often yields more than if grown without rotation (Sindelar et al., 2015). Development of stalk rot and subsequent late-season plant lodging is a concern for corn grown after corn. In this trial, no noticeable differences in disease levels were noted in any year. Late-season lodging was evident in 2022, and ranged from 10–20%, but differences could not be attributed to crop rotation.

Wheat

Wheat yields were generally good with an average yield of 66 to 76 bu./ac (Table 4), depending on rotation from 2014-2022. Wheat yield was influenced by previous crops 6 out of 8 years. When averaged across all years, wheat yield following early planted soybean was 76 bu./ac, 10 bu./ac greater than wheat following full-season grain sorghum. The reason for lower wheat yields following full-season grain sorghum is not clear; however, fall and early winter growth was visibly reduced in most years. Grain sorghum is reported to be allelopathic to wheat under some circumstances (Roth et al., 2000). Although not definitive, allelopathy is suspected to have reduced wheat growth and yields in this study some years since all other management inputs such as tillage, seeding rate, fertilizer, foliar disease level, and plant stands were constant between treatments. Wheat yield following corn was, on average, 5 bu./ac less than when following early planted soybean and 1 bu./ac more than when following double-crop soybean.

In 2022, wheat yields were significantly lower where a continuous wheat/double crop rotation had been implemented. High levels of the disease Take-all of Wheat (*Gaeumannomyces graminis variety tricici*) reduced yields substantially that year. Yields of continuous wheat-double crop soybean were 63 bu./ac, while wheat yields following early planted soybean were 89 bu./ac. Take-all symptoms were variable across the wheat-double crop soybean plots, but symptoms were not found in any other rotations, even when wheat had been grown every other year in the corn-wheat-double crop soybean, or grain sorghum-wheat-double crop soybean rotations.

Grain Sorghum

Full-season grain sorghum was grown as a rotational crop and was always planted following soybean or double-crop soybean. Yields of full-season grain sorghum averaged 113 bu./ac (Table 5) and did not differ between early planted group 4 soybean or double-crop soybean treatments over the 9-year period. State average grain sorghum yields generally range from 80–100 bu./ac (Table 5). Double-crop grain sorghum planted following wheat averaged 84 bu./ac (Table 5).

Practical Applications

Results from this crop rotation trial provide Arkansas producers with local non-biased information on how long-term crop rotation can impact yields of early planted soybean, double-crop soybean, corn, grain sorghum, double-crop grain sorghum, and wheat on their farms, which ultimately impacts profitability of their farms. Overall yields of soybean, wheat, and corn were each positively impacted by cropping sequence, but not every year. Reasons for differences in yields within a crop were not always obvious but take-all of wheat and soybean cyst nematode were two potential reasons that wheat and soybean yields were lower where no rotation was included. Crop rotation continues to be a recommended cultural practice to reduce overall risk and is needed to maintain high crop yields in our production systems.

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Literature Cited

Howard, D.D., A.Y. Chambers, and G.M. Lessman. 1998. Rotation and Fertilization Effects on Corn and Soybean Yields and Soybean Cyst Nematode Populations in a No-Tillage System. Agron. J. 90: 518-522.

Reddy, K.N., R.M. Zablotowiez, and L.J. Krutz. 2013. Corn and Soybean Rotation under Reduced Tillage Management: Impacts on Soil Properties, Yield, and Net Return. Am. J. Plant Sci. 2013, 4:10-17. Accessed 23 April 2023. Available at: https://www.scirp.org/html/2-2600731_32242.htm

Roth, C.M., Shroyer, J.P. and Paulsen, G.M. 2000. Allelopathy of Sorghum on Wheat under several Tillage Systems. Agron. J. 92:855-60. Accessed 15 May 2023. Available at: https://doi.org/10.2134/agronj2000.925855x

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

Table 1. The effect of the previous crop on the yield of early planted (April), irrigated group 4 soybean yield grown at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas, 2014–2022.

	Early Planted Soybean Grain Yield									
Previous Crop	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Avg.**
	(bu./ac)									
Early Planted Soybean	43	49	47	65	56	62	62	56	72	57
Corn	64	49	52	71	67	58	62	60	73	62
Full-Season Grain Sorghum	64	51	56	74	64	62	61	62	74	63
Wheat/Double-Crop Sorghum	--	50	54	71	65	58	66	58	73	62
$LSD_{0.05}$	13	NSD[a]	NSD	6	6	NSD	NSD	4	NSD	--

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

Table 2. The effect of the previous crop on the yield of irrigated double-crop soybean grown following wheat at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas 2014–2022.

	Double-Crop Soybean Grain Yield									
Previous Crop	**2014**	**2015**	**2016[a]**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Avg.**
	(bu./ac)									
Double-Crop Soybean/Wheat	30	38	46	46	43	45	46	45	40	42
Corn/Wheat	39	43	49	48	46	47	47	47	43	45
Grain Sorghum/Wheat	40	42	50	48	46	46	46	50	43	46
$LSD_{0.05}$	4	NSD[b]	NSD	NSD	NSD	NSD	NSD	3	NSD	--

[a] Wheat was not planted during the fall of 2015 due to wet conditions, but soybean was planted in June 2016 during the normal time for double-crop planting.
[b] NSD = no significant difference at α = 0.05.

Table 3. The effect of the previous crop on the yield of irrigated corn grown at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas 2014–2022.

	Corn Grain Yield									
Previous Crop	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Avg.**
	(bu./ac)									
Early Planted Soybean	250	221	207	205	196	181	194	216	175	205
Wheat/Double-Crop Soybean	250	214	198	207	199	186	196	216	177	205
Corn	245	224	181	201	191	173	196	205	155	197
$LSD_{0.05}$	NSD[a]	NSD	20	NSD	NSD	NSD	NSD	9	19	--

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

Table 4. The effect of the previous crop on the yield of winter wheat grown at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas 2014–2022.

	Wheat Grain Yield									
Previous Crop	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Avg.**
	(bu./ac)									
Early Planted Soybean	75	72	--	76	67	69	80	78	89	76
Double-Crop Soybean	75	69	--	73	64	64	75	75	63	70
Corn	72	68	--	74	69	61	65	79	77	71
Full-Season Grain Sorghum	69	73	--	56	62	65	64	68	73	66
$LSD_{0.05}$	NSD[a]	4	--	12	6	NSD	8	10	11	--

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

Table 5. The yield of irrigated full-season grain sorghum and double-crop grain sorghum grown at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas 2014–2022.

	Grain Sorghum Grain Yield									
Crop	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Avg.**
	(bu./ac)									
Full-Season Grain Sorghum	143	123	113	99	98	106	118	111	103	113
Double-Crop Sorghum	--	88	92	86	87	81	88	85	62	84

Mining Stress Tolerance Genes from Teosinte (*Zea mays ssp. parviglumis*), the Ancestor of Modern Corn Hybrids

K.B. Swift[1] and B.H. Bluhm[1]

Abstract

Aflatoxin is a persistent problem for Arkansas corn producers. Environmental stress is one of the key factors that predispose corn to aflatoxin contamination. Various environmental stresses commonly affect Arkansas corn production, and climate change is predicted to exacerbate the problem. Most high-yielding, commercial corn germplasm is susceptible to environmental stress. Interestingly, wild ancestors of corn have substantially higher levels of stress tolerance than modern corn hybrids, which suggests that some stress tolerance was lost during domestication. Currently, the genes and molecular mechanisms underlying stress tolerance in teosinte are unknown. The goal of this study was to analyze the genetic basis of stress tolerance in teosinte, with the ultimate goal of improving stress tolerance in commercial hybrids. In this study, we focused first on defining differences between corn and teosinte in the heat shock protection pathway. Overall, the genetic components of the heat shock protection pathway were well conserved in corn and teosinte, with differences noted in gene copy number and genomic synteny in two heat shock protein families (HSP18 and HSP70). However, the analysis highlighted limitations of existing genetic, genomic, and phenomic resources for teosinte. Thus, a strategy was devised to close these knowledge gaps and provide a more definitive genetic analysis of abiotic stress resistance using teosinte landraces, inbred lines, and teosinte/corn introgression lines.

Introduction

Aspergillus ear rot of corn, caused primarily by *Aspergillus flavus* in Arkansas, commonly leads to contamination of infested grain with aflatoxin. Aflatoxin is one of the most carcinogenic naturally occurring compounds known to humankind and is harmful to humans and animals at extremely low levels (Shabeer et al., 2022). Thus, its presence in raw agricultural commodities and food products is strictly regulated by governmental agencies worldwide.

Recent climatological trends suggest climate change will likely affect agriculture in Arkansas for decades to come. Climate-induced stresses are predicted to include heat, drought, flooding, planting/harvest delays, and general patterns of volatility/unpredictability in weather trends and events (Pareek et al., 2020). Because environmental stress is arguably the single greatest risk factor for *A. flavus* infection and aflatoxin contamination of corn, a more thorough, molecular-level understanding of stress responses in corn is urgently needed to mitigate the increasing risk of aflatoxin in Arkansas corn production.

Conventional breeding has revolutionized modern corn production by enhancing various traits, particularly yield. However, conventional breeding has not been able to provide acceptable resistance to aflatoxin. Abiotic stress tolerance and aflatoxin resistance are complex traits influenced by multiple genes, making them difficult to achieve through traditional breeding methods that rely on crossing and selection. Developing corn hybrids with robust aflatoxin resistance would be accelerated most rapidly by making precise modifications in multiple genes, which historically has been hindered due to a lack of genomic editing resources.

Genome editing with CRISPR-Cas9 is a new technique that allows the DNA of living organisms to be modified with great precision (Adli, 2018). For a given target gene, a guide RNA (gRNA) complementary to the gene target is designed to disable, modify, or insert new genetic material at the genetic locus. The gRNA, along with the Cas9 enzyme, forms a complex that essentially functions as molecular scissors. The gRNA guides Cas9 to the target gene to introduce a double-stranded DNA break. The DNA break triggers the cell's natural repair mechanisms, which then use information encoded in the gRNA to precisely alter the original DNA sequence.

Genome editing with CRISPR-Cas9 holds immense potential for agricultural biotechnology in general. However, there are two key hurdles limiting the application of this technology to improve aflatoxin resistance in corn. First, the specific genes and molecular mechanisms underlying resistance are not fully understood. As a result, information about what genes to target, and how they should be targeted, is incomplete. Second, delivering the CRISPR-Cas9 machinery into corn cells can be challenging, in part due to the recalcitrance of many inbred lines to transformation.

Teosinte (*Zea mays* ssp. *parviglumis*), a wild grass originating from Mexico and Central America, is the direct ancestor of corn (Wright et al., 2005). Teosinte is a hardy, stress-tolerant plant; as an example of its adaptability, it has recently become an invasive weed in parts of Europe (Le Corre et al., 2020). We hypothesize that important genes associated with stress tolerance were lost during the domestication of corn from teosinte, and that stress resistance can be recapitulated in modern corn hybrids through a combination of genome editing and traditional breeding. However, the genetic basis of abiotic stress tolerance in teosinte has not been investigated, and thus the underlying genes are unknown.

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Heat shock proteins (HSPs) play a crucial role in protecting plants against abiotic stress as well as pathogen attack (Ul Haq et al., 2019; Park and Seo, 2015). For example, when corn is exposed to heat stress, HSPs are produced in response to the increased temperatures. These proteins act as molecular chaperones, helping other proteins maintain their proper structure and function during stressful conditions. HSPs assist in preventing the aggregation or denaturation of proteins, ensuring their stability and functionality. Additionally, HSPs play a role in refolding damaged proteins and facilitating their degradation if they cannot be repaired. By safeguarding essential cellular processes and maintaining protein homeostasis, HSPs aid in the survival and resilience of maize plants under heat stress. Understanding the mechanisms and functions of heat shock proteins in maize is crucial for developing heat-tolerant, aflatoxin-resistant hybrids that perform well in the face of climate change.

The focus of this study is to analyze the molecular and genetic basis of abiotic stress tolerance in teosinte, with emphasis on the heat shock repair pathways. Based on comparative genomics analyses, a strategy to further define stress tolerance in teosinte is proposed. The ultimate goal of this work is to increase stress tolerance and aflatoxin resistance in corn, which will contribute to sustainable production in Arkansas as extreme weather is forecast to become more common.

Procedures

A comprehensive list of HSPs from corn (Tables 1 and 2) was assembled from analyses of the corn reference genome (derived from inbred line B73; Russell, 1972) and from published reports (Pegoraro et al., 2011). The coding sequence for each gene was downloaded as a FASTA file from GenBank (https://www.ncbi.nlm.nih.gov/genbank/) as a single, compiled .txt file. The MaizeGDB database (https://www.maizegdb.org/) was utilized for comparative genomic analyses for each HSP. BLAST searches were performed, using HSP sequences from B73 (obtained from GenBank) as the query, against the corn reference genome (inbred line B73; Jiao et al., 2017) and a teosinte reference genome (*Zea mays* ssp. *parviglumis* inbred line TIL01; Yang et al., 2016). BLAST searches were performed to identify similarities in HSP gene families based on e-value scores and percent identity (Altschul et al., 1990). A cutoff e-value of 1.0e-50 was used for analyses. Comparative analyses included determining the degree of sequence conservation, expansion/contraction of gene families/orthologs, conservation of alternative gene models, and genomic synteny of each HSP. Gene expression data, when available, were also analyzed for each HSP to assess potential regulatory mechanisms. To identify publicly available germplasm to advance stress-tolerance research in teosinte, the Maize Genetics Cooperation Stock Center (http://maizecoop.cropsci.uiuc.edu/) database was searched for teosinte accessions, introgression lines, and other relevant resources.

Results and Discussion

In corn, several families of HSPs play important roles in responding to stress and maintaining cellular homeostasis (Pegoraro et al., 2011). These families include HSP100, HSP90, HSP70, HSP60, and small HSPs (sHSPs). HSP100 proteins, such as Hsp101, are involved in protein disaggregation and refolding under stress conditions. HSP90 acts as a molecular chaperone, assisting in the proper folding and stabilization of client proteins. HSP70 proteins are responsible for a wide range of functions, including protein folding, assembly, and transport. HSP60 forms a complex known as the chaperonin, which mediates the folding of newly synthesized proteins. Small HSPs are a diverse group of proteins that exhibit chaperone activity and play a role in protecting other proteins from damage during stress. Each of these HSP families contributes in distinct ways to the overall stress response in corn.

Comparative genomics analyses between corn and teosinte revealed a considerable level of conservation regarding sequence and copy number among major HSP families (Tables 1 and 2; data not shown for sHSPs). Additionally, genomic synteny was observed between corn and teosinte for many HSPs (data not shown). However, expansion and diversification of the HSP18 and HSP70 gene families were observed in teosinte compared to corn (Tables 1 and 2). In corn, the HSP18 family is induced in seedlings subjected to heat stress (Atkinson et al., 2011). Notably, the HSP18 family is highly differentially expressed in different corn inbred backgrounds (Jorgensen et al., 1992), with lower numbers of HSP18 orthologs detected in inbred line B73 compared to Mo17. The HSP70 family is particularly intriguing, as members have been documented to display differential expression in various tissues and developmental stages of corn (Jiang et al., 2021). The postulated specialization of HSP70 genes in stress response makes 'lost' members of this family particularly interesting for further investigation. Together, these findings suggest that the variation in environmental stress tolerance between teosinte and corn is likely attributed to a mixture of factors, potentially including specialized HSP variants in combination with differences in upstream or regulatory factors.

While the analysis of HSPs in corn and teosinte has provided insight into stress responses, knowledge gaps regarding teosinte complicated the comparative genomics approach. One significant limitation is the lack of comprehensive genome sequence information for teosinte. Currently, limited reference genome information is available for teosinte, and it is not clear how representative these data are across diverse teosinte populations, or contemporary vs. ancestral populations. Teosinte, being a wild, undomesticated plant, is expected to possess considerable genetic variation that could influence its HSP composition and expression. Furthermore, the scarcity of available gene expression data for teosinte poses another challenge. Gene expression data can provide valuable information about the activity and regulation of HSPs under different stress conditions. The limited availability of such data for teosinte hinders a comprehensive comparative analysis of HSPs between teosinte and corn. Additionally, phenomics data for teosinte is limited, including the accession used for genome sequencing. Therefore, while this analysis provides important insights, it also highlights the need for complementary approaches to dissect stress tolerance in teosinte.

Teosinte introgression lines of corn are a valuable tool to dissect mechanisms of environmental stress resistance. One advantage of using introgression lines is that they are created in an unbiased manner, without selection for agronomic traits. As a result, stress tolerance will be incorporated into introgression lines even if the trait is linked to commercially valuable traits, such as yield. Comparing stress responses of introgression lines allows the rapid identification of specific regions of the genome conveying stress tolerance (and susceptibility). Since introgression blocks from teosinte can be easily detected in the corn genome, stress-tolerant introgression lines provide a powerful means for gene discovery. A collection of teosinte backcross 4 (BC_4) introgression populations (Liu et al., 2016) is publicly available from the Maize Genetics Cooperation Stock Center (http://maizecoop.cropsci.uiuc.edu/) and will be assessed for stress tolerance in future work.

Practical Applications

Enhancing corn's resistance to environmental stress and, subsequently, aflatoxin contamination, has significant practical applications in agriculture and food safety. Environmental stressors, such as drought, heat, and disease, can severely impact corn yields and render corn susceptible to aflatoxin contamination. This project seeks to uncover the genetic resources found in teosinte that may reduce stress in modern corn hybrids. The goal would be to introduce stress-resistant genes into corn hybrids so that producers can ensure more reliable crop production, even under adverse conditions. This translates to greater food security and economic stability. Furthermore, aflatoxins pose a serious health risk when present in corn. By enhancing corn's resistance to aflatoxin-producing fungi, the potential for aflatoxin contamination in food and feed can be significantly reduced. This helps safeguard human and animal health, as well as mitigates economic losses caused by contaminated corn products. Overall, enhancing corn's resistance to environmental stress and aflatoxin contamination brings numerous benefits in terms of agricultural productivity, food safety, and public health.

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Literature Cited

Adli, M. 2018. The CRISPR tool kit for genome editing and beyond. Nat. Commun. 9:1911. https://doi.org/10.1038/s41467-018-04252-2

Altschul, S.F., Gish, W., Miller, W., Myers, E.W., and D.J. Lipman. Basic local alignment search tool. J. Mol. Biol. 215:403-10. https://doi.org/10.1016/S0022-2836(05)80360-2

Atkinson, B.G., Liu, L., Goping, I.S., and D.B. Walden. 2011. Expression of the genes encoding hsp73, hsp18, and ubiquitin in radicles of heat-shocked maize seedlings. Genome. 31:698-704. https://doi.org/10.1139/g89-127

Jiang, L., Hu, W., Qian, Y., Ren, Q., and J. Zhang. 2021. Genome-wide identification, classification and expression analysis of the Hsf and Hsp70 gene families in maize. Gene 770:145348. https://doi.org/10.1016/j.gene.2020.145348

Jorgensen, J.A., Weng, J., Ho, Th.D., and H.T. Nguyen. 1992. Genotype-specific heat shock proteins in two maize inbreds. Plant Cell Rep. 11:576–580. https://doi.org/10.1007/BF00233096

Le Corre, V., Siol, M., Vigouroux, Y., and C. Delye. 2020. Adaptive introgression from maize has facilitated the establishment of teosinte as a noxious weed in Europe. Proc. Natl. Acad. Sci. 117:25618-25627. https://doi.org/10.1073/pnas.2006633117

Liu, Z., Cook, J., Melia-Hancock, S., Guill, K.E., Bottoms, C., Garcia, A., Ott, O., Nelson, R., Recker, J., Balint-Kurti, P.J., Larsson, S., Lepak, N.K., Buckler, E.S., Trimble, L., Tracy, W., McMullen, M.D., Flint-Garcia, S.A. 2016. Expanding maize genetic resources with predomestication alleles: maize-teosinte introgression populations. Plant Genome. 9(1). https://doi.org/10.3835/plantgenome2015.07.0053

Pareek, A., Dhankher, O.P., and C.H. Foyer. 2020. Mitigating the impact of climate change on plant productivity and ecosystem sustainability. J. Exp. Botany. 71:451- 456. https://doi.org/10.1093/jxb/erz518

Pegoraro, C., Mertz, L.M., da Maia, L.C. Rombaldi, C.V., and A. C. de Oliveira. 2011. Importance of heat shock proteins in maize. J. Crop Sci. Biotechnol. 1:85–95. https://doi.org/10.1007/s12892-010-0119-3

Park, C.J., and Y.S. Seo. 2015. Heat Shock Proteins: A review of the molecular chaperones for plant immunity. Plant Pathol. J. 31:323-33. https://doi.org/10.5423/PPJ.RW.08.2015.0150

Russell, W.A. 1972. Registration of B70 and B73 parental lines of maize. Crop Sci. 12:721.

Shabeer, S., Asad, S., Jamal, A., and A. Ali. 2022. Aflatoxin contamination, its impact and management strategies: An updated review. Toxins 14:307. https://doi.org/10.3390/toxins14050307

Ul Haq, S., Khan, A., Ali, M., Khattak, A.M., Gai, W.X., Zhang, H.X., Wei, A.M., and Z.H. Gong. 2019. Heat shock proteins: Dynamic biomolecules to counter plant biotic and abiotic stresses. Int. J. Mol. Sci. 20:5321. https://doi.org/10.3390/ijms20215321

Wright, S.I., Bi, I.V., Schroeder, S.G., Yamasaki, M., Doebley, J.F., McMullen, M.D., and B.S. Gaut. 2005. The effects of artificial selection on the maize genome. Science. 308:1310-4. https://doi.org/10.1126/science.1107891

Yang, C.J., Kursel, L.E., Studer, A.J., Bartlett, M.E., Whipple, C.J., and J.F. Doebley. 2016. A gene for genetic background in *Zea mays*: Fine-Mapping enhancer of teosinte branched1.2 to a YABBY class transcription factor. Genetics. 204:1573-1585. https://doi: 10.1534/genetics.116.194928.

Table 1. BLAST analysis of Heat Shock Proteins in the B73 genome.

Gene	GenBank accession number	BLAST results: Location in genome	e-value[a]	% identity[b]
Hsp16.9	NM_001158467	Chr3[c]	0	100
Hsp17.4	NM_001158163	Chr5	0	100
Hsp18	NM_001111882	Chr9	0	100
		Chr8	2.013e-176	96.09
		Chr3	2.013e-176	95.84
Hsp18.3	NM_001157527	Chr4	0	100
Hsp22	NM_001112137	Chr4	0	99.52
Hsp26	NM_001112113	Chr1	0	100
Hsp60	NM_001112220	Chr1	5.327e-88	100
		Chr5	1.161e-79	97.21
Hsp70	NM_001154726	Chr1	0	100
		Chr9	0	86.70
		Chr8	0	85.57
		Chr3	0	84.39
		Chr4	1.213e-134	73.75
		Chr5	1.293e-89	72.78
		Chr2	2.838e-76	72.90
		Chr6	1.358e-54	85.38
Hsp82	NM_001141944	Chr10	0	100
		Chr1	0	81.97
		Chr4	0	81.31
		Chr2	0	79.19
		Chr7	0	79.03
Hsp90	NM_001177009	Chr4	0	100
		Chr1	0	92.92
		Chr2	0	87.61
		Chr7	0	87.42
		Chr10	0	81.05
Hsp101	NM_001111465	Chr6	0	100
		Chr4	2.988e-102	90.88
		Chr2	1.390e-100	90.78
		Chr5	2.326e-98	90.14
		Chr8	1.082e-96	89.79
		Chr9	2.343e-93	89.08
		Chr7	5.071e-90	88.38
		Chr3	5.144e-80	84.51
		Chr10	1.917e-54	84.89

[a] e-value = Statistical calculation of the probability of the match occurring by chance. The lower the number, the stronger the alignment.

[b] % identity = The number of matching bases over the number of alignment columns.

[c] Chr = chromosome.

Table 2. BLAST analysis of Heat Shock Proteins in the TIL01 genome.

		BLAST results		
Gene	**GenBank accession number**	**Location in genome**	**e-value[a]**	**% identity[b]**
Hsp16.9	NM_001158467	Chr3[c]	0	99.53
Hsp17.4	NM_001158163	Chr5	0	96.65
Hsp18	NM_001111882	Chr9	0	100
		Chr8	2.414e-176	96.09
		Chr3	1.123e-174	95.58
		Chr4	1.698e-63	89.47
Hsp18.3	NM_001157527	Chr4	0	97.87
Hsp22	NM_001112137	Chr4	0	99.52
Hsp26	NM_001112113	Chr1	0	99.35
Hsp60	NM_001112220	Chr1	6.389e-88	100
		Chr5	1.393e-79	97.21
		Chr2	2.414e-52	86.24
		Chr9	1.123e-50	85.78
		Chr6	1.123e-50	85.78
Hsp70	NM_001154726	Chr1	0	99.31
		Chr8	0	85.80
		Chr9	0	86.69
		Chr3	0	84.39
		Chr4	6.767e-133	73.67
		Chr2	1.518e-104	72.56
		Chr5	3.332e-91	72.87
		Chr6	9.734e-57	88.36
		Chr10	7.578e-53	84.91
Hsp82	NM_001141944	Chr10	0	99.00
		Chr1	0	81.83
		Chr4	0	81.22
		Chr2	0	79.19
		Chr7	0	78.96
Hsp90	NM_001177009	Chr4	0	99.23
		Chr1	0	93.17
		Chr2	0	87.61
		Chr7	0	87.36
		Chr10	0	81.01
Hsp101	NM_001111465	Chr6	0	98.66
		Chr2	2.636e-138	98.92
		Chr4	3.583e-102	90.88
		Chr5	1.298e-96	89.79
		Chr1	1.298e-96	89.79
		Chr9	2.810e-93	89.08
		Chr3	1.307e-91	88.73
		Chr8	2.830e-88	88.03
		Chr7	2.282e-59	90.50

[a] e-value = Statistical calculation of the probability of the match occurring by chance. The lower the number, the stronger the alignment.
[b] % identity = The number of matching bases over the number of alignment columns.
[c] Chr = chromosome.

Arkansas Future Ag Leaders Tour

J. C. Robinson[1]

Abstract

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

Introduction

Agriculture is Arkansas' largest industry, adding around $16 billion to the state's economy in 2020. In fact, Arkansas had 23 agricultural products ranked in the top 25 among states. According to the U.S. Bureau of Labor Statistics (BLS), employment opportunities between 2020 and 2025 will remain strong for new college graduates with interest and expertise in food, agriculture, renewable natural resources, and the environment. The BLS forecasts an overall increase in the U.S. labor force between 2018 and 2028 due primarily to openings from retirements and job growth. It is expected that employment opportunities in occupations related to food, agriculture, renewable natural resources, and the environment will grow 2.6% between 2020 and 2025 for college graduates with bachelor's or higher degrees (APLU, 2009).

As new graduates enter the workforce, there is also a training gap between technical skills and knowledge and soft skills that employers look for. Among the career readiness competencies identified by the National Association of Colleges and Employers (NACE), graduates that are successful in transitioning into the workplace demonstrate professionalism, defined by NACE as demonstrating personal accountability and effective work habits, e.g., punctuality, working productively with others, and time workload management, and understand the impact of non-verbal communication on professional work image.

Procedures

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

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

Results and Discussion

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

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

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

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

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

Majors of tour participants included:

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

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

- JBS Foods, Russellville
- Anheuser-Busch, Jonesboro
- Cooperative Extension Service, Franklin County
- Woodruff County Electric Coop, Forrest City
- Farm Credit, Ozark
- Delta Dirt Distillery, Helena
- OK Foods, Forth Smith
- Kingwood Forestry Services, Inc, Monticello
- Tyson Discovery Center, Springdale
- Riceland, Stuttgart
- Farm Bureau, Boone County
- Dabbs Farm, Stuttgart
- Peco Foods, Batesville
- Jake Appleberry Farm, Tillar
- Greenway Equipment, Weiner
- Bayou Meto Water District, Scott
- Five Oaks, Humphrey
- Arkansas Department of Agriculture, Little Rock
- NRCS, Little Rock
- The Cotton Board (Cotton Research and Promotion Program), Director of Communications met the tour group in McGehee

Practical Applications

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

Acknowledgments

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Literature Cited

APLU. 2009. Association of Public and Land-Grant Universities. Human capacity development: The road to global competitiveness and leadership in food, agriculture, natural resources, and related sciences. Washington, D.C.: APLU.

National Association of Colleges and Employers. (n.d.). Career readiness defined. https://www.naceweb.org/career-readiness/competencies/career-readiness-defined/

Table 1. Participant responses to the evaluation question – "What did you learn?"

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

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

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

Enhancing the Flavor of White Whole Sorghum Flour Using Supercritical Carbon Dioxide

A. Tuhanioglu[1] and A. Ubeyitogullari[1,2]

Abstract

Removal of undesired odor-active compounds from sorghum flour is vital for the widespread production of sorghum-based foods. This study investigated the use of supercritical carbon dioxide (SC-CO_2) to extract volatile compounds from white sorghum flour. The extraction temperature (91–152 °F), pressure (1186–6065 psi), and time (1.3–4.7 h) were optimized for the extraction of a total of 11 volatile compounds (decane, undecane, tetradecane, dodecane, hexanal, nonanal, hexanol, dodecanol, limonene, styrene, and butylated hydroxytoluene) from whole white sorghum flour using central composite response surface design. At the optimized conditions (i.e., 140 °F and 2175 psi with 2 h), ~90% of the volatile compounds were removed. The volatile compound extraction resulted in significant changes in the functional properties of sorghum flour. Specifically, water absorption index, oil absorption capacity, and swelling power increased, whereas moisture and lipid contents, water solubility index, and particle size were reduced. The color analysis showed that the lightness of the sorghum flour treated with SC-CO_2 increased significantly compared to untreated sorghum flour. Overall, this study developed a novel green approach to enhancing the flavor of sorghum flour, which has a high potential for scale-up and generating sorghum flours with bland flavors for numerous food applications.

Introduction

There is a considerable increase in food demand worldwide even though the world's cultivable area is decreasing (Stefoska-Needham and Tapsell, 2020). Global water deficit is perhaps one of the most critical limiting factors for declining arable areas and crop productivity (Batista et al., 2019). Grain sorghum is a Sub-Saharan Africa-originated, drought-resistant cereal, making it a valuable food crop in semi-arid and arid regions (Kapanigowda et al., 2013). It is the fifth most-produced cereal totaling 61 million tons worldwide in 2021, where the United States was the largest producer with 11 million tons, followed by Nigeria and India with 7 and 5 million tons, respectively. In the United States, the primary use of sorghum is for animal feed and bioenergy production (Mutava et al., 2011). Nonetheless, sorghum has some advantages over other major grains due to its gluten-free nature, sustainability, and exceptional health benefits, including anticancer, antioxidant, anti-inflammatory, and anti-diabetes activities (Stefoska-Needham et al., 2015).

There are various challenges in the way of making palatable food products out of sorghum. Based on the sensory evaluations in the literature, the undesired flavor stands out as a major issue with sorghum-based products. For example, Oliveira et al. (2020) investigated consumer responses to yogurts fortified with whole sorghum flour. The results showed that depending on the amount and the variety of the added sorghum, the sorghum-fortified yogurt could barely be as desirable as the plain yogurt in terms of overall acceptability, with aroma (therefore flavor) being the most problematic property (Oliveira et al., 2020). Volatile organic compounds (VC) are responsible for beany, musty, gasoline-like, sour, or bitter aromas that are not tolerated in grains (Vázquez-Araújo et al., 2011). The VCs present in sorghum flour include decane, undecane, tetradecane, dodecane, hexanal, nonanal, hexanol, dodecanol, limonene, styrene, and butylated hydroxytoluene.

Supercritical carbon dioxide (SC-CO_2) is an environmentally friendly method with multiple applications in extracting moderately polar and non-polar compounds (Tuhanioglu and Ubeyitogullari, 2022). Response surface methodology has been known as an effective statistical tool to optimize SC-CO_2 processes for aroma extraction from plant materials (Gracia et al., 2007; Shao et al., 2014). For instance, Vatansever and Hall (2020) demonstrated that off-odor compounds could be successfully removed from pea proteins using SC-CO_2 (Vatansever and Hall, 2020). Nonetheless, there is a lack of literature information on the extraction of volatile compounds from sorghum flour. Therefore, this study aims to offer SC-CO_2 as an effective method to clear sorghum flour from volatiles and optimize the process using a statistical tool, i.e., response surface methodology, to render the process reproducible for further utilization of the extracted sorghum in industrial purposes.

Procedures

SC-CO_2 Treatment

A lab-scale SC-CO_2 extractor (SFT-120, Supercritical Fluid Technologies, Inc., Del., USA) was used for the experiments. The whole white sorghum flour samples (0.63 oz) were placed in a 3.4 fl oz stainless-steel high-pressure vessel, and 2.1 oz glass beads (0.12-in. diameter) were added to avoid packing and channeling during extraction. To remove any air trapped in the system, the

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system was flushed with CO_2 for 5 sec. The static extraction was carried out for 20 min prior to each run to achieve a uniform state with the CO_2 flow rate of 0.13 oz/min (measured at the ambient conditions). The extracted lipids were collected in a 1.35 fl oz brown glass vial kept in an ice bath. As soon as the extraction was completed, the SC-CO_2-treated samples in the vessel were transferred into 1.35 fl oz screw-cap amber vials, flushed with nitrogen, and stored at -4 °F until further analyses.

Design of Experiment

A central composite rotatable design (CCD) was created using JMP Pro v. 16.0.0 (SAS Institute, Inc., Cary, N.C.) to further optimize the process and provide a predictive equation based on three independent variables, namely temperature (104–140 °F), pressure (2175–5076 psi), and time (2–4 h) (Table 1). The design was set with a total of 32 runs ($2^k + 2k + 2$) with duplicates, where *k* represents the independent variables. The model was optimized for 11 VCs, namely, decane, undecane, tetradecane, dodecane, hexanal, nonanal, hexanol, dodecanol, limonene, styrene, and butylated hydroxytoluene, in sorghum flour. The total peak area at the total ion chromatogram was used as the response. The collected data were fitted to the following quadratic equation:

$$Y = \beta_0 + \Sigma_{i=1}^{3}\beta_i X_i + \Sigma_{i=1}^{3}\beta_{ii} X_i^2 + \Sigma_{i=1}^{3}\Sigma_{j=i+1}^{3}\beta_{ij} X_i X_j \quad \text{Eq. (1)}$$

where *Y* is the response, β_0 is the constant coefficient, β_i is the linear coefficient, X_i and X_j represent independent variables, β_{ii} is the quadratic coefficient, and β_{ij} is the coefficient of interaction.

GC/MS Analysis

Volatile compounds analysis was performed on 0.035 oz of sorghum flour (dry basis) in a 0.67 fl oz amber screw cap vial using a Shimadzu Nexis GC-2030 system equipped with a triple-quadruple mass selective detector. The volatiles were absorbed using an AOC-6000 Autosampler equipped with 0.39-in. long SPME fiber coated with DVB/CAR/PDMS. The capillary column used was ZB-5MSplus (Phenomenex, Calif., USA). Helium was used as the carrier gas at a flow rate of 0.03 fl oz/min. The initial oven temperature was set to 95 °F, held for 5 min, then raised to 302 °F at a ramping rate of 41 °F/min, then raised to 536 °F at a rate of 46 °F/min, and held for 5 min. Compounds were identified on Shimadzu LabSolution software with the library search. Linear retention indices were created using an alkane standard mix solution (C7–C20) to confirm the molecule identifications. Deuterated hexanal was added to each vial as an internal standard.

Functional properties

The water absorption index (WAI) and water solubility index (WSI) were determined based on the study by Simons et al. (2012). Oil absorption capacity (OAC) and swelling power (SP) were measured based on the studies by Maskus et al. (2016) and Dayakar Rao et al. (2016), respectively. Color determination was carried out using a calorimeter (Minolta CR-300, Konica Minolta, N.J., USA). The results were denoted as L*, a*, and b* values, indicating the lightness/darkness, redness/greenness, and yellowness/blueness, respectively.

Formation of Cookies from SC-CO_2-Treated Sorghum Flour

Untreated and SC-CO_2-treated sorghum flour cookies were prepared according to Rai et al. (2014). Briefly, 0.35 oz of flour was combined with 0.2 oz sugar, 0.09 oz shortening, 0.003 oz salt, 0.004 oz sodium bicarbonate, and 0.17 fl oz water. The mixture was blended with a spoon, hand-kneaded for 1 min, spread to a thickness of ~0.2 in., and cut into a disc shape of ~2 in. in diameter. The samples were baked in a preheated conventional oven at 360 °F for 10 min.

Statistical Analysis

Statistical analyses were conducted using JMP Pro v. 16.0.0 (SAS Institute, Inc., Cary, N.C., USA). Tukey's multiple comparison of means was employed at $\alpha = 0.05$ level.

Results and Discussion

Model Fitting

The CCD was applied to optimize the three independent variables at five levels for the sum of 11 VCs (Table 2). Among the main and interaction effects, only the interaction effect of temperature*time was not significant. Thus, the second-order polynomial equation was generated to explain the variation in the removal of the targeted compounds by all three main effects and temperature*pressure, and pressure*time interactions. The final model was significant with a *P*-value of <0.0001 and had a determination coefficient (R^2) of 0.96. The lack of fit was not significant ($P = 0.1057$).

Optimization of the SC-CO_2 Extraction of VCs from Sorghum Flour

The optimum conditions were determined as 140 °F, 2175 psi and 2 h, resulting in a 1.2 × 106 total peak area. No significant differences were detected when the extraction time was doubled at 140 °F and 2175 psi. High temperatures (>122 °F) achieved the maximum VC removal across all the runs, with two exceptions. At 140 °F, 5076 psi, the yield of VC was one of the highest, regardless of time.

The response surface plots for the statistical model are shown in Fig. 1. It is clearly shown that the response (VC total peak area) plummets with increasing temperature at low pressures (<2175 psi) (Fig. 1A). On the contrary, an increase was observed at very high pressures (>5801 psi) with rising temperatures.

Functional Properties

In order to assess the potential applications of the SC-CO_2-treated sorghum flours, their functional properties were determined (Table 3). The optimized SC-CO_2 extraction conditions (i.e., 140 °F, 2175 psi, 2 h) were implemented to generate the samples for these tests. Untreated sorghum flour was used as a control. Furthermore, SC-CO_2 extraction significantly increased the WAI from 2.07 ± 0.01 to 2.32 ± 0.01 ($P < 0.05$), while reducing the WSI slightly from 0.067 ± 0.001 to 0.059 ± 0.002, which was borderline significant ($P = 0.049$). Moreover, the SP of sorghum flour also enhanced significantly after the extraction ($P < 0.05$). Modified hydration properties of sorghum flour might also be explained by the significant reduction in the particle size after the SC-CO_2 extraction (Dayakar Rao et al., 2016). There is also a slight increase in the OAC after SC-CO_2, though statistically significant ($P = 0.02$). This is probably resulting from the fact that SC-CO_2 treatment extracted lipids from the sorghum samples along with the volatiles; therefore, the SC-CO_2-treated samples absorbed the oil better. The lightness of the flour (L*) increased while the yellowness (b*) decreased significantly after the SC-CO_2 extraction.

Cookie Formation

Cookies formed from untreated sorghum flour and SC-CO_2-treated sorghum flour after baking are shown in Fig. 2. The untreated sorghum dough was stickier than the one prepared with treated flour. Although they were baked under the same conditions, the untreated flour sorghum cookie looked considerably darker than the SC-CO_2-treated sorghum flour cookie. This brighter color is more similar to wheat flour cookies, with a high potential for gluten-free applications.

Practical Applications

The undesired flavor of grain sorghum prevents its widespread use in manufacturing food products. Therefore, in this study, a novel green method was developed to extract undesired volatile compounds using SC-CO_2. This study (i) provides a platform technology for enhancing the flavor of sorghum flour, (ii) produces a sustainable source of gluten-free flour ingredients with a bland flavor, (iii) improves/modifies the flavor of food ingredients with clean label options, and (iv) averts the need for toxic organic solvents. The next steps in this project are to determine the textural properties and sensory attributes of the sorghum cookies and conduct larger-scale extractions of undesired aromas from sorghum flour.

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Literature Cited

Batista, P.S.C., A.J. Carvalho, A.F. Portugal, E.A. Bastos, M.J. Cardoso, L.G. Torres, M.P. Mingote Júlio, and C.B. De Menezes. 2019. Selection of sorghum for drought tolerance in a semiarid environment. Genet. Mol. Res. 18(1):1–11.

Dayakar Rao, B., M. Anis, K. Kalpana, K.V. Sunooj, J.V. Patil, and T. Ganesh. 2016. Influence of milling methods and particle size on hydration properties of sorghum flour and quality of sorghum biscuits. Lwt. 67:8–13.

Gracia, I., J.F. Rodríguez, M.T. García, A. Alvarez, and A. García. 2007. Isolation of aroma compounds from sugar cane spirits by supercritical CO_2. J. Supercrit. Fluids. 43(1):37–42.

Kapanigowda, M. H., R. Perumal, M. Djanaguiraman, R.M. Aiken, T. Tesso, P.V.V. Prasad, amd C.R. Little. 2013. Genotypic variation in sorghum [*Sorghum bicolor* (L.) Moench] exotic germplasm collections for drought and disease tolerance. Springerplus. 2(1):1–13.

Maskus, H., L. Bourré, S. Fraser, A. Sarkar, and L. Malcolmson. 2016. Effects of grinding method on the compositional, physical, and functional properties of whole and split yellow pea flours. Cereal Foods World. 61(2):59–64.

Menezes, C. B., C.A. Ticona-Benavente, F.D. Tardin, M.J. Cardoso, E.A. Bastos, D. W. Nogueira, A.F. Portugal, C.V. Santos, and R.E. Schaffert. 2014. Selection indices to identify drought-tolerant grain sorghum cultivars. Genet. Mol. Res. 13(4):9817–9827.

Mutava, R. N., P.V.V. Prasad, M.R. Tuinstra, K.D. Kofoid, and J. Yu. 2011. Characterization of sorghum genotypes for traits related to drought tolerance. F. Crop. Res. 123(1):10–18.

Oliveira, F., J.P. Pontes, V.A. Queiroz, and E.F.S. Roncheti. 2020. Greek yogurt with added sorghum flours: antioxidant potential and sensory acceptance. Rev. Chil. Nutr. Órgano Of. La Soc. Chil. Nutr. Bromatol. y Toxicol. 47(2):272–280.

Rai, S., A. Kaur, and B. Singh. 2014. Quality characteristics of gluten free cookies prepared from different flour combinations. J. Food Sci. Technol. 51(4):785–789.

Simons, C. W., C. Hall, and M. Tulbek. 2012. Effects of extruder screw speeds on physical properties and in vitro starch hydrolysis of precooked pinto, navy, red, and black bean extrudates. Cereal Chem. 89(3):176–181.

Stefoska-Needham, A., E.J. Beck, S.K. Johnson, and L.C. Tapsell. 2015. Sorghum: An Underutilized Cereal Whole Grain with the Potential to Assist in the Prevention of Chronic Disease. Food Rev. Int. 31(4):401–437.

Stefoska-Needham, A., and L. Tapsel. 2020. Considerations for progressing a mainstream position for sorghum, a potentially sustainable cereal crop, for food product innovation pipelines. Trends Food Sci. Technol. 97:249–253.

Tuhanioglu, A., and A. Ubeyitogullari. (2022). Extraction of high-value lipids and phenolic compounds from sorghum bran via a sequential supercritical carbon dioxide approach. ACS Food Sci. Technol. 2(12), 1879-1887.

Vatansever, S., and C. Hall. 2020. Flavor modification of yellow pea flour using supercritical carbon dioxide + ethanol extraction and response surface methodology. J. Supercrit. Fluids. 156:104659.

Vázquez-Araújo, L., E. Chambers, and D.B. Funk. 2011. References for "musty" odor notes in sensory analysis of grain sorghum. J. Cereal Sci. 54(3):460–466.

Table 1. Three-level central composite rotatable design for the supercritical carbon dioxide extraction of volatiles from white whole sorghum flour.

	Level				
Variable	**-1.68**	**-1**	**0**	**1**	**1.68**
Temperature (°F)	91.7	104	122	140	152.2
Pressure (psi)	1186	2175	3625	5076	6065
Time (h)	1.31	2	3	4	4.68

Table 2. The response surface methodology table for the total area under the curve for the major volatile compounds.

Run	Temperature (°F)	Pressure (psi)	Time (h)	Total peak area ($x10^6$)
1	122	3626	1.3	2.31 ± 0.03
2	140	2175	2.0	1.22 ± 0.06
3	122	3626	3.0	1.83 ± 0.08
4	104	2175	2.0	2.12 ± 0.05
5	140	2175	4.0	1.33 ± 0.01
6	140	5076	4.0	2.10 ± 0.04
7	91	3626	3.0	2.44 ± 0.04
8	104	2175	4.0	2.09 ± 0.04
9	122	6065	3.0	2.31 ± 0.01
10	152	3626	3.0	1.70 ± 0.09
11	140	5076	2.0	2.00 ± 0.06
12	104	5076	2.0	1.90 ± 0.07
13	122	3626	4.7	1.57 ± 0.07
14	104	5076	4.0	2.25 ± 0.09
15	122	1186	3.0	1.66 ± 0.17

Table 3. Functional properties of untreated sorghum flour and treated sorghum flour at the optimized $SC\text{-}CO_2$ conditions (140 °F, 2175 psi, 2 h).

Analysis[†]	Untreated sorghum flour[‡]	$SC\text{-}CO_2$-treated sorghum flour
Moisture content (% w/w)	9.19 ± 0.007 a	8.28 ± 0.07 b
WAI	2.07 ± 0.01 b	2.32 ± 0.01 a
WSI	0.067 ± 0.001 a	0.059 ± 0.002 b
OAC	0.82 ± 0.001 a	0.91 ± 0.001 b
SP	7.41 ± 0.14 b	8.67 ± 0.14 a
Color		
*L**	88.8 ± 0.25 b	90.4 ± 0.29 a
*a**	0.3 ± 0.007 a	0.2 ± 0.04 a
*b**	11.2 ± 0.11 a	9.8 ± 0.4 b
Particle size (%)		
>0.0469 in.	5.3 ± 0.77 a	Tr b
>0.0394 in.	7.2 ± 1.91 a	Tr b
>0.0098 in.	77.3 ± 2.26 a	46.3 ± 1.76 b
>0.0083 in.	7.3 ± 3.53 b	13.7 ± 1.55 a
>0.0070 in.	1.7 ± 0.14 b	30.9 ± 1.76 a
>0.0059 in.	0.6 ± 0.71 b	1.8 ± 0.28 a
Rest	0.5 ± 0.56 b	7.2 ± 1.69 a

[†] Abbreviations: Tr = Trace amount; $SC\text{-}CO_2$ = supercritical carbon dioxide; WAI = water absorption index; WSI = water solubility index; OAC = oil absorption capacity; SP = swelling power.

[‡] Letters not connected with the same letters within the same row are significantly different ($P < 0.05$).

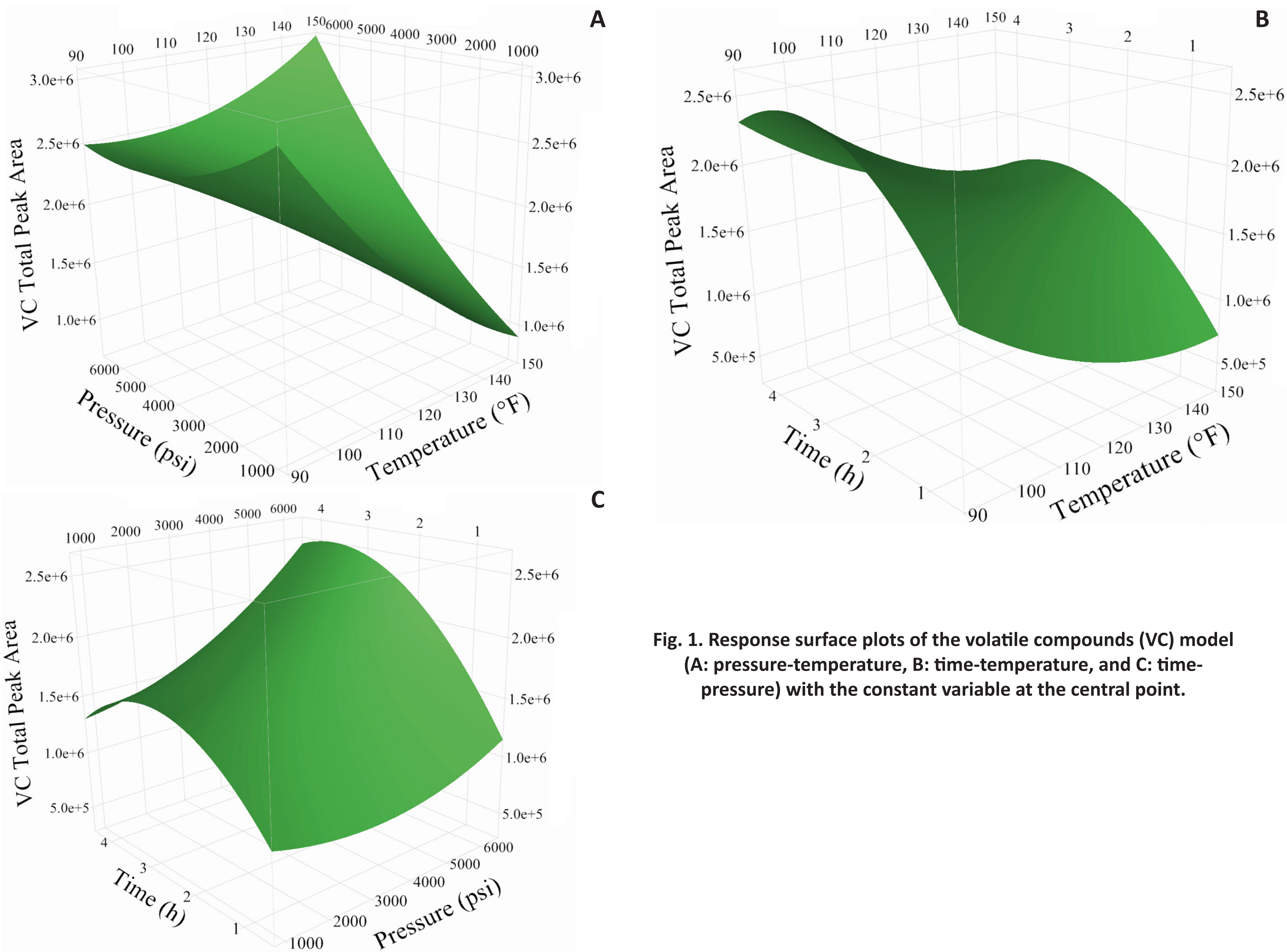

Fig. 1. Response surface plots of the volatile compounds (VC) model (A: pressure-temperature, B: time-temperature, and C: time-pressure) with the constant variable at the central point.

Fig. 2. Pictures of sorghum cookies developed using untreated (A) and SC-CO_2-treated (B) flours. SC-CO_2: supercritical carbon dioxide.

Corn and Grain Sorghum Enterprise Budgets and Production Economic Analysis

B.J. Watkins[1]

Abstract

Crop enterprise budgets for Corn and Grain Sorghum have been 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 Cooperative Extension Service recommendations from Crop Specialists and from the Corn and Grain Sorghum Research Verification Programs. Unique budgets can be customized by users based on either Extension recommendations or information from producers utilizing their individual production practices. The budget program is used to conduct economic analysis of field data from various corn and grain sorghum research plots as well as the research verification trials. The crop enterprise budgets are designed to help producers estimate the profitability of employing various field activities associated with crop production and unique farming operations. Costs and returns analysis included with the budgets are used to investigate factors impacting farm profitability.

Introduction

Volatile input prices and supply availability of key herbicides and fertilizers presented challenges for producers in maintaining not only profitability but solvency within their operations. For 2022, we saw a slight reduction in input costs after some of the supply issues waned and the weather became more favorable for exporting grain and importing inputs. With volatility being a prevalent concern, corn and grain sorghum producers need a user-friendly tool to calculate costs and returns of production alternatives to estimate potential profitability. This profitability measure also needs to encompass not only changes in input costs but also changes producers seek to adapt for their unique operation. The objective of this project is to develop an interactive computational program that will enable stakeholders of the Arkansas corn and grain sorghum 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 calculated from engineering formulas developed by the American Society of Agricultural and Biological Engineers. Input costs for fertilizers and chemicals are determined by applying prices to typical input rates. Input prices, custom hire rates, and fees are estimated with information from industry contacts. Methods of estimating the operating expenses presented in crop enterprise budgets are identical to producers obtaining cost information for their specific farms. These prices, however, fail to factor in discounts from buying products in bulk, preordering items, and other promotions that may be available at the point of purchase.

Ownership costs and repair expenses for machinery are estimated by applying engineering formulas to representative prices of new equipment (Givan, 1991; Lazarus and Selly, 2002). Repair expenses in crop enterprise budgets should be regarded as value estimates of full-service repairs. Repairs and maintenance performed by hired farm labor will be partially realized as wages paid to employees. Machinery performance rates of field activities utilized for machinery costs are used to estimate the time requirements of an activity which is applied to an hourly wage rate for determining labor costs (USDA-NASS, 2022).

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 the fall of 2022. Representative prices for machinery and equipment are based on contacts with Arkansas dealers, manufacturer's suggested retail prices (MSRP), and reference sources (Deere & Company 2022; MSU 2022). Revenue in crop enterprise budgets is the product of expected yields from following Extension practices under optimal growing conditions combined with actual yield data from research verification plot trials and commodity prices received data from USDA-NASS.

Results and Discussion

The University of Arkansas System Division of Agriculture's Department of Agricultural Economics and Agribusiness

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(AEAB) and Agriculture and Natural Resources (ANR) together develop annual crop enterprise budgets to assist Arkansas producers and other agricultural stakeholders in evaluating expected costs and returns for the upcoming field crop production year. Production methods represent typical field activities as determined by consultations with producers within the state, County Agents, Agronomists, Weed Scientists, Plant Pathologists, Entomologists, and information from Crop Research Verification Program Coordinators in the Department of Crop, Soil, and Environmental Sciences. Actual production practices vary greatly among individual farms due to management preferences believed to be the best methods for greatest success as stewards of the land. Analyses are for generalized circumstances with a focus on consistent and coordinated application of budget methods for all field crops. This approach results in meaningful costs and returns comparisons for decision-making related to acreage allocations among field crops. Results should be regarded only as a guide and basis as individual farmers should develop budgets for their production practices, soil types, and other unique circumstances within the budget tool to more accurately represent each unique operation.

Table 1 presents an example of the 2022 budget developed for Arkansas furrow irrigated corn utilizing field activities associated with a stacked gene production system. Costs are presented on a per-acre basis and with an assumed 1,000 acres. Program flexibility allows users to alter all variables to create a unique representation of many farm situations. Returns to total specified expenses are $469.40/ac. The budget program includes similar capabilities for center pivot irrigated and non-irrigated corn and grain sorghum production, as well as providing for both stacked gene and conventional corn evaluation. Table 2 presents the 2022 grain sorghum non-irrigated enterprise budget. The budgets assume grower-owned land, and costs are given on a per-acre basis. In 2022, net returns from non-irrigated sorghum are expected to be -$27.68 compared to last year's expected net returns of -$118.33/ac. Net returns increased due to increasing commodity prices over the past year, plus reduction of fertilizer costs.

Practical Applications

A copy of the current crop enterprise budgets is available to the public through the website, uaex.uada.edu. Once on the webpage, type "crop budgets" into the search box, and the first option available brings you to the crop enterprise budget page. It is here, on the Crop Enterprise Budgets for Arkansas website, that users can find a list of the available crop budgets in their most recent form. The interactive budgets utilize Microsoft Excel, but an updated, accessible tool is near completion and will be made available once concluded. The benefits provided by the economic analysis of alternative corn and grain sorghum 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 and for planning production methods with the greatest potential for financial success. Flexible budgets enable farm financial outlooks to be revised during the production season as inputs, input prices, yields, and commodity prices change. For the 2022 crop budgets, a spring update of fuel and fertilizer prices was made. The update also included updates to commodity prices with an increase in expected net revenue. Incorporating changing information and circumstances into budget analysis assists producers and lenders in making decisions that manage financial risks inherent in agricultural production.

Acknowledgments

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Literature Cited

Deere & Company. Products, Agriculture. Moline, Ill. Accessed September 2022. Available at: http://www.deere.com/en_US/industry/agriculture/agriculture.page?

Edwards, W. Estimating Farm Machinery Costs. Iowa State University, University Extension, Ames, Iowa, 2005.

Givan, W. Using Machinery Costs to Make Decisions, AG ECON 91-003, Cooperative Extension Service, Extension Agricultural Economics, The University of Georgia, Athens, Ga., March 1991.

Kay, R.D. and W.M. Edwards. Farm Management, Fourth Edition. WCB/McGraw-Hill, Boston, Mass. 1999.

Lazarus, W.F. and R.A. Selly. 2002. Suggested Procedures for Estimating Farm Machinery. Staff Paper P02-16, Department of Applied Economics, College of Agricultural, Food, and Environmental Sciences, University of Minnesota, Minneapolis-St. Paul, Minn. December 2002.

Mississippi State University. Planning Budgets. Department of Agricultural Economics, Mississippi State University, Starkville, Miss. Accessed October 2022. Available at: http://www.agecon.msstate.edu/whatwedo/budgets.php

USDA-NASS. United States Department of Agriculture, National Agricultural Statistics Service. Farm Labor. Washington, D.C. October 2022.

Table 1. 2022 Corn Enterprise Budget, stacked gene, furrow irrigation.

Crop Value	Grower %	Unit	Yield[a]	Price/Unit	Revenue
Crop Value, Enter Expected Farm Yield & Price	100%	bu.	215.00	6.80	1,462.00
Operating Expenses		**Unit**	**Quantity**	**Price/Unit[b]**	**Costs**
Seed, Includes Applicable Fees	100%	ac	1	120.00	120.00
Nitrogen 100%	100%	lb/ac	435	0.50	215.33
Phosphate (0-46-0)	100%	lb/ac	130	0.47	60.45
Potash (0-0-60)	100%	lb/ac	175	0.45	77.88
Ammonium Sulfate (21-0-0-24)	100%	lb/ac	100	0.37	36.75
Zinc Sulfate	100%	lb/ac	29.00	1.50	43.50
Other Nutrients, Including Poultry Litter	100%	ac	1.00	0.00	0.00
Herbicide	100%	ac	1	67.23	67.23
Insecticide	100%	ac	1	0.00	0.00
Fungicide	100%	ac	1	0.00	0.00
Other Chemical	100%	ac	1	0.00	0.00
Other Chemical	100%	ac	1	0.00	0.00
Custom Chemical & Fertilizer Applications					
Ground Application: Fertilizer & Chemical	100%	ac	0	7.50	0.00
Air Application: Fertilizer & Chemical	100%	ac	0	8.00	0.00
Air Application: lb	100%	lb	100	0.080	8.00
Other Custom Hire, Air Seeding	100%	ac	0	7.50	0.00
Machinery and Equipment					
Diesel Fuel, Pre-Post Harvest	100%	gal	4.188	3.89	16.29
Repairs and Maintenance, Pre-Post Harvest	100%	ac	1	9.12	9.12
Diesel Fuel, Harvest	100%	gal	2.027	3.89	7.89
Repairs and Maintenance, Harvest	100%	ac	1	7.92	7.92
Irrigation Energy Cost	100%	ac-in.	14	4.59	64.32
Irrigation System Repairs & Maintenance		ac-in.	14	0.24	3.36
Supplies (ex. polypipe)	100%	ac	1	3.88	3.88
Other Inputs	100%	ac	1	0.00	0.00
Labor, Field Activities	100%	hours	0.845	11.33	9.57
Scouting/Consultant Fee	100%	ac	1	6.00	6.00
Other Expenses	100%	ac	1	0.00	0.00
Crop Insurance	100%	ac	1	16.15	16.15
Interest, Annual Rate Applied for 6 Months	100%	Rate %	4.45	773.64	17.21
Custom Harvest	100%	ac	0.00	0.00	0.00
Post-Harvest Expenses					
Drying	100%	bu.	215.00	0.19	40.85
Hauling	100%	bu.	215.00	0.25	53.75
Check Off, Boards	100%	bu.	215.00	0.01	2.15
Cash Land Rent		ac	1	0.00	0.00
Total Operating Expenses					**$887.60**
Returns to Operating Expenses					**$574.40**
Capital Recovery & Fixed Costs					
Machinery and Equipment		ac	1	79.23	79.23
Irrigation Equipment		ac	1	21.80	21.80
Farm Overhead[c]		ac	1	3.96	3.96
Total Capital Recovery & Fixed Costs					**$105.00**
Total Specified Expenses					**$992.60**
Net Returns					**$469.40**

[a] Yield and inputs are based on Extension research data. Enter expected farm yield and inputs.
[b] All price estimates do NOT include rebates, bulk deals, or discounts available through suppliers.
[c] Estimate based on machinery and equipment.

Table 2. 2022 Grain Sorghum Enterprise Budget, no irrigation.

Crop Value	Grower %	Unit	Yield[a]	Price/Unit	Revenue
Crop Value, Enter Expected Farm Yield & Price	100%	bu.	65.00	6.50	422.50
Operating Expenses		**Unit**	**Quantity**	**Price/Unit[b]**	**Costs**
Seed, per acre	100%	lb	5	3.96	17.82
Nitrogen (Urea, 46-0-0)	100%	lb	200	0.50	99.00
Phosphate (0-46-0)	100%	lb	110	0.47	51.15
Potash (0-0-60)	100%	lb	100	0.45	44.50
Ammonium Sulfate (21-0-0-24)	100%	lb	0	0.37	0.00
Boron 15%	100%	lb	0.00	0.60	0.00
Other Nutrients, Including Poultry Litter	100%	ac	1.00	0.00	0.00
Herbicide	100%	ac	1	33.70	33.70
Insecticide	100%	ac	1	27.71	27.71
Fungicide	100%	ac	1	0.00	0.00
Other Chemical	100%	ac	1	0.00	0.00
Other Chemical	100%	ac	1	0.00	0.00
Custom Chemical & Fertilizer Applications					
Ground Application: Fertilizer & Chemical	100%	ac	0	7.50	0.00
Air Application: Fertilizer & Chemical	100%	ac	1	8.00	8.00
Air Application: lb	100%	lb	0	0.080	0.00
Other Custom Hire, Air Seeding	100%	ac	0	7.50	0.00
Machinery and Equipment					
Diesel Fuel, Pre-Post Harvest	100%	gal	3.388	3.89	13.18
Repairs and Maintenance, Pre-Post Harvest	100%	ac	1	7.65	7.65
Diesel Fuel, Harvest	100%	gal	2.027	3.89	7.89
Repairs and Maintenance, Harvest	100%	ac	1	6.89	6.89
Irrigation Energy Cost	100%	ac-in.	0	0.00	0.00
Irrigation System Repairs & Maintenance		ac-in.	0	0.00	0.00
Supplies (ex. polypipe)	100%	ac	1	0.00	0.00
Other Inputs	100%	ac	1	0.00	0.00
Labor, Field Activities	100%	hours	0.603	11.33	6.83
Scouting/Consultant Fee	100%	ac	1	6.00	6.00
Other Expenses	100%	Ac	1	0.00	0.00
Crop Insurance	100%	ac	1	16.73	16.73
Interest, Annual Rate Applied for 6 Months	100%	Rate %	4.45	347.04	7.72
Custom Harvest	100%	ac	0.00	0.00	0.00
Post-Harvest Expenses					
Drying	100%	bu.	65.00	0.00	0.00
Hauling	100%	bu.	65.00	0.25	16.25
Check Off, Boards	100%	bu.	65.00	0.01	0.65
Cash Land Rent		ac	1	0.00	0.00
Total Operating Expenses					**$371.66**
Returns to Operating Expenses					**$50.84**
Capital Recovery & Fixed Costs					
Machinery and Equipment		ac	1	74.78	74.78
Irrigation Equipment		ac	1	0.00	0.00
Farm Overhead[c]		ac	1	3.74	3.74
Total Capital Recovery & Fixed Costs					**$78.52**
Total Specified Expenses					**$450.18**
Net Returns					**-$27.68**

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

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

[c] Estimate based on machinery and equipment.

APPENDIX: CORN AND GRAIN SORGHUM RESEARCH PROPOSALS

2022–2023 Corn and Grain Sorghum Research Proposals

Principle Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
L. Connor		Performance Crop Insurance as a Risk Management Tool for Corn and Grain Sorghum Producers in Arkansas	1 of 3	$29,455
J. Robinson		Arkansas Future Ag Leaders Tour	1 of 3	$10,000
B. Deaton		Economic Analysis of Corn and Grain Sorghum Production and Marketing Practices	1 of 3	$5,735
L. Esppinoza	J. Kelley and T. Roberts	Fine-Tuning Potassium Recommendations for Sustainable Corn Production	1 of 3	$35,000
J. Kelley	T. Faske, T. Spurlock, L. Espinoza, T. Roberts, T. Barber, G. Studebaker, and C. Henry	Arkansas Corn and Grain Sorghum Research Verification Program	2 of 3	$124,000
V. Ford	B. Watkins	Corn and Grain Sorghum Enterprise Budgets	Ongoing	$10,000
J. Kelley	T. Roberts, T. Faske, G. Studebaker, and T. Barber	Developing Profitable Irrigated Rotational Cropping Systems for Arkansas	9 of 9	$19,000
A. Poncet	L. Purcell, T. Roberts, and J. Kelley	A web tool to assess mid-season N fertilizer needs from aerial imagery.	2 of 3	$54,000
T. Roberts	J. Kelley and L. Purcell	Comparing the Effects of Nitrogen Sources and Application Strategies on Corn Performance	2 of 3	$73,467
T. Spurlock	J. Kelley and L. Purcell	Determining the Value Added of Starter Fertilizer with In-Furrow Fungicide on Corn	2 of 3	$26,000
T. Faske	D. Rivera	Assess Management Options for Corn Nematodes in Arkansas	1 of 3	$53,032
S. Sadaka	G. Atungulu and N. Joshi	Utilization of Ozone Fumigation to Reduce Aflatoxin Contamination and Suppress Insects in Stored Corn.	3 of 9	$56,679
G. Studebaker	N. Bateman, B. Thrash, and N. Joshi	Assessing Susceptibility of Insect Pests of Corn in Storage to Selected Insecticides	1 of 3	$34,558
L. Espinoza	A. Poncet and C. Henry	Implementation of Remote and Proximal Sensing Driven Practices in Corn Production	3 of 3	$29,633
L. Purcell	T. Roberts and A. Poncet	Calibrating Mid-Season N Fertilizer Rates Based Upon Leaf N Concentration and Remote Sensing	3 of 3	$31,107
C. Henry	L. Espinoza, T. Spurlock, and J. Kelley	Improving Irrigation Scheduling and Irrigation Efficiency for Corn Production in Arkansas	3 of 3	$174,500

Continued

2022–2023 Corn and Grain Sorghum Research Proposals, continued

Principle Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
T. Barber	J. Norsworthy	Evaluation of New Herbicides, Premixes, Programs, and Application Methods for Improved Control of Problematic Weeds in Corn	1 of 3	$74,000
B. Bluhm		Gene Editing: A New Approach to Overcome Mycotoxins and Environmental Stress in Arkansas Corn Production (Phase II)	3 of 3	$40,000
M. Daniels		The Arkansas Discovery Farm Program	1 of 3	$5,000
J. Kelley	N. McKinney and V. Ford	Arkansas Corn and Grain Sorghum Research Studies Series, an Annual Report and Archival System for All Board-Funded Research	Ongoing	$5,122
T. Roberts	T. Spurlock, T. Faske, A. Rojas, and J. Kelley	Implementing Cover Crops into Corn Rotations and the Impact on Soil Health	3 of 3	$61,710
A. Ubeyitogullari		Developing a Green Integrated Approach to Enhance the Utilization of Grain Sorghum in Foods	2 of 3	$42,205
C. Henry		The Arkansas Irrigation Yield Contest (Year 5 Funded Separately)		$10,000
		Total Awards		**$1,004,203**
Unfunded in 2022–2023				
G. Atungulu	B. Bluhm and S. Sadaka	Prevention of Post-Harvest Grain Contamination by Aflatoxin Using Carbon Dioxide (CO_2) Monitoring and Aeration/Cooling		0
A. Poncet	L. Espinoza	A Survey to Establish Precision Agriculture Research and Educational Priorities for Arkansas Producers		0
H.S. Seo		Artificial Intelligence-Based Identification of Corn Appearance-Characteristics that Consumers Prefer		0
Y.J. Wang		Novel Sorghum Products with Increased Viscosity and Decreased Starch Digestibility by Parboiling		0
K. Brye	T. Roberts	Evaluation of Struvite as a Viable Fertilizer-P Source for Corn		0
A. Poncet		Mapping Weed Pressure with Drones		0
J. Kelley	L. Espinoza and T. Roberts	Overcoming Yield Limitations in Corn	Completed	0
N. Bateman	B. Thrash, G. Lorenz, and G. Studebaker	Evaluating the Efficacy of BT Ccorn Traits by Survival of Corn Earworm and Fall Armyworm	Completed	0
S. Green	J. Massey, A. Hashem, and E. Brown	Timing Cover Crop Termination to Optimize Corn Yields and Water-Use Eefficiency	Completed	0
J. Kelley	T. Roberts, T. Faske, T. Barber, C. Henry, and G. Studebaker	Development of a Corn DD50 Program	Completed	0

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