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Arkansas Corn and Grain Sorghum Research Studies 2023

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Arkansas
Corn and Grain Sorghum Research Studies 2023

Edited by
Jason Kelley
Travis Faske

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Corn near maturity in a plant population × nitrogen rate study August 7, 2023 at the University of Arkansas System Division of Agriculture's Jackson County Extension Center, Newport. Photograph by: Jason Kelley, University of Arkansas System Division of Agriculture, Cooperative Extension Service, Little Rock.

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ARKANSAS
CORN AND GRAIN SORGHUM RESEARCH STUDIES
– 2023 –

Jason Kelley and Travis Faske, Editors
University of Arkansas System Division of Agriculture,
Little Rock and Lonoke, Arkansas

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

INTRODUCTION

The 2023 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; irrigation; agronomics; 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.

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.

Jason Kelley and Travis Faske, Editors
University of Arkansas System Division of Agriculture,
Little Rock and Lonoke, Arkansas

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2023 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 the 2023 growing season, the Corn and Grain Sorghum Research Verification Program was conducted on 8 irrigated corn (*Zea mays* L.) fields and 1 non-irrigated corn field. Counties participating included Clark, Clay, Drew, Faulkner, Independence, Jefferson, Lonoke, Mississippi, and White. Corn grain yields averaged 209 bu./ac across the 9 fields. The Arkansas state average corn grain yield for 2023 was 183 bu./ac (USDA-NASS, 2024). Fields were planted between 23 March and 25 April, with an average planting date of 10 April. Final plant populations ranged from 25,500 to 35,000 plants/ac and averaged 32,200 plants/ac. Fields were irrigated an average of 2.3 times, while the Clark County field was non-irrigated due to timely rainfall during the growing season. On irrigated fields, soil moisture sensors were used to assist with irrigation scheduling. Preplant fertilizer applied averaged 41-37-65-9-2 lb/ac of nitrogen, phosphorus, potassium, sulfur, and zinc, respectively. The average total in-season fertilizer applied across all fields was 223-37-73-20-2 lb/ac of nitrogen, phosphorus, potassium, sulfur, and zinc, respectively. The resulting nitrogen fertilization program achieved 1.0 bu. of corn grain for every 1.06 lb/ac of nitrogen fertilizer applied. Economic returns to total costs/ac were $425.57 when no land charges were applied. Fertilizer/nutrients and seed were the largest input costs at $264.37 and $123.75/ac, respectively, and accounted for 40.4% and 18.9% of total operating 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 currently available technology. The objectives of the programs are: 1) to educate producers on the benefits of utilizing the University of Arkansas System Division of Agriculture recommendations for improved yields and 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 extension 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 administered by the Arkansas Corn and Grain Sorghum Promotion Board. Since the program's inception, 187 corn or grain sorghum fields have been enrolled in the program in 35 counties.

Procedures

In the fall of each year, the CGSRVP program coordinator sends out requests to county extension agriculture agents in counties with corn production 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 promptly throughout the growing season. During the winter, the program coordinator and county extension agent meet with the producer to discuss field expectations and review soil fertility, weed control, irrigation, insect control, hybrid recommendations, and program details. As the planting season begins, the program coordinator, the county agent, and the cooperator scout each field weekly and discuss management decisions 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 and high- and low-temperature data, which is used to calculate weekly accumulated growing degree days. When applicable, irrigation well flow meters are installed prior to irrigation initiation 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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[3] Associate Professor/Extension Economist and Professor Emeritus, respectively, College of Forestry, Agriculture, and Natural Resources, University of Arkansas at Monticello.

Results and Discussions

Corn yields during the 2023 growing season averaged 208.7 bu./ac from 9 fields and ranged from 168 bu./ac in Clark County (non-irrigated) to 245 bu./ac in Drew County (Table 1). The state average corn yield for 2023 was 183 bu./ac (USDA-NASS, 2024). All corn fields were planted promptly in 2023, with a range of planting dates from 23 March to 25 April, with an average planting date of 10 April. A relatively warm and dry March and April allowed for timely planting and uniform stands, which was partially responsible for the high yields obtained in 2023. Harvest dates ranged from 19 August to 30 September, with an average harvest date of 5 September. A dry August and September allowed for a timely harvest with minimal rain delays. Plant populations averaged 32,200 plants/ac, a recommended level for most irrigated fields and hybrids.

Fertilizers applied to fields closely followed the current University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) recommendations and were based on soil nutrient analysis and yield goals (Table 2). Preplant fertilizer applied to corn fields averaged 41-37-65-9-2 lb/ac of nitrogen-phosphorus-potassium-sulfur-zinc, where nitrogen applied pre-plant or at planting totaled approximately 18% of the total nitrogen applied during the season. Side-dressed nitrogen applied at the V4–V8 growth stage averaged 130 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 46–69 lb nitrogen/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 223 lb/ac when averaged across all fields. Applied nitrogen fertilizer resulted in an average yield of 208.7 bu./ac, which led to 1 bushel of corn grain for every 1.06 lb/ac of nitrogen fertilizer.

Pest management practices followed current CES recommendations. None of the corn fields met the threshold level of insects or disease; therefore, no fields were sprayed with a foliar insecticide or fungicide. Herbicides applied to corn fields varied but most commonly consisted of a combination of glyphosate, metolachlor, atrazine, and mesotrione applied in a one or two-pass program.

Irrigation is a vital production practice for Arkansas corn. Approximately 95% of the corn grown is statewide irrigated (USDA-FSA, 2024). Irrigation initiation, frequency, and termination were scheduled with the help of the Arkansas Irrigation Scheduler program and using soil moisture sensors to determine soil moisture content. During the 2023 cropping season, overall irrigation requirements for corn were less than average for most fields compared to previous years due to timely rainfall in June and July. On average, fields were irrigated 2 or 3 times (Table 3). Each furrow irrigation event was estimated to provide two acre-inches of irrigation water. The Faulkner County field was pivot irrigated, a common practice on fields with rolling terrain. The Clark County field was intended to be furrow irrigated, but timely rains negated the need for irrigation. The average rainfall on corn verification fields in 2023 from planting to maturity was 16.36 inches, ranging from 10.69 inches in Clay County to 23.83 inches in Clark County (Table 3).

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 2023 average GDDs accumulated by each growth stage. These values align closely with reported GDDs needed to reach maturity for full-season hybrids (110–120 days) that we typically grow in Arkansas. The accumulation of GDDs can be used to predict corn growth stages and assist in management decisions such as irrigation termination.

Economic Analysis

Production data from the 9 corn fields were applied to determine costs and returns above operating costs and total specified costs. Operating costs and total costs/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 reported by the cooperators are used in this analysis. Data from the Crop Enterprise Budgets determine input prices (Watkins, 2024) 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. The actual cash outlays could differ as producers utilize employee labor or provide unpaid labor for equipment maintenance.

Operating expenses include production expenses, interest paid on operating capital, and post-harvest expenses. Post-harvest expenses include 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 new equipment prices. This measure differs from typical depreciation methods and actual annual cash expenses for machinery but establishes a benchmark that estimates farm profitability.

Operating costs, total costs, costs/bu., 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 $5.62/bu., the average Arkansas 2023 crop booking and cash prices from 1 January through 31 August 2023. The average corn yield from the 9 corn verification fields was 208.7

bu./ac. On average, fertilizers and nutrients were the largest expense category at $264.37/ac or 40.4% of production expenses for all 9 fields. Seed costs averaged $123.75/ac, 18.9% of total operating expenses.

With an average corn yield of 208.7 bu./ac for all fields, operating costs were $653.25/ac for 2023. Return to operating costs for all fields for 2023 was $519.46/ac. Fixed costs for irrigated fields were $93.89/ac. Returns to total cost for irrigated fields was $425.57/ac. Total specified costs for irrigated corn fields in the 2023 program averaged $3.60/bu. but ranged from $3.12/bu. in Drew County to $4.08/bu. in Independence County (Table 5). The Drew County field had the highest grain yield and the lowest total specified cost/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 needing more research. 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 being evaluated in the corn and grain sorghum research verification program fields include foliar tissue testing during the growing season to assess whether or not current fertilizer recommendations for corn provide adequate levels of nutrients in the plants. Tissue samples are taken during the V10-tassel stage to determine whether nitrogen levels in the plant are sufficient and if a pre-tassel nitrogen application is needed. End-of-season corn stalk nitrate samples are 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 program has annually demonstrated that corn can be a profitable crop for Arkansas growers, and the published research-based recommendations for corn production are dependable for profitable, high-yielding, and sustainable production. The University of Arkansas Extension 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.

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Table 1. 2023 Corn Research Verification Program locations, hybrid planted, field size, row spacing, previous crop, plants per acre, plant date, harvest date, and yield.

County	Hybrid	Hybrid Maturity	Field Size	Row Space	Previous Crop	Plants Per Acre	Plant Date	Harvest Date	Yield
		(day)	(ac)	(in.)					(bu./ac)
Clark	DeKalb DKC 67-44	117	32	36	Soybean	25,500	4/25	9/15	168.4
Clay	Pioneer 1718VYHRP	117	40	30	Soybean	31,500	4/1	9/28	214.4
Drew	Dekalb DKC 65-99	115	82	38	Soybean	32,500	3/23	8/19	245.2
Faulkner	Stine 9818-12 RR/LL	116	65	30	Soybean	30,625	4/15	8/28	197.1
Independence	Dekalb DKC 66-94	116	40	30	Soybean	34,800	4/13	9/5	176.0
Jefferson	Progeny 2118VT2	118	86	38	Soybean	33,250	4/12	8/21	215.9
Lonoke	Dekalb DKC 65-99	115	80	30	Soybean	35,000	4/18	8/25	225.0
Mississippi	Becks 6774	117	42	38	Soybean	34,000	3/29	8/27	234.1
White	Progeny 2118VT2	118	40	30	Soybean	31,900	4/14	9/30	201.9
Mean	**---**		**56.3**	**---**	**---**	**32,199**	**4/10**	**9/5**	**208.7**

Table 2. 2023 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----------------------				
Clark	2 tons of litter	138-0-0-0-0	0	184-0-0-0-0	Sardis Silt Loam
Clay	45-100-100-12-5	137-0-0-12-0	46-0-0-0-0	228-100-100-24-5	Dexter Silt Loam
Drew	37-35-69-0-5	131-0-30-24-0	46-0-0-0-0	214-35-99-24-5	Hebert Silt Loam
Faulkner	39-0-60-18-0	96-0-0-18-0	69-0-0-0-0	204-0-60-36-0	Gallion Silt Loam
Independence	39-46-36-24-0	138-0-0-0-0	69-0-0-0-0	246-46-36-24-0	Egam Silt Loam
Jefferson	34-0-72-12-3	139-0-0-12-0	46-0-0-0-0	219-0-72-24-3	Rilla Silt Loam
Lonoke	51-71-69-0-0	126-0-0-12-0	46-0-0-0-0	223-71-69-12-0	DeWitt Silt Loam
Mississippi	40-45-60-6-0	143-0-36-18-0	46-0-0-0-0	229-45-96-24-0	Dundee Silt Loam
White	46-0-54-0-0	125-0-0-0-0	46-0-0-0-0	217-0-54-0-0	Calloway Silt Loam
Mean	**41-37-65-9-2**	**130-0-8-11-0**	**52-0-0-0-0**	**223-37-73-20-2**	---

[a] Applied between V12 to R1 (silking) corn growth stages.

Table 3. 2023 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.)
Clark	Non-Irrigated	0	23.83
Clay	Furrow	3	10.69
Drew	Furrow	2	16.92
Faulkner	Pivot	3	15.63
Independence	Furrow	3	14.48
Jefferson	Furrow	3	17.19
Lonoke	Furrow	3	14.31
Mississippi	Furrow	2	20.32
White	Furrow	3	13.84
Mean	---	**2.4**	**16.36**

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

Table 4. The corn growth stage and the corresponding average accumulated growing degree days were determined by weekly field visits in all cornfields in 2023.

Corn Growth Stage	Accumulated Growing Degree Days From Planting
VE – Emergence	149
V2	262
V4	437
V6	613
V8	787
V10	941
V12	1078
V14	1199
V16	1325
R1 – Silking	1500
R2 – Blister	1653
R3 – Milk	1830
R4 – Dough	2020
R5 – Dent	2225
R6 – Physiological Maturity (Black Layer)	2861

Table 5. Operating costs, total costs, and returns for corn research verification program fields, 2023.

County	Operating Costs	Operating Costs	Returns to Operating	Fixed Costs	Total Costs	Returns to Total Costs	Total Costs per Bushel
	($/ac)	($/bu.)	--------------------------	--------($/ac)	--------------------------		($/bu.)
Clark	528.90	3.14	417.51	81.19	610.09	336.32	3.62
Clay	771.85	3.60	433.08	83.71	855.56	349.37	3.99
Drew	662.87	2.70	715.15	102.08	764.95	613.08	3.12
Faulkner	593.42	3.01	514.28	90.24	683.66	424.04	3.47
Independence	619.54	3.52	369.58	99.35	718.89	270.23	4.08
Jefferson	673.57	3.12	539.78	96.21	769.78	443.58	3.57
Lonoke	682.34	3.03	582.16	87.94	770.28	494.22	3.42
Mississippi	722.49	3.09	593.15	113.73	836.22	479.43	3.57
White	624.27	3.09	510.41	90.58	714.85	419.83	3.54
Mean	**653.25**	**3.14**	**519.46**	**93.89**	**747.14**	**425.57**	**3.60**

Table 6. Detailed summary of operating costs, total costs, and returns for corn research verification program fields, 2023.

	Clark	Clay	Drew	Faulkner	Independence
Yield (bu./ac)	168.4	214.4	245.2	197.1	176.0
Price ($/bu.)	5.62	5.62	5.62	5.62	5.62
Total Crop Revenue	946.41	1204.93	1378.02	1107.70	989.12
Production Expenses			---------$/ac---------		
Seed	111.94	123.52	123.52	120.00	104.00
Fertilizers and Nutrients	215.04	371.31	234.99	214.28	286.39
Herbicides	46.66	62.71	80.72	67.23	27.40
Fungicide	0.00	0.00	0.00	0.00	0.00
Custom Application	0.00	24.00	16.00	16.00	16.00
Diesel Fuel, Field Activities	22.99	20.45	21.29	16.47	20.05
Irrigation Energy Costs	0.00	7.03	7.03	8.61	18.43
Other Inputs, Pre-harvest	0.00	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 and Maintenance	17.66	16.65	20.26	19.64	18.63
Labor, Field Activities	6.82	8.97	10.67	5.48	11.65

Continued

Table 6. Continued.

	Jefferson	Lonoke	Mississippi	White	Mean
Yield (bu./ac)	215.9	225.0	234.1	201.9	208.67
Price ($/bu.)	5.62	5.62	5.62	5.62	5.62
Total Crop Revenue	1213.36	1264.50	1315.64	1134.68	1172.71
Production Expenses	--$/ac--				
Seed	131.24	135.10	131.24	133.17	123.75
Fertilizers and Nutrients	257.55	272.07	298.29	229.39	264.37
Herbicides	63.49	58.25	60.64	56.45	58.17
Fungicide	0.00	0.00	0.00	0.00	0.00
Custom Application	16.00	16.00	16.00	16.00	15.11
Diesel Fuel, Field Activities	20.78	20.98	28.64	20.11	21.31
Irrigation Energy Costs	18.43	11.54	7.69	11.54	10.03
Other Inputs, Pre-harvest	3.88	3.88	3.88	3.88	3.45
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 and Maintenance	18.71	16.83	22.54	17.47	18.71
Labor, Field Activities	11.65	11.65	12.64	11.65	10.13

Continued

Table 6. Continued.

	Clark	Clay	Drew	Faulkner	Independence
Expenses	---$/ac---				
Interest	9.86	14.70	12.03	10.99	11.76
Post-harvest Expenses	75.78	96.48	110.34	88.70	79.20
Total Operating Expenses	528.90	771.85	662.87	593.42	619.54
Returns to Operating Expenses	417.51	433.08	715.15	514.28	369.58
Capital Recovery and Fixed Costs	81.19	83.71	102.08	90.24	99.35
Total Specified Expenses	610.09	855.56	764.95	683.66	718.89
Returns to Specified Expenses	336.32	349.37	613.08	424.04	270.23
Operating Expenses Per bu.	3.14	3.60	2.70	3.01	3.52
Total Specified Expenses Per bu.	3.62	3.99	3.12	3.47	4.08

Continued

Table 6. Continued.

	Jefferson	Lonoke	Mississippi	White	Mean
Expenses	---------------------	---------------------	$/ac	---------------------	---------------------
Interest	12.55	12.65	13.43	11.61	12.18
Post-harvest Expenses	97.16	101.25	105.35	90.86	93.90
Total Operating Expenses	673.57	682.34	722.49	624.27	653.25
Returns to Operating Expenses	539.78	582.16	593.15	510.41	519.46
Capital Recovery and Fixed Costs	96.21	87.94	113.73	90.58	93.89
Total Specified Expenses	769.78	770.28	836.22	714.85	747.14
Returns to Specified Expenses	443.58	494.22	479.43	419.83	425.57
Operating Expenses Per bu.	3.12	3.03	3.09	3.09	3.14
Total Specified Expenses Per bu.	3.57	3.42	3.57	3.54	3.60

Economic Analysis of the 2023 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 2023 corn research verification field results provide additional economic insights between conventional and stacked trait corn (herbicide +*Bt*) systems and between center pivot, furrow, and no irrigation systems. The stacked trait system fields had an average yield that was 36.75 bu./ac higher than that of the conventional field. The stacked trait system fields also had an average of $174.75/ac more return to land and management than the conventional field. The furrow irrigated fields had an average yield that was 18.97 bu./ac or higher than fields with other irrigation systems. The furrow irrigated fields also had average returns to land and management of $14.49/ac or higher than fields with other irrigation systems.

Introduction

The Arkansas Corn and Grain Sorghum Research Verification Program (CGSRVP) originated in 2000, and records have been compiled each succeeding year from the 187 fields of participating cooperators that now comprise the state data set. Among other goals, the program seeks to validate the 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 the CGSRVP coordinator on a regular basis and from state extension specialists as needed. The CGSRVP coordinator records input rates and production practices throughout the growing season, including official yield measures at harvest. A CES state extension economist compiles the data into the spreadsheet used for an annual cost of production budget development. Measures of profitability and production efficiency are calculated for each cooperator's field and then grouped by production system.

Procedures

Nine cooperating corn producers from across Arkansas provided input quantities and production practices utilized in the 2023 growing season. A state average corn market price was estimated by compiling daily forward booking and cash market prices for the 2023 crop. The price collection period was 1 January through 31 August 2023. These prices are the same as those used for the weekly corn and grain sorghum market reports published on the Arkansas Row Crops Blog (Deaton, 2024). Data was entered into the 2023 Arkansas corn enterprise budgets for each respective production system (Watkins, 2023). 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 2023 (Laughlin and Spurlock, 2016). Summary reports, by field, were compiled to generate system results.

Results and Discussion

The 9 fields included in the 2023 Arkansas Corn Research Verification Program report (Capps et al., 2023) had an average yield of 208.67 bu./ac generating an average revenue of $1,172.71/ac. Producers accumulated $653.25/ac of variable costs and $93.89/ac of fixed costs, for a total cost/ac of $747.14, resulting in an average return to land and management of $425.57/ac. Eight fields used stacked trait (herbicide +*Bt*) technology, and 1 field used conventional herbicide technology. One field used no irrigation system, 1 field used a center pivot irrigation system, and 7 fields used furrow irrigation. All economic comparisons were developed from corn daily forward booking and cash market prices for the 2023 crop reported by Deaton in weekly market reports (Deaton, 2024). The corn forward booking and cash market price for the 2023 crop averaged $5.62/bu. over the period of 1 January–31 August 2023. Market price multiplied by yield gave field revenues. No grade reductions or premiums were included. All grain 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 across corn traits (Table 1) and irrigation (Table 2) characteristics. The values for yield, revenue, total variable cost, total fixed cost, total cost, and return to land and management are discussed by characteristics. Variable costs include such items as fuel, seed, fertilizer, chemicals, and hired labor. Fixed costs include estimates of capital recovery

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values for all field equipment and irrigation systems used. No land rent was charged. Returns may be regarded as the return to management and operator labor.

Trait Comparisons

The stacked trait (herbicide +*Bt*) system was used in 8 fields, while the conventional (no herbicide or inset trait) was used in only 1 field (Table 1). Yield comparisons by system show that the stacked trait (herbicide +*Bt*) fields had an average advantage of 36.75 bu./ac over the conventional trait field. The stacked trait fields also had an average of $206.54/ac higher revenue, $37.92/ac higher total variable costs, $6.14/ac lower total fixed costs, $31.78/ac higher total costs, and $174.75/ac higher return to land and management than the conventional trait field.

Irrigation Comparisons

Eight of the 9 fields in the 2023 program were irrigated. Seven fields were furrow irrigated, and 1 field was irrigated by center pivot. The furrow-irrigated fields had an average of 18.97 bu./ac over the center pivot irrigated field, and a 47.67 bu./ac advantage over the non-irrigated field. The furrow-irrigated fields also had an average of $106.62/ac or higher revenue, $86.14/ac or higher total variable costs, $5.99/ac or higher total fixed costs, $92.13/ac or higher total costs, and $14.49/ac or higher return to land and management than the other fields. The non-irrigated field had a lower yield, lower revenue, lower costs, and lower return to land and management than those of the average furrow-irrigated field or those of the center-pivot-irrigated field.

Overall Comparisons

The 2023 Arkansas Corn Research Verification Program fields had a 208.67 bu./ac statewide average yield. This was 13.64 bushels more than in 2022 and more than 25 bushels above the 2023 Arkansas state average yield of 183 bu./ac (USDA-NASS, 2024). Revenue averaged $1,172.71 from this production and market price. The revenue mark represents a decrease of $237.38/ac compared to 2022. Total variable costs averaged $653.25, a $69.25 increase, and total fixed costs averaged $93.89, a $6.98 increase, for an average total cost per acre of $747.14, a $76.23 increase over 2022. These revenue and cost averages left producers with an average per acre return to land and management of $42*5.57 across all production systems, a $313.61 decrease per acre compared to 2022.

Practical Applications

The results of the corn research verification program 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 both producers currently growing corn and those contemplating production.

Acknowledgments

The authors wish to thank the Arkansas Corn and Grain Sorghum Promotion 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 to the University of Arkansas at Monticello College of Forestry, Agriculture, & Natural Resources, both of which provided funding and other support for this research project. Appreciation is especially extended to Mr. Chuck Capps, Arkansas Corn and Grain Sorghum Research Verification Program Coordinator, and Dr. Jason Kelley, Arkansas Corn and Grain Sorghum Research Verification Program Director, without whom this research would not have been possible.

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Table 1. Economic results by trait system for the 2023 Corn and Grain Sorghum Research Verification Program.

Trait System	Stacked Trait	Conventional	All Fields
# Fields	**8**	**1**	**9**
Yield (bu./ac)	212.75	176.00	208.67
Revenue ($/ac)	1195.66	989.12	1172.71
Total Variable Costs ($/ac)	657.46	619.54	653.25
Total Fixed Costs ($/ac)	93.21	99.35	93.89
Total Costs ($/ac)	750.67	718.89	747.14
Returns to Land and Management ($/ac)	444.98	270.23	425.57

Table 2. Economic results by irrigation system for the 2023 Corn and Grain Sorghum Research Verification Program.

Irrigation System	Furrow	Center Pivot	None	All Fields
# Fields	**7**	**1**	**1**	**9**
Yield (bu./ac)	216.07	197.10	168.40	208.67
Revenue ($/ac)	1214.32	1107.70	946.41	1172.71
Total Variable Costs ($/ac)	679.56	593.42	528.90	653.25
Total Fixed Costs ($/ac)	96.23	90.24	81.19	93.89
Total Costs ($/ac)	775.79	683.66	610.09	747.14
Returns to Land and Management ($/ac)	438.53	424.04	336.32	425.57

Field Efficacy of Soil-Applied Fluopyram at Low Nematode Densities in Corn

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

Abstract

The field efficacy of three soil-applied nematicides was evaluated in a field naturally infested with stubby-root nematodes (*Paratrichodorus* spp.), lesion nematodes (*Pratylenchus* spp.), southern root-knot nematode (*Meloidogyne incognita*), and stunt nematodes (*Tylenchorhynchus* spp.) in Pulaski County Arkansas. All nematodes were observed at densities below the damage threshold for corn. The corn hybrid used, GoldenHarvest G16K01-3111, is susceptible to corn nematodes. None of the soil-applied nematicides had a significant impact on nematode reproduction or grain yield protection. There was a numeric trend in grain yield protection by Velum (fluopyram) but not Propulse (fluopyram + prothioconazole) or Counter (terbufos) compared to the non-treated control. Overall, these data suggest these soil-applied nematicides provide little nematode suppression and grain yield protection when nematode densities are low in a sandy loam soil and emphasize the importance of nematode sampling to determine if a nematicide is needed.

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* spp.), lesion nematodes (*Pratylenchus* spp.), root-knot nematodes (*Meloidogyne* spp.) and stunt nematode (*Tylenchorhynchus* 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 the benefit of using a nematicide when multiple nematode species are present at densities below a damage threshold for corn.

Fluopyram, a succinate dehydrogenase inhibitor fungicide (SDHI), is marketed as a seed- and soil-applied nematicide in several crops, including cotton, corn, and soybean. Currently, soil-applied fluopyram is marketed as a corn nematicide under the trade names Velum® (fluopyram) and Propulse® (fluopyram + prothioconazole (DeMethylation inhibitor fungicide)). These liquid formulations are applied in-furrow at planting to suppress the impact of early-season corn nematodes on the developing seedling root system. Currently, there is little information on the benefit of Velum when several nematode species are present at densities below a damage threshold. The objective of this study was to evaluate the field efficacy of fluopyram in suppressing corn nematodes and protecting grain yield potential.

Procedures

The field efficacy of fluopyram was evaluated in a field experiment in 2023 in Pulaski County, Arkansas (Table 1). The soil texture was a sandy loam soil with 48% sand, 48% silt, and 2% clay. The corn hybrid, GoldenHarvest 'G16K01-3111' (Syngenta, Greensboro, N.C.; 116-day maturity), was planted on 11 April 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 the 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 0.07-in.-diameter poly tubing using a pressurized sprayer to deliver a total volume of 6.5 gal/ac. Counter was applied in-furrow through a 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. Soil samples were collected at mid-season (23 May; 42 days after planting (DAP) and V5 growth stage) and at harvest. Nematodes were collected from 100 cm^3 (3.4 fl oz) soil using a semiautomatic elutriator and sucrose-centrifugation technique and enumerated using a stereoscope. Soil samples collected after harvest were processed using a modified Baermann pan system. Stand counts, which is the number of plants per ten row feet, were determined at 21 DAP. A vigor rating was given for the entire plot at 21 DAP, where 1 = poor growth and 5 = best growth. The two center rows of each plot were harvested on 7 September with an ALMACO SPC40 plot combine (ALMACO, Nevada, Iowa) equipped with a HarvestMaster Single BDS HiCap HM800 weigh system (HarvestMaster Logan, Utah).

Data were subjected to analysis of variance using ARM 2023 (GDM Solutions, Inc., Brookings, S.D.) and mean separation when appropriate at $P = 0.05$ according to Tukey's hon-

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estly significant difference procedure. All nematode data were transformed ($\log_{10} +1$) to normalize for analysis, and reverse transformed data are reported.

Results and Discussion

The was no ($P > 0.05$) effect of soil-applied nematicide on seedling stand counts or vigor. The average plant density was 18.7 plants per ten ft. of row, and the average vigor rating was 5.0. No significant ($P \geq 0.29$) suppression of stubby-root nematode, lesion nematode, or southern root-knot nematode densities was observed by any soil-applied nematicide (Fig. 1). The densities of stunt nematodes were lower ($P \leq 0.05$) on the non-treated control than any of the soil-nematicide treatments, which suggest nematicides have little or no impact on stunt nematodes. Furthermore, nematicides had no ($P = 0.64$) impact on corn grain yield (Fig. 2). A greater grain yield trend was observed with Velum compared to the non-treated control. It is noteworthy that the rate of fluopyram in 3 fl oz/ac of Velum is equal to that in 8 fl oz/ac of Propulse, which suggests that fluopyram had little to no impact on grain yield. If so, a greater grain yield would have been observed in Propulse as well. 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; 2022).

The fall damage threshold for stubby-root nematode, lesion nematode, root-knot nematode, and stunt nematode is 40, 500, 500, and 700 individuals/100 cm^3 soil, respectively. Based on soil samples collected at harvest, none of the corn nematode densities were within 5% of the damage threshold for corn. Thus, the inconsistency in yield protection may have been due to low densities in corn nematodes in this study, which emphasizes the importance of sampling fields for nematodes when considering a nematicide in corn. Finally, these data further our understanding of the limited impact of multiple species of corn nematodes at low densities on corn grain yield.

Practical Applications

Soil-applied nematicides were inconsistent in nematode suppression and grain yield protection when nematode densities were low in sandy loam soil. Thus, a nematicide is unlikely to be profitable when nematode densities, even multiple species, are below the damage threshold, which emphasizes the importance of sampling fields for nematodes when considering a nematicide in corn.

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Table 1. Trade names, rates, and active ingredients for nematicides used in a corn nematicide experiment in 2023 in Pulaski County, Arkansas.

Trade name and formulation	Rate	App[a]	Active ingredient
Velum 4.16 SC[b]	3.0 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 a 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.

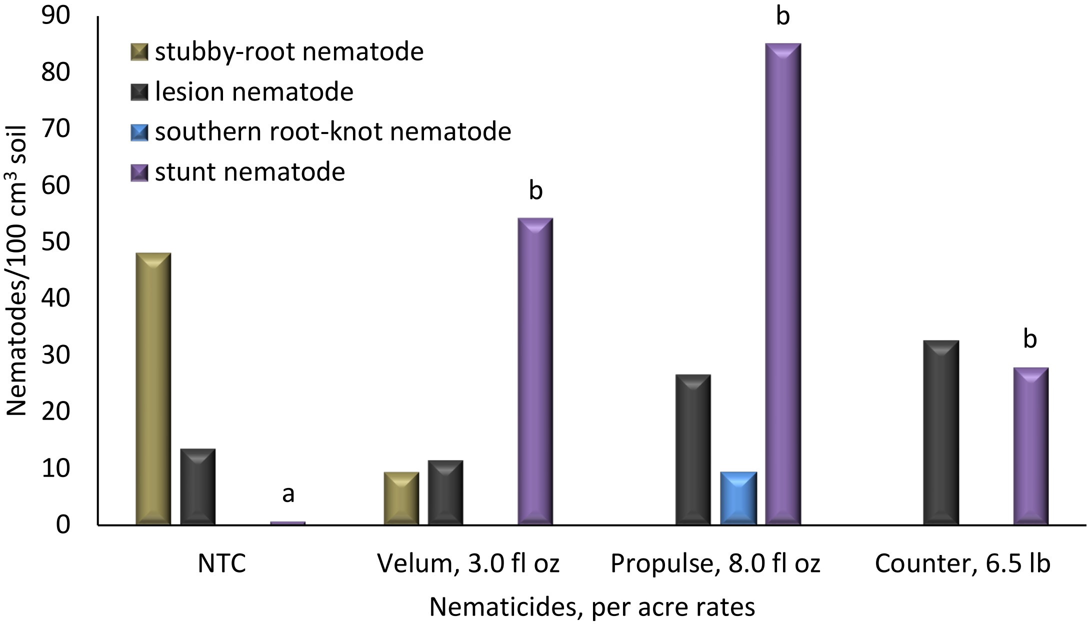

Fig. 1. Suppression of corn nematodes by three nematicides in 2023 in a field experiment in Pulaski County, Arkansas. Each bar represents the average nematode density from six replicates collected 42 days after planting. Different letters above bars indicate a significant difference at α = 0.05 according to Tukey's honestly significant difference test.

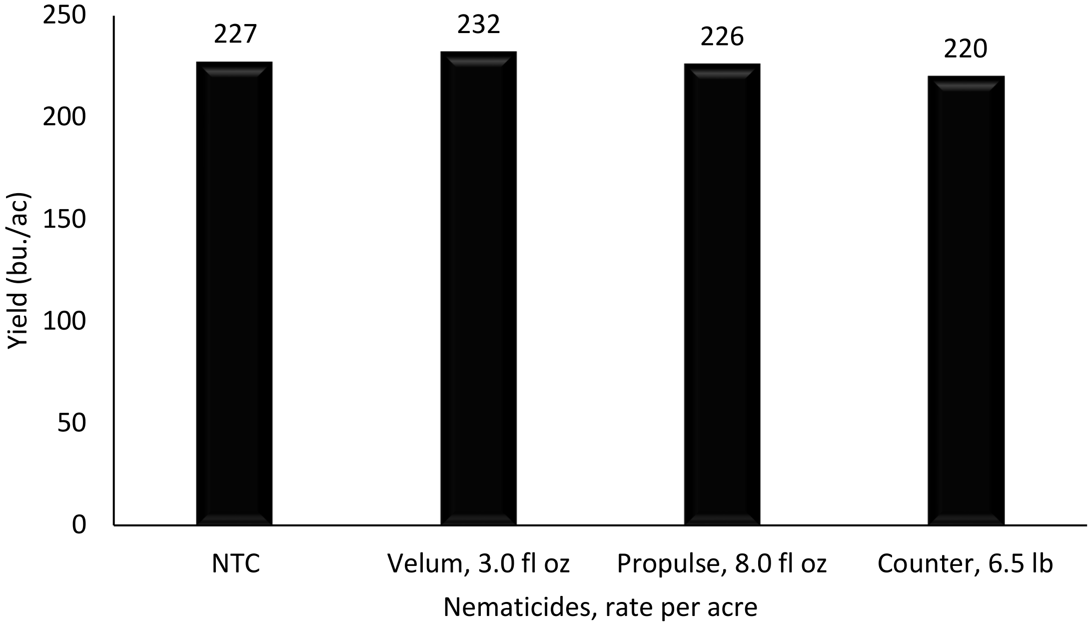

Fig. 2. Yield protection by three nematicides in 2023 in a field with low densities of stubby-root nematode, lesion nematode, southern root-knot nematode, and stunt nematode in Pulaski County, Arkansas. Grain yield was adjusted to 15.5% moisture.

Evaluation of In-furrow Fungicides on Corn, 2023

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

Two fungicide trials were conducted on hybrid corn (*Zea mays* L.) in 2023 at the University of Arkansas System Division of Agriculture's Rohwer Research Station and one at the Lon Mann Cotton Research Station. At Rohwer, fungicides were applied at planting in a 2 x 2 system (outside the seed furrow) or at R3 as a foliar application. Whereas at Lon Mann, fungicides were applied in the seed furrow at planting or at R3 as a foliar application. Corn plant populations were similar across treatments at all locations. Foliar disease severity was low in the earlier planted test at Rohwer due to hot and dry conditions, and although a greater severity was observed in the later planted test, there were no differences among treatments. Foliar disease severity was low in the trial at Lon Mann. Grain yield was not affected by fungicide treatments in any trial. Overall, fungicides had no impact on foliar diseases or grain yield in these trials.

Introduction

When corn is planted into cool and wet soils, it can suffer reduced population densities, plant vigor, and yield losses due to a 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 irrigation initiation). Delaying planting into warmer and dryer soils would alleviate or eliminate these early season issues; however, delayed planting (after May) increases the risk of foliar diseases such as southern rust (Kelley and Capps, 2024). The objective of this study 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 (UADA) Lon Mann Cotton Research Station on 19 April in a randomized complete block design using Pioneer 2024VYHR at a seeding rate of 34,000 seed/ac. Three in-furrow treatments were applied at 5 gal/ac, Agroliquid Pro-germinator 9-24-3 (pop-up starter), pop-up starter + Quadris (azoxystrobin) at 13.8 fl oz/ac, and pop-up starter + Xyway LFR (Flutiafol) at 12 fl oz/ac. Plots were 4 rows wide on 38 in. beds and 50 ft long. Two foliar fungicide treatments, Veltyma (pyraclostrobin+mefentrifluconazole) and Trivapro (benzovindiflupyr+azoxystrobin+propiconazole), 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 and overhead boom. The 2 center rows were sprayed using TeeJet XR 110015-VS nozzles, propelled with carbon dioxide at 4 mph. The trial was furrow irrigated and managed according to UADA recommendations. Stand data were collected on 7 June. Foliar disease levels were determined at the time of foliar fungicide application and again at R5.5 on 26 August. Foliar diseases located on the ear leaf and above were rated individually on a 0-9 scale, with a rating of 9 indicating severe disease. Disease data were treated as ordinal and rank transformed prior to analysis. At maturity, the center two rows of each plot were harvested with a small plot combine equipped with a research weigh system on 11 September, and yields were adjusted to 15.5% grain moisture. All data were subjected to ANOVA for analysis.

Two trials were planted at the University of Arkansas System Division of Agriculture Rohwer Research Station near Kelso, Ark., on 17 May and 2 June. The trial planted on 17 May was originally planted in April but had to be re-planted two more times due to bird damage at emergence. Plots were 4 rows wide on 38 in. beds and 40 ft. long. Each trial consisted of the same 12 treatments. Fungicide treatments were applied at planting using a 2 x 2 planter attachment or as a foliar application at R3. For foliar fungicide applications, the 2 center rows were sprayed with a backpack sprayer and overhead boom using TeeJet XR 110015-VS nozzles, propelled with carbon dioxide at 4 mph at a 10 gal/ac water volume. Treatments included Quadris at 13.8 fl oz/ac + Agroliquid Pro-germinator 9-24-3 at 5 gal/ac, Quadris at 13.8 fl oz/ac + Agroliquid Pro-germinator 9-24-3 at 5 gal/ac + Trivapro at 13.7 fl oz/ac, Quadris at 13.8 fl oz/ac + Agroliquid Pro-germinator 9-24-3 at 5 gal/ac + Veltyma at 7 fl oz/ac, Xyway LFR at 12 fl oz/ac + Agroliquid Pro-germinator 9-24-3 at 5 gal/ac, Xyway LFR at 12 fl oz/ac + Agroliquid Pro-germinator 9-24-3 at 5 gal/ac + Trivapro at 13.7 fl oz/ac, Xyway LFR at 12 fl oz/ac, Agroliquid Pro-germinator 9-24-3 at 5 gal/ac + Veltyma at 7 fl oz/ac, Trivapro at 13.7 fl oz/ac, Veltyma at 7 fl oz/ac, Agroliquid Pro-germinator 9-24-3 at 5 gal/ac, and a nontreated control. All Quadris and Xyway treatments were applied 2 x 2 at planting. Veltyma and Trivapro were applied as a foliar spray at R3. Plant stands were collected 7 days after planting for each trial. Foliar diseases were rated at the time of foliar fungicide application and again at R6 on 16 August for the 17 May planted trial and R5 and R6 on 31 August

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and 11 September for the 2 June planted trial. Foliar diseases located on the ear leaf or above were rated individually on a 0–9 scale, with a rating of 9 indicating severe disease. Plots were harvested 15 September and 19 October with a plot combine equipped with a weighing system. Disease data were treated as ordinal and rank transformed prior to analysis. All data were subjected to analysis of variance.

Results and Discussion

Curvularia leaf spot, caused by the fungus *Curvularia lunata*, was the only disease that occurred with high enough incidence to be rated at Lon Mann. Stand, Curvularia leaf spot severity and yield were similar among treatments (Table 1).

The early planted trial at Rohwer had low disease pressure. Stand counts were highly variable due to bird damage and were not significantly different among treatments. Overall, foliar disease levels were low with only Curvularia leaf spot occurring at a high enough incidence to be rated. Grain yields were not different by treatment and were lower than expected due to an irrigation well outage that occurred 3–5 weeks after planting. (Table 2).

In the later planted trial at Rohwer, southern rust and Curvularia leaf blight were observed at low levels. Plant stands, foliar disease, and yield were not significantly different by treatment. This trial was also significantly impacted by the irrigation pump outage, which occurred the 3 weeks following planting (Table 3).

Practical Applications

Fungicides applied at planting did not sufficiently reduce the later season impacts of foliar disease to add value to the crop (by increasing yield) above estimated product and application costs. Based on these results, the benefit of in-furrow or 2x2 fungicide application in Arkansas remains 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 applied into the seed furrow in mid-May. However, it was not beneficial to yield or control of Curvularia leaf spot when compared to the nontreated controls. In addition to Veltyma and Trivapro, products used in these studies, numerous other foliar fungicides are labeled for use on corn. These products and their relative efficacy ratings on several diseases can be found in MP154 (Faske and Spurlock, 2023).

Acknowledgments

The authors would like to thank the Arkansas Corn and Grain Sorghum Board for funding this project through corn and grain sorghum check-off funds, as well as the University of Arkansas System Division of Agriculture for providing other facilities and resources to complete this project's objectives.

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Table 1. Plant stands, foliar disease, and yield data from a corn in-furrow and foliar fungicide trial at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, 2023.

Treatment and rate/acre	Growth stage at application	Stand	Curvularia leaf spot	Yield
		(plants/ac)	(0-9)[a]	(bu./ac)
Nontreated	---	27,646	3.5	184.0
Fertilizer only[b]	Plant[c]	27,728	2.4	190.6
Fertilizer + Quadris 13.8 fl oz	Plant	28,792	2.0	188.5
Fertilizer + Xyway 12 fl oz	Plant	29,383	2.0	183.8
Trivapro 13.6 fl oz	R3	28,577	2.8	188.2
Veltyma 7 fl oz	R3	27,371	2.8	194.5
Pr >F		0.64	0.43	0.75

[a] Foliar disease ratings based on a 0–9 scale where 9 = severe disease at the R5.5 growth stage.

[b] Fertilizer = Agroliquid Pro-germinator 9-24-3 at 5 gal/ac.

[c] "Plant" denotes treatment was applied in-furrow at planting.

Table 2. Plant stands, foliar disease, and yield data from a corn 2 x 2 and foliar fungicide trial at the University of Arkansas System Division of Agriculture's Rohwer Research Station, planted 17 May 2023.

Treatment and rate/ac[a]	Growth stage at application	Stand	Curvularia leaf spot	Yield
		(plants/ac)	(0-9)[b]	(bu./ac)
Nontreated	---	22,868	2.6	109.9
Fertilizer + Quadris + Trivapro	Plant[c] + Plant + R3	24,301	2.3	95.4
Fertilizer + Quadris + Veltyma	Plant + Plant + R3	20,426	2.2	126.7
Fertilizer + Quadris 11 fl oz/ac	Plant	22,008	2.5	133.4
Fertilizer + Trivapro	Plant + R3	25,825	2.4	120.3
Fertilizer + Veltyma	Plant + R3	22,765	2.6	127.9
Fertilizer + Xyway + Trivapro	Plant + Plant + R3	28,112	2.0	126.7
Fertilizer + Xyway + Veltyma	Plant + Plant + R3	20,392	2.2	121.8
Fertilizer + Xyway	Plant + R3	24,656	2.4	133.6
Fertilizer	Plant	26,066	2.6	114.9
Trivapro	R3	25,378	2.4	125.7
Veltyma	R3	29,832	2.0	138.4
Pr >F		0.18	0.66	0.69

[a] Fertilizer = Agroliquid Pro-germinator 9-24-3 at 5 gal/ac, Quadris = 11 fl oz/ac, Trivapro = 13.7 fl oz/ac, Veltyma = 15.2 fl oz/ac, Xyway = 15.2 fl oz/ac.

[b] Foliar disease ratings based on a 0–9 scale where 9 = severe disease, rated at the R6 growth stage.

[c] "Plant" denotes treatment was applied in a 2 x 2 system at planting.

Table 3. Plant stands, foliar disease, and yield data from a corn 2 x 2 and foliar fungicide trial at the University of Arkansas System Division of Agriculture's Rohwer Research Station, planted 2 June 2023.

Treatment and rate/ac[a]	Growth stage at application	Stand	Southern rust	Curvularia leaf spot	Yield
		(plants/ac)	(0-9)[b]	(0-9)[b]	(bu./ac)
Nontreated	---	22,868	2.6	4.2	133.3
Fertilizer + Quadris + Trivapro	Plant[c] + Plant + R3	24,301	2.4	3.8	111.4
Fertilizer + Quadris + Veltyma	Plant + Plant + R3	20,426	2.0	4.0	105.2
Fertilizer + Quadris	Plant	22,008	1.4	2.4	140.9
Fertilizer + Trivapro	Plant + R3	25,825	2.6	4.4	133.3
Fertilizer + Veltyma	Plant + R3	22,765	1.4	4.4	133.1
Fertilizer + Xyway + Trivapro	Plant + Plant + R3	28,112	2.6	4.2	115.5
Fertilizer + Xyway + Veltyma	Plant + Plant + R3	20,392	2.0	4.2	143.7
Fertilizer + Xyway	Plant + R3	24,656	2.8	3.4	138.0
Fertilizer	Plant	26,066	3.2	3.6	136.0
Trivapro	R3	25,378	2.0	4.4	115.2
Veltyma	R3	29,832	1.8	4.2	115.9
Pr >F		0.31	0.59	0.10	0.23

[a] Fertilizer = Agroliquid Pro-germinator 9-24-3 at 5 gal/ac, Quadris = 11 fl oz/ac, Trivapro = 13.7 fl oz/ac, Veltyma = 15.2 fl oz/ac, Xyway = 15.2 fl oz/ac.

[b] Foliar disease ratings based on a 0–9 scale where 9 = severe disease at R6 growth stage.

[c] "Plant" denotes treatment was applied 2 x 2 at planting.

Evaluating Transgenes for Managing Mycotoxins in Corn

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

Abstract

Mycotoxins such as aflatoxin pose a significant risk to Arkansas corn production. Management options to mitigate aflatoxin contamination of corn are limited, and decades of conventional breeding have failed to produce commercial hybrids with sufficient genetic resistance to aflatoxin accumulation. Transgenic approaches to control aflatoxin accumulation in corn have shown considerable promise, but various technical hurdles hinder the speed at which transgenes can be deployed into commercially viable corn hybrids. In this study, we addressed technical hurdles associated with determining the copy number and specific location of transgenes in the corn genome. We developed a target enrichment sequencing strategy that focused on the border regions of transgenes, with the goal of enriching sequencing reads containing the break-junction sites of transgene integration. This technique was applied to a transgenic corn line containing multiple copies of a transgene targeting *Aspergillus flavus*, the predominant pathogen associated with aflatoxin of corn in Arkansas. The technique was able to successfully resolve transgene copy number, as well as integration sites within the genome. However, additional refinement of capture probe design, as well as alternative sequencing technologies, would further increase the effectiveness of the approach. This approach facilitates the rapid development of integration-specific molecular markers for breeding with transgenic lines and enumeration of transgene copy number in individual lines. This technique brings value to Arkansas corn producers by greatly improving the speed and efficiency of introgressing transgenic aflatoxin resistance into high-yielding, Southern-adapted corn hybrids.

Introduction

Aflatoxin, produced predominantly by the fungal pathogens *Aspergillus flavus* and *A. parasiticus*, is one of the most problematic disease issues affecting corn production in Arkansas. Aflatoxin is a potent carcinogen, and thus, its presence in raw and processed agricultural commodities is strictly regulated in the U.S. and abroad. Among major U.S. row crops, corn is particularly susceptible to aflatoxin contamination, as genetic resistance is not available in commercial hybrids, and management tools are limited. Environmental stresses prevalent in Arkansas and other Southeastern states, such as extreme heat and drought, exacerbate aflatoxin contamination in corn.

Transgenic resistance to aflatoxin is a rapid alternative to conventional genetic resistance. Host-induced gene silencing (HIGS) is a particularly promising transgenic strategy. In this approach, transgenic corn is engineered to express segments of a fungal gene required for pathogenesis. When the fungal pathogen attacks the transgenic corn plant, the fungus inadvertently uptakes excess copies of the expressed transgene. To process these excess copies of its own pathogenicity gene, the fungus silences its expression, rendering the pathogen unable to infect the corn plant. In essence, HIGS ‘confuses’ a fungal pathogen into shutting down its own genes required for plant infection.

We are currently utilizing HIGS to target *A. flavus*, the predominant aflatoxin-producing pathogen affecting corn production in Arkansas. We have constructed a series of transgenes targeting multiple fungal genes involved in pathogenesis and aflatoxin production (via HIGS) and created transgenic corn lines harboring these transgenes. However, to efficiently create transgenic, inbred lines suitable as parents for high-yielding aflatoxin-resistant hybrids, we need a process to rapidly and accurately identify the number of transgenic integrations per inbred line, as well as the position of each transgene in the genome. This information is required to create markers for efficient molecular breeding, pyramiding various transgenes in individual inbred lines, and dissecting potential linkage drag when introgressing transgenes into elite corn germplasm.

In this study, we developed a target-enrichment sequencing strategy to identify specific locations of transgene integrations in the genomes of corn inbred lines. This approach facilitates the enumeration of transgene copy number in individual transgenic corn lines and allows for integration-specific markers to be developed inexpensively and rapidly. In turn, the development of integration-specific markers greatly accelerates the development and deployment of transgenic aflatoxin resistance in commercial corn hybrids.

Procedures

Transgenic Corn Lines

For this study, we utilized a transgenic corn line created in our research program containing a HIGS construct targeting the hexokinase gene *AfHxk1* of *A. flavus*. *AfHxk1* is a putative carbohydrate sensor and regulator of pathogenesis and aflatoxin biosynthesis in *A. flavus* (Huang et al., 2023). The HIGS hairpin construct targeting *AfHxk1* was initially created in the pSilent-1 ascomycete silencing vector for functional validation and subse-

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quently cloned into pTF101.1, a binary vector suitable for corn transformation. Transformation of corn callus tissue was performed by the Crop Bioengineering Center at Iowa State University. Upon return of transgenic corn callus tissue, plantlets were regenerated and propagated at the University of Arkansas System Division of Agriculture laboratories and greenhouse facilities. A single transgenic line, preliminarily determined to contain multiple transgene integrations via Southern blot analysis, was analyzed via target enrichment sequencing as described below.

Target Enrichment Sequencing

For target enrichment, six DNA capture probes were designed to hybridize with border regions of T-DNA flanking the *AfHxk1* HIGS construct (Table 1). Biotinylated capture probes were designed to capture approximately 240–360 bp from the left and right borders of T-DNA (Fig. 1). Pooled libraries from the six capture probes were prepared for sequencing as described by Sharma (2018). Libraries were sequenced with an Ion PGM sequencer and a 316 V2 chip kit.

Data Analysis

To align individual sequencing reads to the corn reference genome (inbred line B73; https://www.ncbi.nlm.nih.gov/), sequenced reads were assessed for a quality score of >Q20 with FASTQC software package (https://www.bioinformatics.babraham.ac.uk/projects/fastqc/). Reads were first mapped with Burrows-Wheeler Aligner (https://bio-bwa.sourceforge.net/; Li and Durban, 2009) to the *AfHxk1* HIGS construct. Reads that contained sequences from both the *AfHxk1* HIGS construct and corn genome were then aligned to the corn reference genome to pinpoint the site(s) of integration. Integration sites and corresponding sequencing reads were visualized with the Samtools software package (https://www.htslib.org/).

Results and Discussion

Mapping Sequencing Reads

Individual reads that corresponded to plasmid T-DNA sequence were extracted from the pooled sequencing data, and chimeric reads containing corn genomic DNA sequence, which would presumably correspond to the break-junction of transgene integration into the corn genome, were mapped to the corn reference genome. After mapping individual reads to the corn genome, contigs corresponding to the break-junction integration sites were assembled and mapped to the corn genome for confirmation. The number of contigs corresponding to predicted break-junction sites ranged from 2 to 29 per locus, likely due to the presence of nucleotide polymorphisms at one or more genomic loci or, more likely, due to sequencing errors on individual reads.

Determination of Transgene Copy Number and Locations Within the Genome

The chimeric corn/transgene reads corresponding to potential integration sites, and the resulting contig sets are mapped to six distinct loci in the corn genome (Figs. 2–5). Four of the contig sets were mapped to two genomic loci (Figs. 2, 3), which is consistent with the expected pattern of detecting both T-DNA borders of complete transgene integration. For the first integration event (Fig. 2), the predicted spacing between the left border and right border was 64 bp, suggesting that insertion of the transgene caused a small deletion of 64 bp. For the second integration event (Fig. 3), the predicted spacing between borders was approximately 1 kb, indicating a slightly larger deletion event upon transgene insertion. For the third and fourth predicted integration events (Figs. 4, 5), a single border was detected. This could result from fragmentation/partial insertion of the transgene at these two loci or complete integration of the transgene with some degree of T-DNA border degradation upon insertion.

The four predicted integration events were dispersed across the corn genome. The first integration event mapped to chromosome 4, the second mapped to chromosome 1, the third mapped to chromosome 10, and the fourth mapped to chromosome 7. The wide dispersal of the transgenes across multiple chromosomes is advantageous to select (or eliminate) specific transgene integration events, as genetic linkage should not be an interfering factor.

Conclusions

The target enrichment sequencing approach developed in this study effectively enumerated and mapped transgene integration events in the corn genome. While two of the four predicted integration events were strongly supported by numerous sequence reads at both borders, the other two putative integration events were only defined by a single T-DNA border. While the exact explanation for detecting only a single integration event is not clear, the issue can be resolved quickly by PCR to clarify the structure of the other integration border or by including additional, more evenly spaced capture probes across the entirety of the transgene and its flanking sequences.

Practical Applications

Arkansas corn growers urgently need effective, sustainable tools to manage aflatoxin contamination. New transgenic corn hybrids with resistance genes specifically targeting aflatoxin production are one of the most promising options for effective aflatoxin control. In order to develop and deploy resistant hybrids as quickly as possible, molecular markers are needed to track the presence and number of transgenes during the process of creating new hybrids. The assay described in this study allows the rapid development of individual molecular markers for multiple transgene integration events in corn, which is critical to accelerate the introgression of transgenes targeting aflatoxin accumulation into commercially viable hybrids. Ultimately, an acceptable level of aflatoxin control will likely require the pyramiding of multiple transgenes with different modes of action/fungal gene targets. The assay described in this study will dramatically accelerate transgene pyramiding, which will also work to suppress the ability of pathogen populations to overcome transgenic resistance to aflatoxin accumulation.

Acknowledgments

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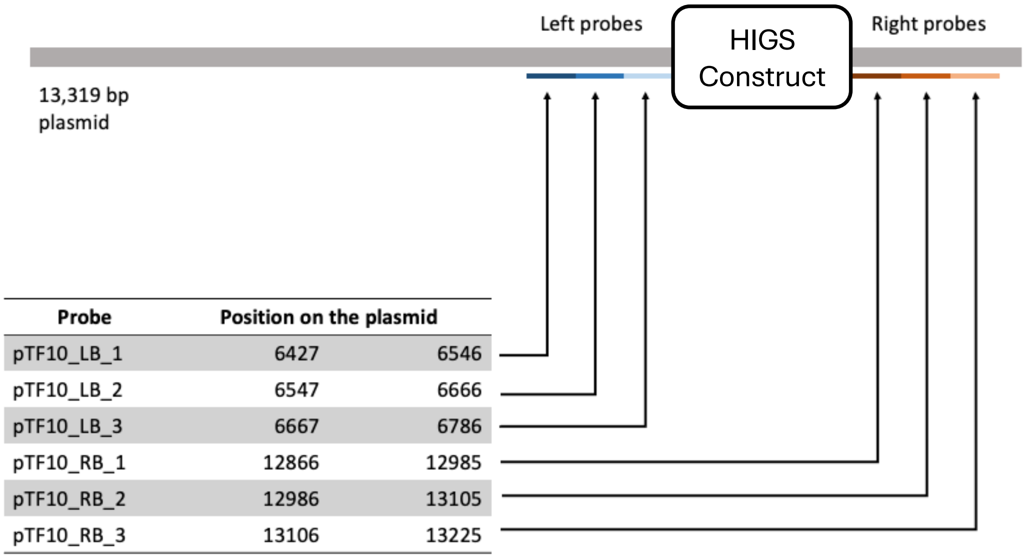
Table 1. Sequences of DNA capture probes designed to hybridize with border regions of T-DNA flanking the *AfHxk1* host-induced gene silencing construct.

DNA capture probe	Sequence
pTF101_LB_1	TGGCAGGATATATTGTGGTGTAAACAAATTGACGCTTAGACAACTTAATAACACATTGCGGACGTTTTTAATGTACTGAATTAACGCCGAATTGCTCTAGCATTCGCCATTCAGGCTGCG
pTF101_LB_2	CAACTGTTGGGAAGGGCGATCGGTGCGGGCCTCTTCGCTATTACGCCAGCTGGCGAAAGGGGGATGTGCTGCAAGGCGATTAAGTTGGGTAACGCCAGGGTTTTCCCAGTCACGACGTTG
pTF101_LB_3	TAAAACGACGGCCAGTGCCAAGCTAATTCGCTTCAAGACGTGCTCAAATCACTATTTCCACACCCCTATATTTCTATTGCACTCCCTTTTAACTGTTTTTTATTACAAAAATGCCCTGGA
pTF101_RB_1	TCGCATGCCTGCGCCCGGGTACCGAGCTCGAATTCGTAATCATGTCATAGCTGTTTCCTGTGTGAAATTGTTATCCGCTCACAATTCCACACAACATACGAGCCGGAAGCATAAAGTGTA
pTF101_RB_2	AAGCCTGGGGTGCCTAATGAGTGAGCTAACTCACATTAATTGCGTTGCGCTCACTGCCCGCTTTCCAGTCGGGAAACCTGTCGTGCCAGCTGCATTAATGAATCGGCCAACGCGCGGGGA
pTF101_RB_3	GAGGCGGTTTGCGTATTGGAGCTTGAGCTTGGATCAGATTGTCGTTTCCCGCCTTCAGTTTAAACTATCAGTGTTTGACAGGATATATTGGCGGGTAAACCTAAGAGAAAAGAGCGTTTA



Probe	Position on the plasmid	
pTF10_LB_1	6427	6546
pTF10_LB_2	6547	6666
pTF10_LB_3	6667	6786
pTF10_RB_1	12866	12985
pTF10_RB_2	12986	13105
pTF10_RB_3	13106	13225

Fig. 1. Diagram of the *AfHxk1* host-induced gene silencing binary plasmid, showing the position of target enrichment probes on the left and right borders of the T-DNA.

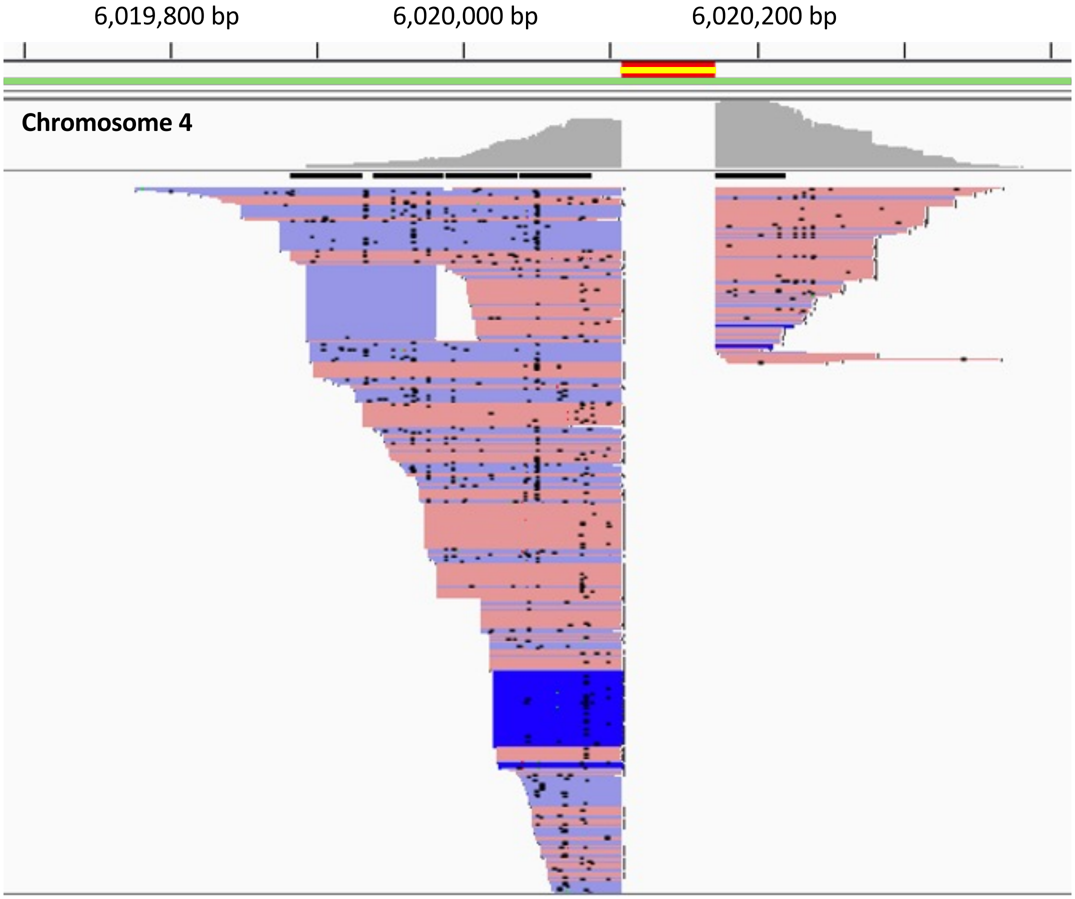


Fig. 2. Map of chimeric corn/transgene sequencing reads corresponding to potential transgene integration sites on chromosome 4 of the corn genome. Individual sequencing reads, depicted as blue or red lines, were aligned to the corn reference genome (green horizontal line). Dots in sequencing reads correspond to nucleotide polymorphisms differing from the consensus sequence. The yellow box indicates a putative deletion of 64 bp at the site of transgene insertion.

Fig. 3. Map of chimeric corn/transgene sequencing reads corresponding to potential transgene integration sites on chromosome 1 of the corn genome. Individual sequencing reads, depicted as blue or red lines, were aligned to the corn reference genome (green horizontal line). Dots in sequencing reads correspond to nucleotide polymorphisms differing from the consensus sequence, and vertical lines within sequencing reads indicated nucleotide consensus that differed from the reference genome sequence. The yellow box indicates a putative deletion of approximately 1000 bp at the site of transgene insertion.

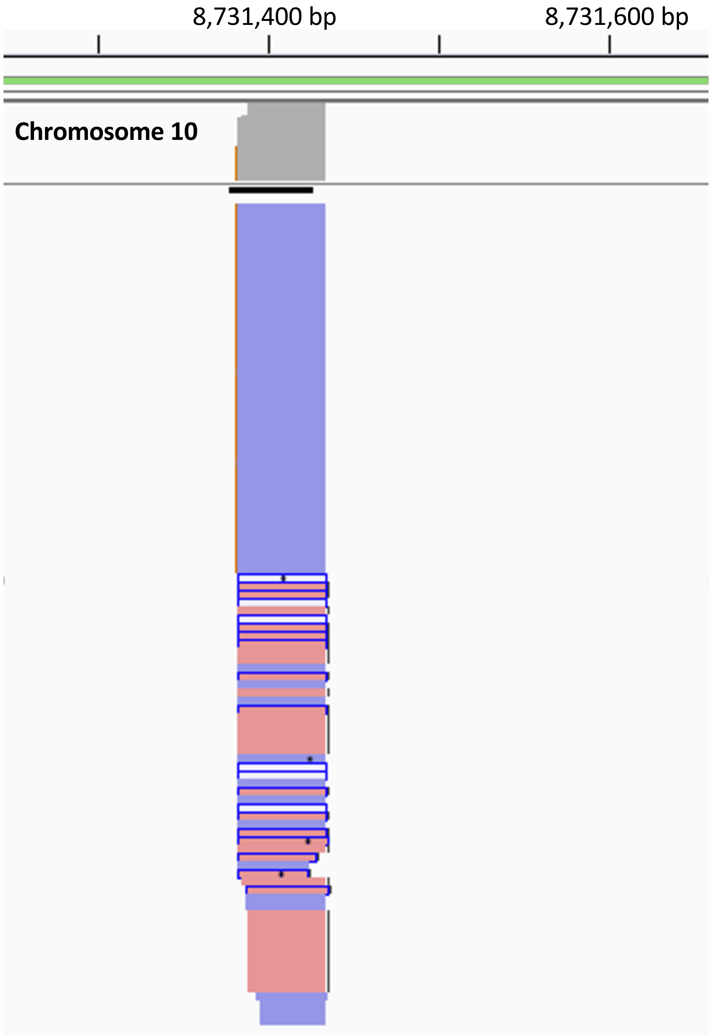


Fig. 4. Map of chimeric corn/transgene sequencing reads corresponding to potential transgene integration sites on chromosome 10 of the corn genome. Individual sequencing reads, depicted as blue or red lines, were aligned to the corn reference genome (green horizontal line). Dots in sequencing reads correspond to nucleotide polymorphisms differing from the consensus sequence. Reads corresponding to a single T-DNA border were detected at this locus.

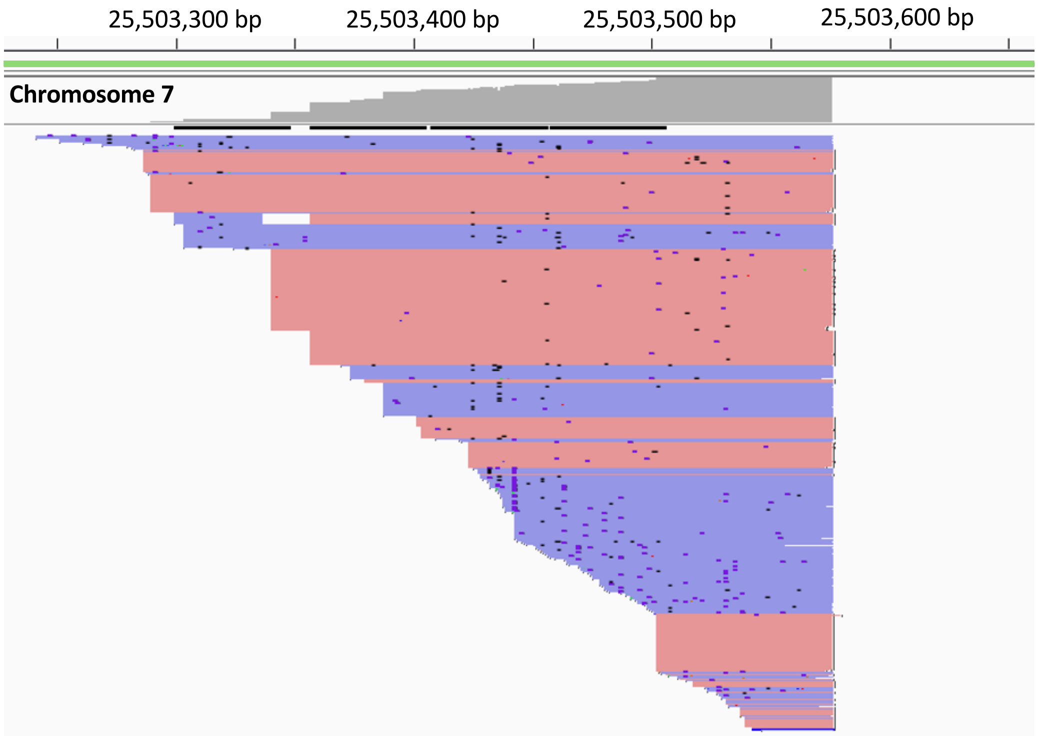


Fig. 5. Map of chimeric corn/transgene sequencing reads corresponding to potential transgene integration sites on chromosome 7 of the corn genome. Individual sequencing reads, depicted as blue or red lines, were aligned to the corn reference genome (green horizontal line). Dots in sequencing reads correspond to nucleotide polymorphisms differing from the consensus sequence. Reads corresponding to a single T-DNA border were detected at this locus.

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

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Abstract

The susceptibilities of the rice weevil, *Sitophilus oryzae*, and the sawtoothed grain beetle, *Oryzaephilus surinamensis*, to pirimiphos-methyl, deltamethrin, malathion, silicone dioxide, and (S)-methoprene were evaluated utilizing 55-gallon barrels of stored corn grain. Deltamethrin and (S)-methoprene provided complete protection to grain for 7 months. Silicon dioxide protected grain for 9 months. Pirimiphos-methyl and malathion-protected grain for 11 months. Bioassays were conducted in the laboratory to measure the mortality of the rice weevil, *S. oryzae*, to four insecticides. Insecticide toxicity was assessed using LC_{50} values, with mortality observed up to 10 days. For *S. oryzae*, pirimiphos-methyl exhibited the highest toxicity, followed by malathion, deltamethrin, and deltamethrin plus (S)-methoprene insecticides.

Introduction

Several insect pests are known to attack corn grain 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 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, sawtoothed 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 in 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 more commonly encountered stored grain pests in Arkansas.

Procedures

There were two separate components to this study. Part one evaluated the residual activity of labeled rates of insecticides, while part two measured insecticide toxicity. For the residual activity part of the study, the insecticides listed in Table 1 were applied to 55-gallon barrels of recently harvested field corn grain at the Northeast Research and Extension Center, Keiser, Arkansas, on 4 October 2022. 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 pest species were identified, and their numbers were recorded. A separate study was conducted in an environmental chamber in the laboratory. The same insecticides and rates from Table 1 were applied to corn grain in 48-ounce jars containing 500 grams of corn grain. Individual jars were infested with 10 rice weevils/jar. Each month, the number of weevils and damaged kernels was assessed and recorded. After counts were made, another 10 weevils were added to each jar. Jars were kept in the environmental chamber at a constant temperature of 77 °F. 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 System Division of Agriculture, Fayetteville, and consisted of a series of laboratory experiments. The first laboratory study aimed to evaluate the effectiveness of four insecticide formulations, pirimiphos- methyl, deltamethrin, deltamethrin plus (S)-methoprene, and malathion, against *Sitophilus oryzae* (rice weevil) infesting corn grains. The insects used in the study were reared in whole kernels of corn. Liquid insecticides were diluted with distilled water to achieve desired concentrations and applied to rice weevils using a Lab Spray Tower equipped with a spray nozzle. Distilled water served

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as the control for liquid treatments. Powdered insecticide was mixed with white corn flour to reach desired concentrations, with corn flour alone used as the control. Treatment concentrations were initially chosen based on recommended application rates and then adjusted based on pilot study results to determine the range of concentrations causing 5–95% mortality. Each insecticide's toxicity profile was assessed using at least five different concentrations, with three replications of 15 individuals per concentration. The mortality of *S. oryzae* adults was recorded every 24 hours after exposure until 96 hours. The mortality of *S. oryzae* was assessed in each treatment, with data recorded every 24 hours over a period of 10 days to identify any delayed mortality. Analysis of the datasets was conducted using POLO Plus 2.0 software. This statistical approach was employed to determine the 50% lethal concentration value (LC_{50}) and its corresponding 95% confidence interval, which is vital for assessing insecticide toxicity and refining pest control strategies.

Results and Discussion

Barrel Study

Samples collected throughout the winter months (November-March) did not yield any insect pests. No insect pests were detected until May 2023 (Tables 2 and 3, Figs. 1 and 2). Sawtoothed grain beetle and rice weevil were the predominant species detected throughout the study. Booklice (Psocids), a minor pest of stored grains, were also detected but at extremely low numbers and were not included in the analysis.

Sawtoothed grain beetle numbers were low until July, reaching a peak of 553.5 beetles/pint of grain in the untreated barrels in September and then began to drop off during the cooler months of Nov-Feb (Table 2). All insecticides significantly reduced sawtoothed grain beetle numbers on the September sampling date except for silicon dioxide. Overall, pirimiphos-methyl (Actellic), malathion, and the high rate of deltamethrin (Centynal) appeared to give the longest residual control, keeping sawtoothed grain beetles low for over a year after treatment. Rice weevil numbers peaked later in the barrel study, reaching 475.4 weevils/pint of grain in December 2023 (Table 3). Once again, pirimiphos-methyl (Actellic), malathion, and the high rate of deltamethrin (Centynal) kept weevil numbers low throughout the study. However, silicon dioxide also kept rice weevil numbers low. Results were similar for rice weevil in the lab study. However, weevils reached much higher densities due to being held under constant warm temperatures. Weevil density in the untreated jars reached 2316 weevils per 500-gram sample by 284 days after infestation (Table 4) and reached 100% damaged kernels by 188 days (Table 5). Both rates of pirimiphos-methyl kept weevil numbers and damage at zero up to 284 days after treatment. Malathion kept weevil numbers at zero up to 256 days after treatment yet maintained no damaged kernels at 284 days (Table 5). The high rate of deltamethrin kept weevil numbers under 10 per sample with 3.8% damaged kernels until 256 days. (S)-methoprene (Diacon IGR) had the shortest residual with weevils reaching high numbers by 69 days as well as 100% damaged kernels by 256 days. Throughout the course of the study, the pirimiphos-methyl and malathion treatments maintained the longest level of protection against both sawtoothed grain beetles and rice weevils.

In the laboratory studies, the toxicity profiles of the selected insecticides were determined as follows: pirimiphos-methyl demonstrated the highest toxicity, followed by malathion, deltamethrin, and deltamethrin plus (S)-methoprene, as evidenced by comparison of LC_{50} values and their 95% confidence limits. Pirimiphos-methyl exhibited approximately 15 times greater toxicity than the other three insecticides, with malathion and deltamethrin following closely behind. Deltamethrin plus (S)-methoprene showed the lowest toxicity among all tested insecticides (Table 6). Maximum mortality was observed 48 hours after exposure, and although monitoring continued for 10 days thereafter, no delayed mortality was observed in the test insects.

Practical Applications

These data indicate that all of the products tested provided some level of protection to stored corn grain against sawtoothed grain beetle and rice weevil. (S)-methoprene alone appeared to be the least effective, while pirimiphos-methylc and malathion gave the longest level of protection, keeping grain free of insect pests for up to one year after treatment. Pirimiphos-methyl or malathion appear to be the products of choice for growers wishing to store harvested corn for long periods of time. Under short-term storage (3–5 months), all of the products tested gave acceptable protection with the exception of (S)-methoprene alone, which appears to only give protection against these pests for up to 2 months. Overall, the laboratory enhances our understanding of the comparative toxicity and efficacy of pirimiphos-methyl, deltamethrin, deltamethrin plus (S)-methoprene, and malathion in managing *S. oryzae* populations. Variations in toxicity among these insecticides may arise from differences in mode of action and potential insect resistance development. Nonetheless, additional investigations are warranted to assess the long-term effectiveness of these insecticides and the potential emergence of resistance within local stored-grain insect pest populations.

Acknowledgments

The authors would like to acknowledge the Arkansas Corn and Grain Sorghum Board and the University of Arkansas System Division of Agriculture for providing support to conduct these studies.

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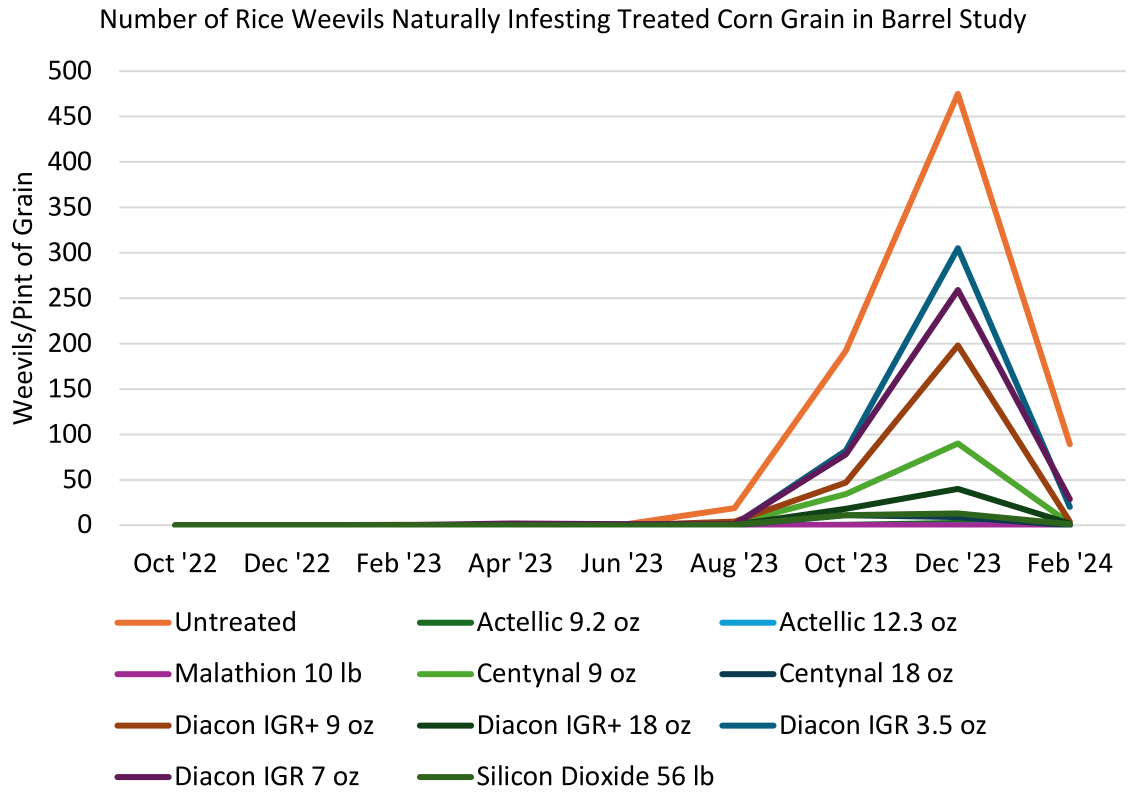

Fig. 1. Rice weevils per 1-pint grain sample from Oct. 2022 through Feb. 2024 after insecticide application on Sept. 2022 in 55-gallon barrels. Insecticide rates are expressed in amount per 1,000 bushels.

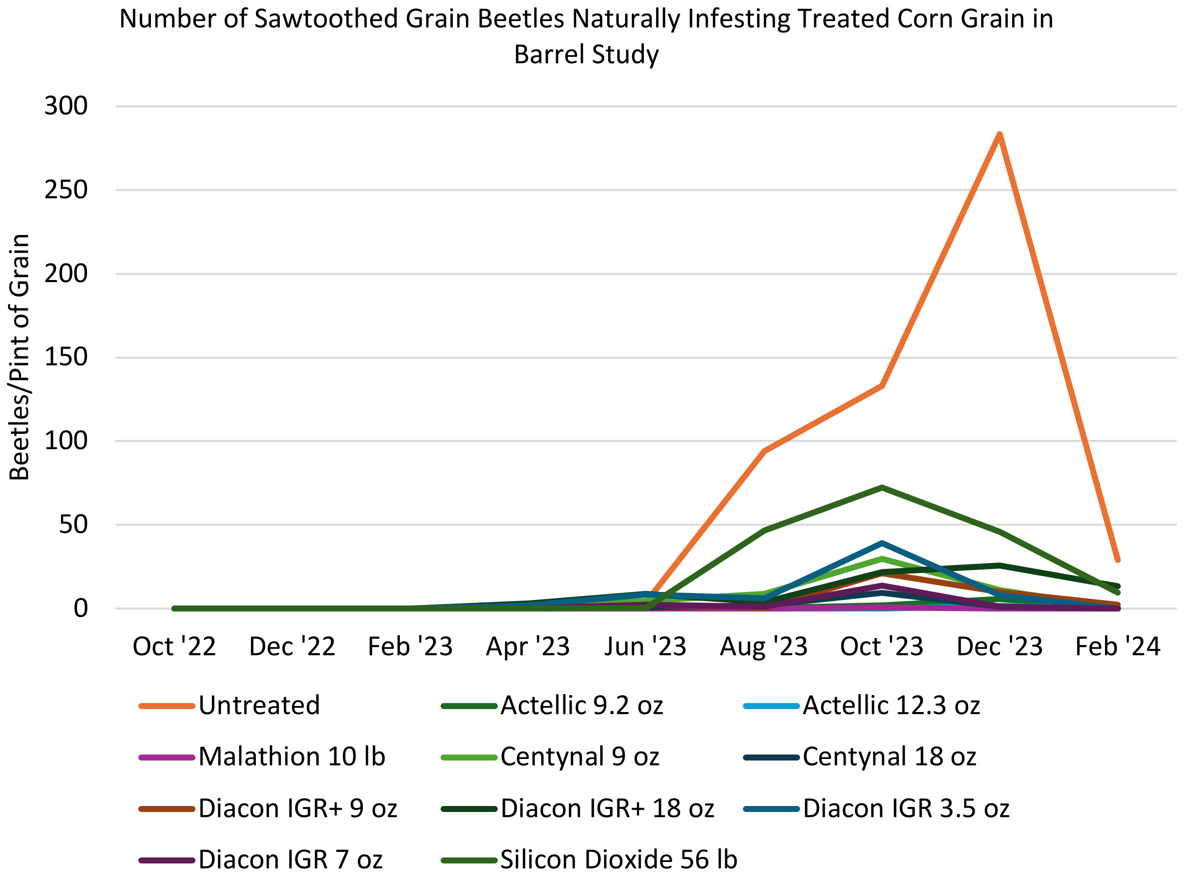

Fig. 2. Sawtoothed grain beetles per 1-pint grain sample from Oct. 2022 through Feb. 2024 after insecticide application on Sept. 2022 in 55-gallon barrels. Insecticide rates are expressed in amount per 1,000 bushels.

Table 1. Stored grain insecticide rates and method of application applied to field corn grain in 55-gallon barrels and 48-oz jars.

Insecticide	Rate	Method of Application
Actellic 5 E (pirimiphos-methyl)	9.2 oz/1,071 bu.	incorporated
Actellic 5 E (pirimiphos-methyl)	12.3 oz/1,071 bu.	incorporated
Centynal 0.42 SC (deltamethrin)	9 oz/1,000 bu.	incorporated
Centynal 0.42 SC (deltamethrin)	18 oz/1,000 bu.	incorporated
Malathion 6% Dust	10 lb/1,000 bu.	incorporated
Diacon IGR 2.5 EC (s-methoprene)	3.5 oz/1,000 bu.	incorporated
Diacon IGR 2.5 EC (s-methoprene)	7 oz/1,000 bu.	incorporated
Silicon Dioxide Dust	2 lb/1,000 bu.	incorporated
Diacon IGR Plus (s-methoprene + deltamethrin)	9 oz/1,000 bu.	incorporated
Diacon IGR Plus (s-methoprene + deltamethrin)	18 oz/1,000 bu.	incorporated
Untreated		

Table 2. Sawtoothed grain beetles per pint of grain sampled from field corn stored in 55-gallon barrels from May 2023 to Feb. 2024.

		Sawtoothed Grain Beetles per Pint of Grain									
Insecticide	Rate[†]	May 2023	June 2023	July 2023	Aug. 2023	Sept. 2023	Oct. 2023	Nov. 2023	Dec. 2023	Jan. 2024	Feb. 2024
Untreated		1.4 bcd[‡]	3.7 ab	26.8 a	87.8 a	553.5 a	131.2 a	138.0 a	283.8 a	72.2 a	29.0 a
Actellic 5E	9.2 oz	0.0 d	0.0 c	0.0 c	0.0 e	1.2 de	1.9 de	3.4 ef	5.7 def	1.0 cde	0.0 b
Actellic 5E	12.3 oz	0.0 d	0.0 c	0.0 c	0.0 e	0.7 de	0.0 e	0.5 fg	1.6 efg	2.2 cde	0.0 b
Centynal 0.42 SC	9 oz	4.4 abc	4.6 ab	6.7 ab	8.6 b	20.3 bc	29.7 abc	22.2 bcd	11.2 cd	0.0 e	0.0 b
Centynal 0.42 SC	18 oz	1.5 bcd	0.8 bc	2.8 bc	1.9 b-e	8.1 bcd	9.4 cd	9.7 de	1.2 fg	0.2 de	0.0 b
Malathion 6% Dust	10 lb	0.0 d	0.0 c	0.0 c	0.0 e	0.2 e	0.7 e	0.0 g	0.0 g	0.0 e	0.0 b
Diacon IGR 2.5 EC	3.5 oz	6.0 ab	2.4 abc	1.9 bc	0.4 de	3.7 cde	21.1 bc	38.5 bc	10.0 cd	5.6 bc	2.3 b
Diacon IGR 2.5 EC	7 oz	10.6 ab	8.9 a	10.6 ab	3.7 bcd	11.7 bc	21.6 bc	43.1 abc	25.7 bc	21.3 ab	13.3 b
Silicon Dioxide	2 lb	0.0 d	0.2 c	5.7 b	46.5 a	203.7 a	72.3 ab	75.2 ab	45.7 b	3.6 cd	9.7 b
Diacon IGR Plus	9 oz	12.9 a	8.3 a	5.9 b	6.2 bc	28.6 b	39.1 abc	37.3 bc	7.9 cde	0.0 e	0.0 b
Diacon IGR Plus	18 oz	4.2 a-d	2.3 abc	0.2 c	1.3 cde	7.9 bcd	13.7 bc	11.5 cde	1.1 fg	0.2 de	0.0 b

[†] Rates expressed as amount of product per 1,000 bushels. Actellic rates expressed as amount per 1,071 bushels.

[‡] Values within a column followed by the same number do not significantly differ at the *P* = 0.05 alpha level.

Table 3. Rice weevils per pint of grain sampled from field corn stored in 55-gallon barrels from May 2023 to Feb. 2024.

		Rice Weevils per Pint of Grain									
Insecticide	**Rate[†]**	**May 2023**	**June 2023**	**July 2023**	**Aug. 2023**	**Sept. 2023**	**Oct. 2023**	**Nov. 2023**	**Dec. 2023**	**Jan. 2024**	**Feb. 2024**
Untreated		0.5 b[‡]	0.4 abc	4.3 a	19.0 a	156.4 a	191.5 a	352.2 a	475.4 a	213.0 a	89.2 a
Actellic 5E	9.2 oz	0.0 b	0.0 c	0.0 a	0.0 c	0.0 c	0.3 c	3.0 de	2.5 ef	6.0 c	0.0 d
Actellic 5E	12.3 oz	0.0 b	0.0 c	0.0 a	0.0 c	0.0 c	0.0 c	0.0 e	0.2 f	1.3 c	0.0 d
Centynal 0.42 SC	9 oz	0.5 b	0.0 c	0.3 a	2.0 c	11.0 bc	34.3 ab	71.0 abc	90.0 abc	148.3 ab	1.9 cd
Centynal 0.42 SC	18 oz	0.3 b	0.1 bc	0.3 a	0.0 c	0.3 c	11.0 b	11.7 cd	8.7 de	3.0 c	0.0 d
Malathion 6% Dust	10 lb	0.0 b	0.0 c	0.3 a	0.0 c	0.0 c	0.3 c	0.0 e	0.0 f	0.3 c	0.0 d
Diacon IGR 2.5 EC	3.5 oz	0.0 b	1.1 a	0.0 a	0.5 c	9.8 bc	81.6 ab	248.5 ab	304.6 ab	220.7 a	19.9 abc
Diacon IGR 2.5 EC	7 oz	1.8 a	0.9 ab	9.0 a	1.3 c	77.0 b	78.9 ab	138.0 ab	259.2 ab	196.0 ab	29.4 ab
Silicon Dioxide	2 lb	0.0 b	0.1 bc	0.3 a	0.3 c	2.3 c	11.2 b	10.5 cd	13.1 cde	3.0 c	1.3 cd
Diacon IGR Plus	9 oz	0.3 b	0.1 bc	1.3 a	4.0 b	9.0 bc	46.9 ab	126.7 ab	197.7 ab	74.0 bc	4.2 bcd
Diacon IGR Plus	18 oz	0.0 b	0.0 c	0.3 a	0.3 c	2.0 c	18.0 b	33.5 bc	39.7 bcd	15.7 c	1.9 cd

[†] Rates expressed as amount of product per 1,000 bushels. Actellic rates expressed as amount per 1,071 bushels.

[‡] Values within a column followed by the same number do not significantly differ at the $P = 0.05$ alpha level.

Table 4. Rice weevil adults per 500-grams of corn sampled at 40 to 284 days after treatment (DAT) in the laboratory.

		Rice Weevil Adults per 500 grams of Grain								
Insecticide	**Rate[†]**	**40 DAT**	**69 DAT**	**104 DAT**	**130 DAT**	**160 DAT**	**188 DAT**	**221 DAT**	**256 DAT**	**284 DAT**
Untreated		9.0 a[‡]	85.9 a	173.5 a	377.3 a	928.8 a	462.5 b	833.6 ab	1603.1 a	2316.5 a
Actellic 5E	9.2 oz	0.0 f	0.0 d	0.0 e	0.0 e	0.0 d	0.0 c	0.0 e	0.0 e	0.0 b
Actellic 5E	12.3 oz	0.0 f	0.0 d	0.0 e	0.0 e	0.0 d	0.0 c	0.0 e	0.0 e	0.0 b
Centynal 0.42 SC	9 oz	3.2bc	8.2 cd	16.1 b	27.4 a	106.0 c	150.8 c	263.5 b	686.2 ab	1453.5 a
Centynal 0.42 SC	18 oz	0.1 ef	3.8 d	3.1 cd	3.2 d	6.3 d	8.0 c	7.8 d	26.9 d	43.0 b
Malathion 6% Dust	10 lb	0.0 f	0.0 d	0.0 e	0.0 e	0.0 d	0.0 c	0.0 e	0.7 e	0.3 b
Diacon IGR 2.5 EC	3.5 oz	9.2 a	95.5 a	208.4 a	496.4 a	1047.2 a	1612.5 a	1583.3 a	811.4 a	1375.8 a
Diacon IGR 2.5 EC	7 oz	6.2 ab	57.8 ab	130.7 a	355.5 a	545.8 b	455.0 b	1731.2 a	1169.4 a	2307.1 a
Silicon Dioxide	2 lb	1.6 cd	33.4 bc	21.7 b	81.3 b	89.9 c	173.0 bc	290.0 b	335.3 b	240.0 b
Diacon IGR Plus	9 oz	1.1 cd	7.6 cd	9.1 bc	14.0 c	42.5 cd	71.3 c	59.2 c	106.5 c	313.8 b
Diacon IGR Plus	18 oz	0.7 de	0.0 d	0.9 de	2.6 d	2.3 d	3.5 c	5.6 d	25.4 d	5.0 b

[†] Rates expressed as amount of product per 1,000 bushels. Actellic rates expressed as amount per 1,071 bushels.

[‡] Values within a column followed by the same number do not significantly differ at the $P = 0.05$ alpha level.

Table 5. Percent rice weevil damaged corn kernels at 40 to 284 days after treatment (DAT) in the laboratory.

		Percent Rice Weevil Damaged Corn Kernels								
Insecticide	**Rate[†]**	**40 DAT**	**69 DAT**	**104 DAT**	**130 DAT**	**160 DAT**	**188 DAT**	**221 DAT**	**256 DAT**	**284 DAT**
Untreated		0.0 a[‡]	11.5 a	8.7 a	28.1 a	46.7 a	100.0 a	100.0 a	100.0 a	100.0 a
Actellic 5E	9.2 oz	0.0 a	0.0 f	0.0 c	0.0 c	0.0 c	0.0 f	0.0 c	0.0 d	0.0 e
Actellic 5E	12.3 oz	0.0 a	0.0 f	0.0 c	0.0 c	0.0 c	0.0 f	0.0 c	0.0 d	0.0 e
Centynal 0.42 SC	9 oz	0.0 a	1.7 cde	0.8 bc	2.8 b	9.7 c	8.5 d	37.8 b	47.6 b	65.5 b
Centynal 0.42 SC	18 oz	0.0 a	0.3 def	0.3 c	0.1 bc	0.3 c	0.8 ef	1.0 c	3.8 cd	7.5 de
Malathion 6% Dust	10 lb	0.0 a	0.0 f	0.0 c	0.0 c	0.0 c	0.0 f	0.0 c	0.0 d	0.0 e
Diacon IGR 2.5 EC	3.5 oz	0.0 a	6.3 ab	12.4 a	20.6 a	38.7 a	81.3 b	95.8 a	100.0 a	100.0 a
Diacon IGR 2.5 EC	7 oz	0.0 a	7.6 a	7.3 a	17.8 a	26.3 b	66.0 c	98.8 a	100.0 a	100.0 a
Silicon Dioxide	2 lb	0.0 a	6.4 ab	1.9 b	1.4 bc	3.0 c	7.3 de	37.3 b	13.8 c	39.5 bc
Diacon IGR Plus	9 oz	0.0 a	0.0 f	0.0 c	0.3 bc	4.0 c	2.5 def	22.5 bc	10.8 c	31.5 cd
Diacon IGR Plus	18 oz	0.0 a	0.0 f	0.0 c	0.1 bc	0.0 c	0.0 f	0.8 c	1.9 d	1.0 e

[†] Rates expressed as amount of product per 1,000 bushels. Actellic rates expressed as amount per 1,071 bushels.

[‡] Values within a column followed by the same number do not significantly differ at the *P* = 0.05 alpha level.

Table 6. Toxicity response of *Sitophilus oryzae* to selected pesticides at 48h after treatment.

Active ingredient[†]	**N[‡]**	**Slope ± SE[§]**	**LC_{50} (ppm) (95% CL)**	**LC_{90} (ppm) (95% CL)**	**Recommended application rate (ppm)[#]**
Pirimiphos-methyl	225	3.608 ± 0.411	0.74 (0.57 – 0.92)	1.68 (1.31 – 2.56)	6 – 8
Malathion	225	1.842 ± 0.214	7.08 (5.44 – 9.01)	35.13 (25.00 – 57.58)	10
Deltamethrin	225	2.381± 0.283	9.11 (6.89 – 12.6)	31.45 (20.34 – 70.50)	0.5 – 1.0
Deltamethrin + (S)-methoprene	225	1.984 ± 0.262	13.94 (9.71 – 18.60)	61.69 (41.05 – 131.0)	0.5 – 1.0

[†] The products are listed based on toxicity profile, from high to low.

[‡] N is the number of individuals tested for each product. Response regression lines are presented by Slope ± SE, LC_{50} (in ppm), and LC_{90} (in ppm).

[§] Control mortality was 0% during the study period.

[#] Recommended application rates were obtained from the pesticide product labels (Balcom Chemicals Inc., 1975; Winfield Solutions LLC, 2015; Central Garden & Pet Company, 2016a, 2016b).

Cereal Rye Termination Timings Effect on Weed Control and Corn Yield

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

Abstract

A field experiment was conducted in Fayetteville, Arkansas, during the 2022–2023 period to investigate the effect of cereal rye termination timings on weed suppression and crop yield in an irrigated corn field. The experiment was arranged in a randomized complete block design with four replications. Cereal rye was drill-planted in the previous fall in October. The treatments were two cereal rye termination timings prior to corn planting, one concurrent with planting, and three post-planting, all approximately one week apart. The two-pass herbicide program consisted of one application of glyphosate, atrazine, and *S*-metolachlor at cereal rye termination or corn planting (in a conventional system) and an additional same herbicide mixture at the corn V4 stage. A no cover crop treatment (conventional system) was included. Cereal rye plots were weed-free at the time of termination. At the V4 corn stage, the system environment and the first herbicide pass provided 99% control of Palmer amaranth in both cover crop and conventional systems. Four weeks later, Palmer amaranth control was greater in cereal rye systems (94–97%) than in the conventional system (88%). Corn height 8 weeks after planting was similar across most cereal rye termination timings, except for a slight decrease when termination was 1 week before planting. Corn yield decreased by 13–29% when cereal rye termination coincided with or followed corn planting. The early cereal rye terminations provided corn yield comparable to that of the conventional system.

Introduction

Effective weed control is crucial for crop production, as inadequate management leads to escalating weed problems over time. While herbicides have been a principal method for controlling weeds in US agriculture, their extensive use has raised concerns about weed resistance. As a result, there has been increasing interest in integrating non-chemical strategies, including cover crops, into weed management programs (Norsworthy et al. 2012). Cover crops, apart from weed suppression, offer multiple benefits such as soil erosion protection and nutrient loss reduction (Blanco–Canqui et al., 2011; Johnson et al., 1993; Lal 2004; Lin, 2011; Poeplau et al., 2015; Runck et al., 2020; and Seifert et al., 2018). Among cover crops, there has been a spurred interest in using cover crops, with cereal rye being notably effective due to its allelopathic properties to suppress weeds (Hartwig and Ammon, 2002; Teasdale et al., 2007; Barnes and Putnam, 1983; Weston, 1996). Despite its many benefits, the integration of cereal rye into cropping systems has been approached with caution due to potential adverse effects on subsequent crops, such as a reduction in corn yield (Koehler–Cole et al., 2020). Such yield reductions are sometimes associated with conditions where soil moisture is limited. This research examines the effect of different cereal rye termination timings on weed suppression and crop yield in irrigated corn in Arkansas.

Procedures

A field experiment was carried out at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center in Fayetteville, Arkansas, during 2022–2023. The experiment was established in a randomized complete block design with four replications. Cereal rye at 60 lb/ac was drill–planted with 7.5-in. row spacing the previous fall in October across the whole trial area. The no cover crop treatment cereal rye was terminated 8 weeks before planting corn and was considered as the conventional system. A glyphosate- and glufosinate-resistant corn hybrid (DKC 62–69, DEKALB® brand, Bayer Crop Sciences) was planted on 26 April 1 in. deep at a seeding rate of 35,000 seeds/ac with a 30-in.-wide row spacing. Each plot consisted of four corn rows 30 ft in length. Treatments consisted of two cereal rye termination timings before corn planting, one at planting, and three after planting– all termination timings approximately 1 week apart. The cover crop at the time of corn planting was in the heading stage with approximately 85% to 90% ground cover. Cereal rye was terminated with glyphosate plus atrazine and *S*–metolachlor for residual weed control. Herbicide information (trade name, active ingredient, and rate application timings) is given in Table 1. An additional application of the same mixture of herbicide was applied at the V4 corn stage. Herbicide treatments were applied using a CO_2-pressurized backpack sprayer. The sprayer was calibrated to deliver 15 GPA at 40 PSI and was fitted with AIXR 110015 flat-fan nozzles. Irrigation was applied weekly when rainfall was less than 1 in. to prevent moisture stress during the growing season. Fertility management followed the University of Arkansas System Division of Agriculture's Cooperative Extension Service corn production recommendations. Weed control ratings, which were based on weed density and vigor, were performed by species at the time of cereal rye termination,

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at the V4 corn stage and 4 weeks after V4 corn. The ratings were based on a scale of 0% (no weed control) to 100% (complete weed death). Crop height was taken from 5 random plants per plot 4 wk after V4 corn. At crop maturity, the two center rows of corn were harvested using a small plot combine. The yield data was then converted to a percentage of the yield from the conventional system. The data was subjected to an analysis of variance. The means were then separated using Fisher's protected least significant difference test, with an alpha value of 0.05.

Results and Discussion

Cereal rye plots were weed-free at the time of termination (data not shown). At the V4 corn growth stage, the first pass of herbicide provided excellent control (99%) control of Palmer amaranth in both the cover crop and conventional corn systems (Table 2). Four weeks later, the control of Palmer amaranth was generally greater in the cereal rye systems (94% to 97% control) compared to the conventional system (88% control). For grasses, control was similarly high as with the early-season Palmer amaranth control across cereal rye and conventional systems both at V4 and 4 WAV4. Corn height across most cereal rye termination timings was similar to that of the conventional corn, except when the termination was 1 week before planting, which decreased the corn height by 11% compared to the height in the conventional system (Fig. 1). Corn yield was notably varied across cereal rye termination timings, with yields comparable to conventional corn in only preplant terminated cereal rye systems (Fig. 2). When the termination of the cereal rye coincided with or followed the corn planting, the yields decreased by 13% to 29%. The findings suggest that the yield impact of cereal rye in irrigated corn in Arkansas can be pronounced when terminated at corn planting or later, whereas the early termination timing can mitigate the potential negative impact. These results largely corroborate the previous findings from several other agroecological conditions (Acharya et al., 2017). In regard to weed control, the goal of integrating cereal rye into corn should not only be to improve the overall outcome of weed management but also to reduce the pressure of herbicide selection in weed populations.

Practical Applications

This study, which supports earlier research from comparable areas, including multi-site in-state studies, offers recommendations for the use of cereal rye as a cover crop in corn systems in Arkansas. The finding that the timely termination of cereal rye can produce corn yields comparable to conventional systems while also contributing to weed control and reducing herbicide selection encourages its integration into corn systems. This integration is becoming increasingly recognized as an important part of sustainable agricultural practices. Overall, this study sheds light on the effects of cereal rye on weed suppression and corn yield expectations in the region.

Acknowledgments

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Table 1. Herbicides in the two-pass herbicide program used in the conventional and cereal rye corn systems.

Herbicide	Trade name	Rate	Manufacturer	Application timing
		(lb ai/ac)		
Atrazine	Aatrex® 4L	1	Syngenta Crop Protection, LLC	CR TERM + V4
Glyphosate	Roundup® PowerMAX	1.4	Monsanto Company	CR TERM
S–metolachlor	Dull II Magnum®	1.24	Syngenta Crop Protection, LLC	CR TERM
Premix[†]	Halex®GT	1.1 + 0.1 + 1.1	Syngenta Crop Protection, LLC	V4

[†] glyphosate + mesotrione + *S*–metolachlor.

Abbreviations: CR TERM = cereal rye termination time; V4 = V4 corn growth stage.

Table 2. Palmer amaranth and grasses control at V4 and 4 WAV4 corn under conventional corn system and cereal rye environments with varying termination timings.

	Palmer amaranth		Grasses[†]	
	at V4	at 4 WAV4	at V4	at 4 WAV4
	---(%)--			
Conventional system	99 ns	88 b[‡]	99 ns	100 ns
CR systems terminated at:				
2 WBP	99	94 a	99	100
1 WBP	99	97 a	100	100
corn planting	99	93 ab	99	100
1 WAP	99	95 a	100	100
2 WAP	99	94 a	99	100
3 WAP	99	97 a	100	100

[†] Grasses include broadleaf signalgrass and large crabgrass.

[‡] Means with similar letters do not differ from each other at $LSD_{0.05}$.

Abbreviations: CR = cereal rye; V4 = V4 corn growth stage; WAP = weeks after corn planting; WBP = weeks before corn planting; WAV4 = weeks after V4 corn.

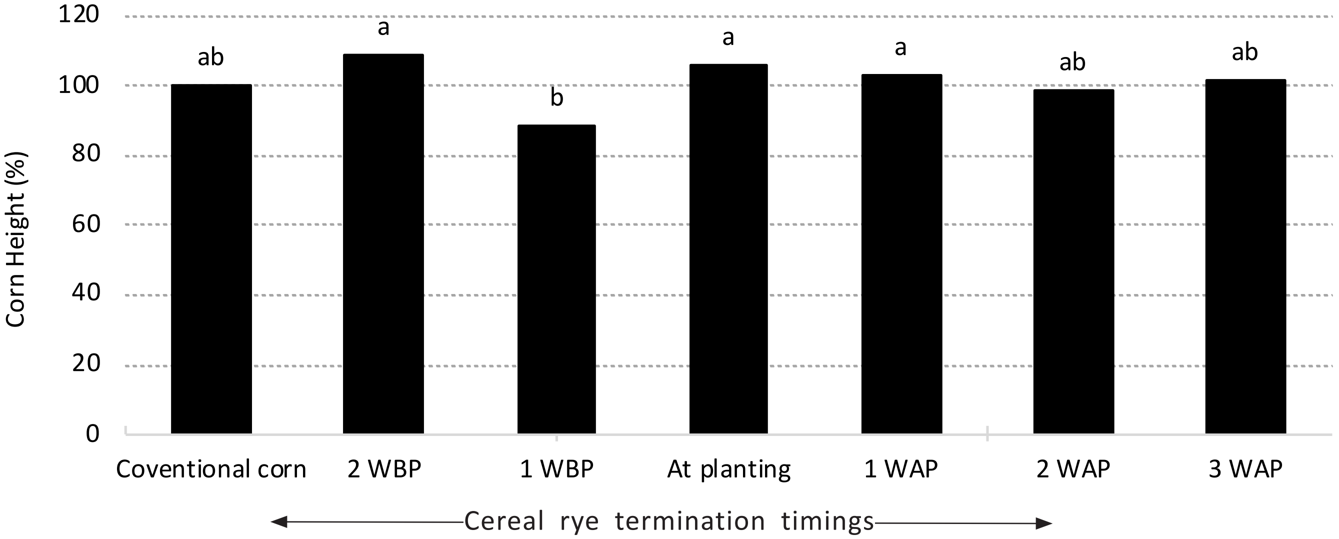

Fig. 1. Effect of cereal rye termination timings on corn height 8 WAP. Means with similar letters do not differ from each other at LSD$_{0.05}$. WAP = weeks after corn planting; WBP = weeks before corn planting.

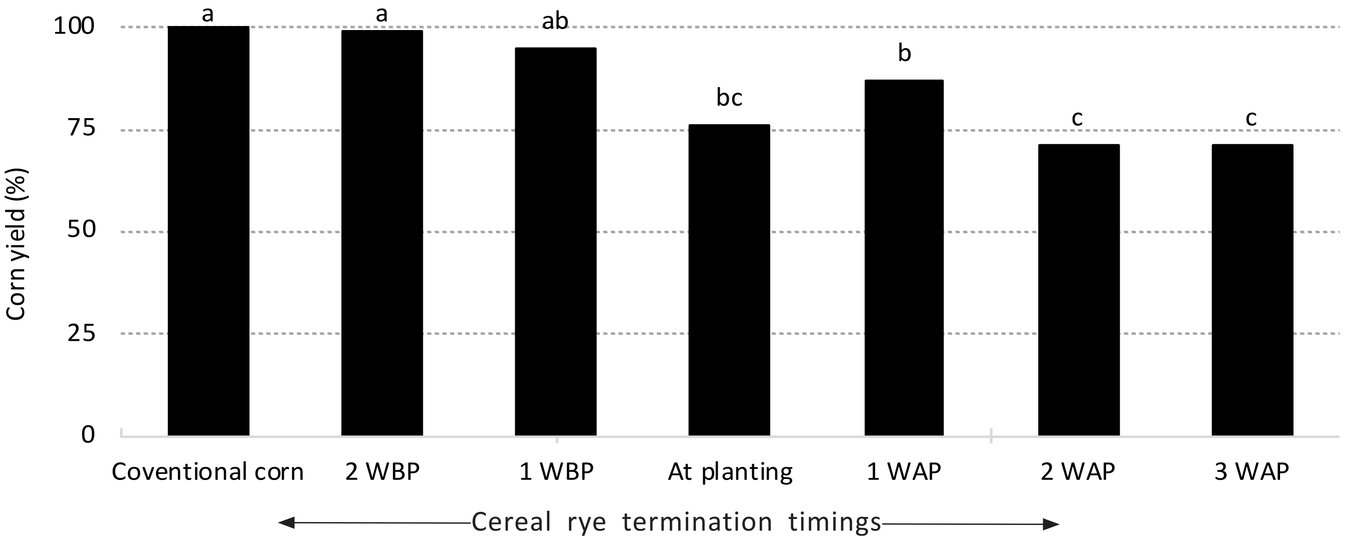

Fig. 2. Effect of cereal rye termination timings on corn yield. Means with similar letters do not differ from each other at LSD$_{0.05}$. WAP = weeks after corn planting; WBP = weeks before corn planting.

Off-Target Movement of Gramoxone® on Corn

Z.T. Hill,[1] L.T. Barber,[2] J.K. Norsworthy,[3] R.C. Doherty,[1] L.M. Collie,[2] and A. Ross[2]

Abstract

Research was conducted from 2021 to 2023 at Marianna, Ark., and Tillar, Ark., to evaluate off-target movement of sublethal rates of Gramoxone® (paraquat) applied alone or in mixture with residual herbicides. Herbicide treatments were applied to corn at the V4 to V5 growth stage and consisted of Gramoxone® applied alone at 0.32- and 3.2 fluid ounces/ac (fl. oz/ac) or mixed with Direx® (diuron) at 0.16- and 1.6 fl. oz/ac, Cotoran® (fluometuron) at 3.2 fl. oz/ac, Cotoran® at 3.2 fl. oz/ac plus Brake® (fluridone) at 1.6 fl. oz/ac, Boundary® (metribuzin plus *S*-metolachlor) at 3.2 fl. oz/ac, Broadaxe® (sulfentrazone plus *S*-metolachlor) at 2.4 fl. oz/ac plus Tricor® (metribuzin) at 0.8 fl. oz/ac. Upon initial evaluation at 3 days after the postemergence (DAPOST) application, all herbicide treatments injured the corn stand to greater than 50% phytotoxicity, except for Gramoxone® at 0.32 fl. oz/ac alone and tank-mixed with Direx® at 0.16 fl. oz/ac. By 7 DAPOST, a slight reduction in phytotoxicity was observed in most treatments, albeit Gramoxone® at 3.2 fl. oz/ac tank mixed with Direx® at 1.6 fl. oz/ac, Boundary® at 3.2 fl. oz/ac, and Broadaxe® at 2.4 fl. oz/ac plus Tricor® at 0.8 fl. oz/ac continued to exhibit greater than 50% phytotoxicity. At 21 DAPOST, observed phytotoxicity from all herbicide treatments had decreased to 30% or less, except for Gramoxone® at 3.2 fl. oz/ac plus Boundary® at 3.2 fl. oz/ac. Compared to the nontreated control, treatment exposure resulted in corn height reductions of 4% to 12%. Overall, corn yields were slightly reduced from most treatments, resulting in a 6 to 22 bu./ac reduction.

Introduction

Arkansas farmers harvested 830,000 acres of corn (*Zea mays* L.) in 2023, which was valued at $789,828,000 in revenue for corn producers in the state (NASS-USDA, 2024). Average planting dates for corn production in Arkansas typically range from mid-March to the end of April (Kelley and Capps, 2022). This production practice allows for corn plants to emerge and grow well by the time preplant or preemergence applications are being applied to crops planted later in the growing season. These applications typically consist of a residual herbicide (Direx®, Cotoran®, Boundary®, Brake®, and Broadaxe®) mixed with a broad-spectrum selective or contact herbicide (glyphosate, paraquat) to effectively control multiple herbicide-resistant Palmer amaranth (*Amaranthus palmeri* L.) that has emerged prior to the crop (Crow et al., 2015). For more effective control of these weeds, Gramoxone® alone or in tank-mixture are typically applied at greater volumes, pressures, and smaller droplet qualities, which allows for greater opportunities for off-target movement on earlier planted corn stands. The objective of this research is to evaluate the off-target movement of Gramoxone® applied alone or in a tank mixture with residual herbicides onto mid-season corn stands.

Procedures

A field experiment was conducted in 2021, 2022, and 2023 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Branch Research Station at Marianna, Ark., and at a producer's field at Tillar, Ark., to evaluate the injury caused by off-target movement of Gramoxone® to corn (*Zea mays* L.). Regardless of location and year, these experiments were set up in a randomized complete block design, with four replications, and in plot sizes of 12.7 feet wide by 30 feet long. In 2021 and 2022, Pioneer P1222YHR corn hybrid was planted between early April and mid-May with a seeding rate of 36,000 seed/ac. In 2023, Pioneer P1847VYHR corn hybrid was planted on 3 May 2023, at Marianna, Ark., and 4 May 2023, at Tillar, Ark., with a seeding rate of 36,000 seed/ac. A standard preemergence application of Acuron® (*S*-metolachlor plus atrazine plus mesotrione plus bicyclopyrone) was applied at 2.5 quarts/ac at planting. All treatments were compared to a nontreated control to determine the effect of each treatment. Herbicide treatments were applied at the V4 to V5 growth stage and included Gramoxone® at 0.32 fluid ounces per acre (fl. oz/ac) and 3.2 fl. oz/ac applied alone and tank-mixed with Direx® at 0.16- and 1.6 fl. oz/ac, Cotoran® at 3.2 fl. oz/ac, Cotoran® t 3.2 fl. oz/ac plus Brake® at 1.6 fl. oz/ac, Boundary® at 3.2 fl. oz/ac, Broadaxe® at 2.4 fl. oz/ac plus Tricor® at 0.8 fl. oz/ac. These rates were set to represent 1/10 of a standard rate except for Gramoxone® and Direx®, where a 1/100 rate of each was evaluated. Additionally, all herbicide treatments were tank-mixed with a non-ionic surfactant at 0.25 % V/V ratio. Herbicides were applied with a compressed air-pressurized Bowman MudMaster-mounted sprayer calibrated to deliver 15 gallons/acre using Teejet® AIXR 11002 nozzles traveling 3.5 mph. Total plant health was evaluated through general visual

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phytotoxicity injury ratings taken at 3-, 7-, and 21 days after the postemergence application (DAPOST). Crop heights were taken 14 days after the postemergence application, and crop yields were taken at maturity. All data were subjected to an analysis of variance, and means were subjected to a student's *t*-test using JMP 17 statistical software with a *P*-value of 0.05.

Results and Discussions

Upon initial evaluation at 3 DAPOST, visual general phytotoxicity varied between 26% and 59% across all herbicide treatments (Table 1). Regardless of being applied alone or in a tank mixture, herbicide treatments with Gramoxone® at 3.2 fl. oz/ac exhibited greater than 50% phytotoxicity. Gramoxone® treatments at 0.32 fl. oz/ac alone and in tank-mixture with Direx® at 0.16 fl. oz/ac provided 28% and 26% phytotoxicity, respectively (Table 1). By 7 DAPOST, a reduction in phytotoxicity was observed from most herbicide treatments (Table 1). Levels of phytotoxicity from Gramoxone® applied alone at 3.2 fl. oz/ac, Gramoxone® plus Cotoran®, and Gramoxone® plus Cotoran® plus Brake® had decreased to 45%, 43%, and 47%, respectively. Treatments containing Gramoxone® at 3.2 fl. oz/ac tank mixed with Direx® at 1.6 fl. oz/ac, Boundary® at 3.2 fl. oz/ac, and Broadaxe® at 2.4 fl. oz/ac plus Tricor® at 0.8 fl. oz/ac continued to exhibit greater than 50% phytotoxicity (Table 1). All herbicide treatments had decreased to less than or equal to 30% phytotoxicity at 21 DAPOST, except for Gramoxone® at 3.2 fl. oz/ac plus Boundary® at 3.2 fl. oz/ac with 35% injury (Table 1). At 14 DAPOST, a reduction in plant heights was observed from all herbicide treatments, except for Gramoxone® at 0.32 fl. oz/ac (Table 2). Gramoxone® at 3.2 fl. oz/ac plus Direx® at 1.6 fl. oz/ac, Gramoxone® at 3.2 fl. oz/ac plus Cotoran® at 3.2 fl. oz/ac plus Brake®, Gramoxone® at 3.2 fl. oz/ac plus Boundary® at 3.2 fl. oz/ac, and Gramoxone® at 3.2 fl. oz/ac plus Broadaxe® at 2.4 fl. oz/ac plus Tricor® at 0.8 fl. oz/ac exhibited the greatest stunting with 12.2, 12.9, 12.2, and 12.5 in., respectively, compared to the nontreated check of 16.9 in. Overall, moderate reductions in grain yield were observed from multiple herbicide treatments, most of which contain Gramoxone® at 3.2 fl. oz/ac tank mixed with one or more residual herbicides. When compared to the nontreated check of 146 bu./ac, no significant reduction in yield was observed from Gramoxone® applied alone at 3.2 fl. oz/ac and 0.32 fl. oz/ac and Gramoxone® at 0.32 fl. oz/ac plus Direx® at 0.16 fl. oz/ac, with 140, 144, and 145 bu./ac, respectively. However, yield reductions were observed with any treatment containing Gramoxone® plus residual at the 3.2 fl. oz/ac rate.

Practical Applications

These findings suggest that off-target movement of Gramoxone® applied alone or tank mixed with residual herbicides can cause significant phytotoxicity to mid-season stage corn. The injury observed in this study shows that phytotoxicity and plant heights from Gramoxone®-related off-target movement can be severe initially, albeit the injury observed dissipates over time. The off-target movement of Gramoxone® applied alone did not affect corn yields; however, when Gramoxone® was tank-mixed with residual herbicides, significant yield reductions were evident. This is likely due to the tank-mix partners used with Gramoxone® in this study not being labeled for use in corn.

Acknowledgments

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Table 1. Phytotoxicity levels evaluated at 3, 7, and 21 days after the postemergence application (DAPOST) at Marianna, Ark., and Tillar, Ark., in 2021, 2022, and 2023.

Treatments[a]	Rate(s)	Application Timing	Evaluation Timings 3 DAPOST[b]	7 DAPOST	21 DAPOST
	(fl. oz/ac)		------------------------%	---------------------------	
Nontreated Control			0	0	0
Gramoxone®	3.2	V4-V5	52	45	26
Gramoxone®	0.32	V4-V5	28	30	30
Gramoxone® + Direx®	3.2 + 1.6	V4-V5	54	56	27
Gramoxone® + Direx®	0.32 + 0.16	V4-V5	26	31	27
Gramoxone® + Cotoran®	3.2 + 3.2	V4-V5	53	43	18
Gramoxone® + Cotoran® + Brake®	3.2 + 3.2 + 1.6	V4-V5	52	47	23
Gramoxone® + Boundary®	3.2 + 3.2	V4-V5	59	54	35
Gramoxone® + Broadaxe® + Tricor®	3.2 + 2.4 + 0.8	V4-V5	52	50	22
LSD (*P* = 0.05)			8	9	3

[a] All herbicide treatments had a preemergence application of Acuron® at 2.5 qt/ac.

[b] All postemergence applications were tank-mixed with a 0.25% v/v ratio of non-ionic surfactant.

Table 2. Plant height observed at 14 days after the postemergence application (DAPOST) and crop yields at Marianna, Ark., and Tillar, Ark., in 2021, 2022, and 2023.

Treatments[a]	Rate(s)	Application Timing[b]	Evaluation Timings	
			Plant Heights	Corn Yields
	(fl. oz/ac)		(in.)	(bu./ac)
Nontreated Control			16.9	146
Gramoxone®	3.2	V4-V5	13.7	140
Gramoxone®	0.32	V4-V5	17.3	144
Gramoxone® + Direx®	3.2 + 1.6	V4-V5	12.2	131
Gramoxone® + Direx®	0.32 + 0.16	V4-V5	15.3	145
Gramoxone® + Cotoran®	3.2 + 3.2	V4-V5	13.3	133
Gramoxone® + Cotoran® + Brake®	3.2 + 3.2 + 1.6	V4-V5	12.9	133
Gramoxone® + Boundary®	3.2 + 3.2	V4-V5	12.2	124
Gramoxone® + Broadaxe® + Tricor®	3.2 + 2.4 + 0.8	V4-V5	12.5	134
LSD (*P* = 0.05)			1	8

[a] All herbicide treatments had a preemergence application of Acuron® at 2.5 qt/ac.

[b] All postemergence applications were tank-mixed with a 0.25% v/v ratio of non-ionic surfactant.

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

C.G. Henry,[1] and R. Parker[1]

Abstract

The University of Arkansas System Division of Agriculture Irrigation Contest was conducted between 2018 and 2023. The contest was designed to promote better use of irrigation water and record data on water use and water use efficiency for various crops. Unlike yield contests, where winners are decided by yield alone, the irrigation contest results are decided by the highest calculated total water use efficiency (WUE) achieved by a producer. The contest consists of 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 using 6-, 8-, 10, or 12-in. portable mechanical flow meters. Rainfall totals were calculated using Farmlogs^{TM}. The contest average WUE for corn from 2018 to 2023 was 8.88 bu./in. The winning WUE was 14.09 bu./in. for 2023, 7.47 bu./in. for 2022, 12.53 bu./in. for 2021, 11.59 bu./in. for 2020, and 11.36 bu./in. for 2019, and 10.55 bu./in. for 2018. The adoption of irrigation water management practices such as computerized hole selection, surge irrigation, and soil moisture sensors is increasing. Corn contest participants report using, on average, 9.6 ac-in./ac of irrigation water over the six years.

Introduction

According to data from 2015 reported by USGS, Arkansas ranks 3rd in the United States for irrigation water use and 2nd for groundwater use (Dieter et al., 2018). For comparison, Arkansas ranked 18th in 2017 in total crop production value (USDA-NASS, 2017). Of the groundwater used for irrigation, 96% comes from the Mississippi River Alluvial Aquifer (Kresse et al., 2014). A study of the aquifer data in 2023 found that many of the wells in the Mississippi Alluvial Aquifer that were tested are still showing signs of long-term decline, and some wells are showing a 5–10-year trend of rebound (Arkansas Department of Agriculture Natural Resource Division, 2023).

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 the other 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 increased water use efficiency (WUE) by 36%. A 40% reduction in water use was observed for the corn fields, and WUE went up by 51%. For soybean, when the cost of the new IWM tools was incorporated, no significant difference in net returns was found, but in corn, net returns were improved by adopting IWM.

The University of Arkansas System Division of Agriculture Irrigation Contest was 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 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 minimum corn yield of 200 bu./ac must be achieved to place in the contest.

A portable propeller-style mechanical flowmeter was used to record water use. All flow meters were checked for proper installation and sealed using polypipe tape and serialized tamper-proof cables. Rainfall was recorded using Farmlogs^{TM}, an online software that provides rainfall data for a given location. Rainfall amounts were totaled from the emergence date to the physiological maturity date. Emergence was assumed to be 7 days after the planting date provided on the entry form. For physiological maturity, the seed companies published days to maturity were used. Rainfall was adjusted for extreme events.

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

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The equation used for calculating WUE for the contest was:

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

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. Statistical analysis was performed using Microsoft Excel and JMP 15 (SAS Institute, Inc., Cary, N.C.).

Results and Discussion

Detailed results are published each year on the contest website (www.uaex.uada.edu/irrigation). Over the six years that the competition has been conducted, there have been 58 fields entered for corn. The average WUE over the 6 years was 8.88 bu./in. By year, the average WUE was 9.94 bu./in. for 2023 with 12 contestants; 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 2023, participation was the second highest to date due primarily to conditions that provided more time for last-minute consideration for contest entry. Total average water use was tied with 2021 for the lowest amount of irrigation water applied plus adjusted rainfall of the six years of the contest, and average yield was the third highest to date for the contest. The winning WUE in 2023 was the highest to date during the six years of the contest. The winning WUE for each year was 14.09 bu./in. for 2023, 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 appears to be a high correlation between the overall contest success and the owner management of irrigation timing versus an employee with no direct incentive to promote irrigation efficiency. Additionally, previous contest winners tend to do well in the contest with other eligible crops. For example, 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 and first in soybeans in 2023. The rice winner from 2020 won the soybean division in 2022.

In 2015, a survey was conducted across the mid-South to determine the adoption rate of various irrigation water management tools (Henry, 2020). 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 and the average use in the mid-South and Arkansas. In the 2015 survey, 40% reported using computerized hole selection, and 66% of the Arkansas growers reported using computerized hole selection. Twenty-four percent of respondents said they used soil moisture sensors on their farms in the region, and only 9% of Arkansas irrigators reported using soil moisture sensors.

Contestants for all crop categories 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% across all 6 years, with 73% in 2018, 43% in 2019, 100% in 2020, 98% in 2021, 79% in 2022, and 100% in 2023. On average, 64% of respondents from all 6 years said they used soil moisture sensors on their farm, with 50% in 2018, 40% in 2019, 42% in 2020, 87% in 2021, 81% in 2022, and 86% in 2023. Surge valves were the least used IWM tool, with a 6-year average use rate of 25%. Those who reported using surge irrigation over the 6 years of the contest were 44% in 2018, 28% in 2019, 25% in 2020, 35% in 2021, 12% in 2022, and 7% in 2023 (Table 2).

Practical Applications

Irrigation WUE 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 Contest provides direct feedback to irrigators about their irrigation performance in maintaining high yields and low irrigation water usage. Direct feedback from Arkansas corn farmers will likely provide many with a competitive advantage when water resources become more limited. 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 six years averaged 9.6 ac-in./ac of irrigation water applied and a total water use of 25.9 inches. The winning WUE of the contest winners improved over the first four years. However, the reduced yield in the contest and other fields due to unfavorable weather during the growing season contributed to a lower WUE in 2022. In 2023, the winning water use efficiency was the highest to date.

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Table 1. Maximum, average, and minimum for 2018–2023 of various water and yield data points for corn from the Arkansas Irrigation Contest.

Year		Water Use Efficiency	Yield	Adjusted Rainfall	Irrigation Water	Total Water (Rain + Irr)
		(bu./in.)	(bu./ac)	(in.)	(ac-in./ac)	(in.)
2023	Maximum	14.09	272	19.6	18.4	29.7
	Average	9.94	225	13.9	9.4	23.4
	Minimum	7.45	165	10.8	3.2	15.5
2022	Maximum	7.47	212	18.0	18.8	35.2
	Average	7.19	197	14.1	14.0	28.1
	Minimum	5.75	183	9.7	8.2	20.9
2021	Maximum	12.53	279	17.3	9.8	25.7
	Average	10.53	243	15.3	7.9	23.3
	Minimum	9.16	216	13.5	5.6	20.6
2020	Maximum	11.59	253	21.4	19.3	33.5
	Average	8.07	211	16.2	10.4	26.6
	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
6-year	Average	8.88	221	16.2	9.6	25.9

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

Year	Computerized Hole Selection	Furrow Irrigated Rice	Multiple Inlet Rice Irrigation	Moisture Sensors	Surge Valve
	-----	-----	(%)	-----	-----
2023	100	33	20	85	7
2022	79	64	25	81	12
2021	98	80	100	87	35
2020	100	73	27	42	25
2019	43	50	17	40	28
2018	73	56	33	50	44
6-year Avg.	82	59	37	64	25

Corn Response to Zinc Sources

T.D. McLain,[1] T.L. Roberts,[1] G.L. Drescher,[1] J.P. Kelley,[1] D.A. Smith,[1] and K.A. Hoegenauer[1]

Abstract

Zinc (Zn) is the most common micronutrient deficiency in corn (*Zea mays* L.) production. New Zn fertilizers have been promoted for corn, but there is limited research confirming their effectiveness. Research was developed in Arkansas on a calcareous Calhoun silt loam to compare Zn fertilizer sources to the current recommendation of applying 10 lb Zn/ac as granular zinc sulfate ($ZnSO_4$) pre-plant incorporated. The following fertilizer-Zn treatments were evaluated: i) non-treated control, ii) granular $ZnSO_4$ applied at 3.0 lb Zn/ac, iii) granular $ZnSO_4$ applied at 10 lb Zn/ac, iv) Zn-EDTA applied at 1.0 lb Zn/ac, v) F-420G applied at 10 lb Zn/ac, vi) F-420G Exp. applied at 10 lb Zn/ac, vii) MicroEssentials (MESZ) applied at 1.0 lb Zn/ac, viii) MESZ applied at 1.0 lb Zn/ac in combination with $ZnSO_4$ applied at 2.0 lb Zn/ac, ix) muriate of potash (MOP) applied at 90 lb K_2O/ac coated with Wolf Trax Zn DDP at 1.1 lb Zn/ac, and x) MOP applied at 90 lb K_2O/ac coated with Yaravita Procote Zn at 1.1 lb Zn/ac. All Zn treatments were applied preplant and incorporated, except for Zn-EDTA, applied as a foliar spray at V2. Tissue-Zn concentration and grain yield were evaluated. Corn tissue-Zn concentration was affected by Zn fertilization at V6, with the foliar-applied Zn-EDTA showing higher Zn concentration than all other treatments. Other fertilizer-Zn treatments exhibited similar tissue-Zn concentrations as the non-treated control at V10, V12, and VT. Fertilizer-Zn treatments had no significant effect on grain yield, but macronutrient coatings and untreated plots had numerically lower yields than other treatments. Preliminary results suggest granular sources should be applied to supply the crop with adequate Zn and build soil-test Zn levels. Foliar-applied Zn-EDTA will correct Zn-deficient corn but will have limited to no effect on building soil-test Zn compared to granular $ZnSO_4$ applied at recommended rates.

Introduction

Zinc (Zn) is one of the 18 plant essential elements and one of the 8 trace elements considered essential to plant nutrition. Zinc is a micronutrient and, according to (Alloway, 2008), among all metals, is needed by the largest number of proteins. In plants, Zn acts as a functional, structural, or regulatory co-factor in all six classes of enzymes; therefore, Zn deficiency can bring about physiological stress in plants due to the dysfunction of these enzymes. Zinc is the most common micronutrient found deficient in agricultural soils worldwide due to high pH, agronomic practices, soil texture, high levels of phosphorus (P), and low soil levels of Zn. A study carried out by the Food and Agricultural Organization of the United Nations (FAO) from 1974–1982 found that 10 out of 29 countries (34.5% of surveyed) had soils and crops of particularly low Zn status (Alloway, 2008). It is reported that the most Zn-deficient soils tend to be calcareous soils with a high pH and a semi-arid climate. A follow-up project conducted by Sillanpää (1990) reported that Zn deficiency was the most ubiquitous micronutrient problem of all in this group of countries.

Rice (*Oryza Sativa* L.), wheat (*Triticum aestivum* L.), and maize (*Zea mays* L.) are the world's three most important cereal crops both in terms of area harvested and in tonnages of grain produced (Alloway, 2008). Major food staples, including rice, maize, and sorghum (*Sorghum bicolor* (L.) Moench), are all highly susceptible to Zn deficiency, especially where the available Zn status of soils is very low (Alloway, 2009). In corn, the tissue-Zn concentration necessary to obtain 90% of the maximum grain yield is 16 ppm in whole 3-to-6-week-old plants and 14 ppm in the ear leaf at tassel. Zinc concentration explained a significant 21% of the variability in the grain yields. Ear leaf Zn concentration at tassel explained only 11% of the variability (Carsky and Reid, 1990). Although Carsky and Reid (1990) found significant yield differences within their study, a study by Alloway (2009) found that Zn concentrations in cereal grains may be relatively low (<20 ppm) without yields being affected by Zn deficiency.

Arkansas corn production has generally increased over recent years, and Arkansas farmers have an advantage in that most of the acres are irrigated. The current production practices of irrigating with calcareous groundwater increase the soil pH to levels that restrict Zn availability (>6.0 pH). The primary objective of this study is to compare new Zn management strategies to the standard practice of applying 10 lb Zn/ac as granular zinc sulfate ($ZnSO_4$) preplant incorporated. Comparisons of the treatments focus on the effects on tissue-Zn concentration and corn grain yields.

Procedures

A Zn fertilization trial was established at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark., during the 2023 cropping season. Preplant soil samples were taken and analyzed at the Agricultural Diagnostic Laboratory (Fayetteville, Ark.) for soil pH and routine soil analysis. The recommended rates of nitrogen (N), potassium (K), and phosphorous (P) as well as

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all Zn treatments, other than the foliar applied Zn-EDTA, were applied pre-plant and incorporated before pulling raised beds. The following Zn treatments were implemented to achieve the objective: i) non-treated control, ii) granular $ZnSO_4$ applied at 3.0 lb Zn/ac, iii) granular $ZnSO_4$ applied at 10 lb Zn/ac, iv) Zn-EDTA applied at 1.0 lb Zn/ac, v) F-420G applied at 10 lb Zn/ac, vi) F-420G Exp. applied at 10 lb Zn/ac, vii) MicroEssentials (MESZ) applied at 1.0 lb Zn/ac, viii) MESZ applied at 1.0 lb Zn/ac in combination with $ZnSO_4$ applied at 2.0 lb Zn/ac, ix) muriate of potash (MOP) applied at 90 lb K_2O/ac coated with Wolf Trax Zn DDP at 1.1 lb Zn/ac, and x) MOP applied at 90 lb K_2O/ac coated with Yaravita Procote Zn at 1.1 lb Zn/ac. The foliar applied Zn-EDTA was applied on 24 May 2023, when the corn reached the V2 growth stage. Corn was planted on raised beds spaced 30 in. apart on 4 May 2023 with the corn hybrid P1718VYHR (Corteva, Indianapolis, Ind.) at approximately 36,000 seeds/ac. Plot dimensions for this trial were four rows wide (10 ft.) by 30 ft. long. Irrigation and pest control practices followed guidelines provided by the Cooperative Extension Service (CES) of the University of Arkansas System Division of Agriculture for high-yielding irrigated corn production. Furrow irrigation timing was managed using the Arkansas irrigation scheduler with a 1.5-in. deficit approach as needed.

All plant samples were taken from the middle two rows of each plot. At the V6 growth stage, whole plant samples were collected from one of the middle rows by laying a 3-foot-long rod down beside the plants and cutting the plants at the soil surface between the ends of the rod. At the V10 and V12 growth stages, 5 of the uppermost collared leaves were collected, and at the VT growth stage, 5 uppermost ear leaves were gathered. Samples were oven-dried at 158 °F 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 with a plot combine and adjusted to 15.5% moisture to determine grain yield.

The experiment was arranged in a randomized complete block design with four replications. The corn grain yield and tissue-Zn concentration were analyzed using a simple one-way analysis of variance to compare the Zn fertilizer treatments, and an alpha level of 0.05 was used to separate means. Statistics were conducted in RStudio 4.3.2.

Results and Discussions

The soil pH of this experiment ranged from 7.6 to 7.7 across replications, and the soil-test Zn concentration (1.6 ppm Zn) of the soil is characterized as low, meaning a yield increase is expected due to fertilization. The yield results of this trial are confounded by severe feral hog damage that occurred when corn reached the R5 growth stage. Several of the plots within the trial had to be excluded from the data due to the damage, which may have impacted the overall yield results presented here. There was a significant difference in corn grain yield across the treatments implemented in this study ($P = 0.01655$, Table 1). Corn grain yield was highest (213 bu./ac) when treatment six was implemented but was not significantly different than all other treatments except treatment nine (190 bu./ac). Although not statistically significant (most likely due to feral hog damage), most treatments that received Zn fertilization resulted in a 5–19 bu./ac increase in corn grain yield. Overall, the highest-yielding treatments tended to be fertilization practices and sources that supplied 10 lb Zn/ac preplant incorporated. Though not statistically different, our non-treated control and the macronutrient coatings were numerically the lowest yielding, with one treatment (9) yielding lower than the non-treated control. The treatments that were applied at the recommended rate of 10 lb Zn/ac were numerically our three highest overall corn grain yields, resulting in 14 to 19 bu./ac more than the non-treated control, as displayed in Table 1.

Corn tissue-Zn concentration was measured in the whole plant at V6, the uppermost collared leaf at V10 and V12, and within the ear leaf at VT. The only tissue-Zn concentration that differed significantly from others was the foliar applied Zn-EDTA at the V6 growth stage, as seen in Table 2, likely due to the absorption of the Zn directly into the tissue and the lack of soil Zn uptake by the corn plants at this growth stage in the other soil applied treatments. The V6 foliar-applied treatment 4 exhibited three times the tissue-Zn concentration of the next closest treatment, exhibiting 60.6 ppm and 21.6 ppm, respectively. After the V6 growth stage, all treatments exhibited similar tissue-Zn concentration, likely due to the increased root area to explore more soil and increased uptake of soil-applied Zn. Treatment 9 was numerically amongst the top three tissue-Zn concentrations except for the V12 growth stage. However, treatment 9 was the lowest-yielding treatment. All tissue-Zn concentrations were at or near the sufficiency range from the Southern Series Cooperative Bulletin for their respective growth stage, suggesting that more work is needed to clearly define the sufficiency range for tissue-Zn concentrations across corn growth stages.

Practical Applications

Based on the data from one site year, conclusions cannot be drawn to relate Zn fertilization to corn grain yield. However, it is apparent that in soils with high pH and low soil-test Zn that apply 10 lb Zn/ac preplant incorporated or Zn-EDTA as a foliar application post-emergence can produce optimal corn yields. Further studies and more site years are needed to evaluate this relationship and provide definitive conclusions. Based on previous research, it is expected that the granular sources applied at the recommended rate of 10 lb Zn/ac will also build soil-test Zn, unlike the foliar applied Zn-EDTA and low amounts of applied granular or coating sources would. Therefore, with higher yields and expectations to increase soil-test Zn levels, it is still recommended to apply 10 lb Zn/ac.

Acknowledgments

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Table 1. Effect of Zn fertilization source on corn grain yield at the University of Arkansas System Division of Agriculture's Pine Tree Research Station in 2023.

Treatment	Rate	Type	Mean Yield
	(lb Zn/ac)		(bu./ac)
1 - No zinc	0.0	Non-treated	194 ab†
2 - Zinc sulfate	3.0	Granular	199 ab
3 - Zinc sulfate	10.0	Granular	210 ab
4 - Zinc EDTA	1.0	Foliar	204 ab
5 - Frit Industries F-420G	10.0	Granular	208 ab
6 - Frit Industries F-420G Exp.	10.0	Granular	213 a
7 - MicroEssentials (MESZ)	1.0	Granular	201 ab
8 - MESZ + Zinc sulfate	1.0 + 2.0	Granular	206 ab
9 - Muriate of Potash (MOP) + Wolf Trax zinc	1.1	Macronutrient Coating	190 b
10 - MOP + Yaravita Procote	1.1	Macronutrient Coating	198 ab

† Means followed by the same letter are not significantly different at $P = 0.01655$

Table 2. Tissue-Zn concentration amongst the V6, V10, V12, and VT growth stages as affected by fertilization source at the University of Arkansas System Division of Agriculture's Pine Tree Research Station During the 2023 growing season.

	Growth Stage			
Treatment	V6	V10	V12	VT
	ppm			
1 - No zinc	19.7 b†	26.9	16.1	18.6
2 - Zinc sulfate	19.6 b	20.6	15.8	18.5
3 - Zinc sulfate	21.6 b	21.9	16.5	19.4
4 - Zinc EDTA	60.6 a	21.9	16.2	18.1
5 - Frit Industries F-420G	20.4 b	21.3	17.3	19.2
6 - Frit Industries F-420G Exp.	19.6 b	21.0	16.2	18.3
7 - MicroEssentials (MESZ)	18.4 b	20.6	15.6	17.5
8 - MESZ + Zinc sulfate	18.4 b	20.0	17.6	19.7
9 - Muriate of Potash (MOP) + Wolf Trax zinc	20.4 b	22.9	16.4	19.9
10 - MOP + Yaravita Procote	19.9 b	19.8	15.3	18.3

† Means followed by the same letter are not significantly different at $P = 0.001$

Corn Yield and Tissue-Potassium Response to Potassium Fertilization

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Abstract

Potassium (K) is a major yield-limiting nutrient for corn (*Zea mays* L.), and accurate K fertilization practices are needed for profitable corn production. Potassium response trials were established across Arkansas in 2023 to verify corn yield response to K fertilization and develop leaf-K concentration data to diagnose in-season K deficiencies. Trials were established within the University of Arkansas System Division of Agriculture (UADA) properties, including the Milo J. Shult Agricultural Research and Extension Center (SAREC), Pine Tree Research Station (PTRS), and the Northeast Rice Research and Extension Center (NERREC). Fertilizer-K rates (0, 40, 80, 120, 160, and 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 categorized soil-test K for each location and suggested that PTRS-C3 (Very Low), PTRS-D20 (Low), and NERREC (Low) would respond to fertilization while SAREC (Optimum) would not respond to fertilizer-K applications. Yield results indicated a significant yield increase from K fertilization at the NERREC and PTRS-C3 locations, with yield increases of 90 and 172 bu./ac, respectively. Corn earleaf-K concentrations ranged from 0.48% to 2.56% K and were significantly influenced by fertilizer-K rate at the PTRS-C3, PTRS-D20, and NERREC locations. The results of these trials suggest that corn is very responsive to K fertilization in soils with sub-optimum K availability and that earleaf-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 for soils with Very Low and Low K availability. 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 to help identify the critical soil-test K concentration for corn and correlate and calibrate fertilizer-K rates. 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 et al. (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 i) increase the database of corn grain yield response to K fertilization on a range of soil-test K concentrations and ii) begin collection of data to assess the ability of leaf tissue-K concentration as a predictor of corn grain yield and K nutritional status.

Procedures

Four corn K response trials were established across different University of Arkansas System Division of Agriculture (UADA) properties during the 2023 cropping season. These locations included the UADA's Milo J. Shult Agricultural Research and Extension Center (SAREC), Fayetteville, Ark., Pine Tree Research Station (PTRS-C3 and PTRS-D20), Colt, Ark., and Northeast Rice Research and Extension Center (NERREC), Harrisburg, Ark. The previous crop was soybean (*Glycine max* L.) at all locations.

Composite soil samples (six to eight individual cores) were collected from the 0- to -6-in. depth from each replicate. The soil was oven-dried, ground to pass through a sieve with 2-mm openings, and submitted to the UADA's Fayetteville

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Agricultural Diagnostic Laboratory for analysis of soil pH (1:2 v/v soil/water mixture; Sikora and Kissel, 2014) and Mehlich-3 extractable nutrients (Zhang et al., 2014). Mean soil properties are provided in Table 1.

At each location, fertilizer-K treatment rates were 0, 40, 80, 120, 160, and 200 lb K_2O/ac (muriate of potash; 0-0-60) applied preplant and incorporated. The plots were 4 rows wide (36-in. wide raised beds at SAREC, and 30-in. wide raised beds at PTRS and NERREC) and 30 ft long. Each trial was a randomized complete block with four replicates. In 2023, the corn hybrid P1718VYHR was planted on 17 April, 18 April, and 4 May at approximately 35,000 seed/ac at the NERREC, PTRS-C3, and PTRS-D20 locations, respectively. At the SAREC- location, the corn hybrid P1464VYHR was planted on 24 April at approximately 35,000 seed/ac. Phosphorus (P) fertilization was managed according to initial soil-test results to provide an adequate amount of P for corn growth; when soil-test P was below optimum, fertilizer-P at a rate of 90 lb P_2O_5/ac (triple superphosphate; 0-46-0) was applied preplant and incorporated into the raised 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). Zinc (Zn) fertilizer (1 lb Zn/ac) was applied as a liquid (EDTA chelate) and sprayed after corn emergence (V2–V3). Irrigation and pest management were conducted based on the 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 131 °F until constant weight, ground to pass through a 1-mm sieve, mixed, digested with concentrated HNO_3 and 30% H_2O_2 (Jones and Case, 1990), and analyzed using inductively coupled plasma atomic emission spectroscopy to determine elemental concentrations. At corn maturity, the middle inside two rows of each plot were harvested, and weights were adjusted to 15.5% moisture to determine grain yield.

Corn grain yield and tissue-K concentration were analyzed using a one-way analysis of variance (ANOVA) to compare the preplant K fertilizer treatments for each location. 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 R-studio version 4.3.2.

Results and Discussion

Corn grain yield can be impacted by several factors, but research has consistently shown that fertilizer-K 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 146, 69, 39, and 65 ppm for the SAREC, NERREC, PTRS-C3, and PTRS-D20 locations, respectively. Based on the current CES soil-test guidelines, the PTRS-C3 (39 ppm) and the PTRS-D20 (65 ppm), and the NERREC (69 ppm) locations are categorized within the Very Low and Low soil-test K categories, respectively, while the SAREC location (146 ppm) showed Optimum soil-test K (Table 1). Therefore, a yield increase to K fertilization is expected to occur at PTRS-C3, PTRS-D20, and NERREC, but no yield increase to K fertilization is expected at SAREC.

The 2023 corn grain yield at the SAREC ranged from 201–223 bu./ac, but no significant ($P > 0.05$) yield response to K fertilization was observed (Table 2). Results from the PTRS-D20 location followed a similar pattern with a range of 154–188 bu./ac, with a numerically greater yield occurring with 80 lb K_2O/ac application. The lack of yield response at SAREC is supported by the Optimum soil-test K levels; however, the lack of yield response at PTRS-D20 on soil with Low soil-test K was unexpected. This behavior may be associated, to some extent, with wildlife damage (feral hogs) within the trial area, which increased yield variability among replicates.

Significant ($P < 0.05$) yield response to K fertilization was observed at the NERREC and PTRS-C3, where the no-K control treatment produced a lower yield than all treatments that received K fertilizer (Table 2). Corn grain yield at the NERREC ranged from 103–193 bu./ac and indicated that a 70 bu./ac yield increase could be achieved with as little as 80 lb K_2O/ac. Corn grain yield at the PTRS-C3 ranged from 47–219 bu./ac and indicated that a 161 bu./ac yield increase could be achieved with as little as 80 lb K_2O/ac. Overall, fertilizer rates of at least 80 lb K_2O/ac maximized corn yield and produced an average of 75 and 350% higher yield than the unfertilized K treatment at NERREC and PTRS-C3, respectively. The yield increase with K fertilization in these two sites was expected based on the soil K availability (Low and Very Low soil-test K) prior to fertilizer applications. These results indicate that irrigated corn in Arkansas is highly responsive to K fertilization and that soil-test K is 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 (Schulte and Kelling, 2016). 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 (Schulte and Kelling, 2016). At the SAREC location, there was no significant yield response to K fertilization, and tissue-K concentrations were above the 1.75% K threshold (Tables 2 and 3). No significant differences in tissue-K concentrations were observed among fertilizer-K treatments at SAREC, with values ranging from 2.34–2.67% K, and fell within the range considered sufficient at the VT growth stage. Tissue-K concentrations at the NERREC ranged from 1.32–2.2%, generally increasing with each additional fertilizer input (Table 3). The 0, 40, 80, and 120 lb K_2O/ac treatments were below the suggested threshold, and the 160 and 200 lb K_2O/ac were above the threshold. Tissue-K concentrations at the

PTRS-C3 location ranged from 0.48–1.53%, and all fertilizer-K treatments fell below the 1.75% K threshold. Each additional input of K-fertilizer increased the average yield of the plots, though differences in yield were only significant between the 0, 40, and 80 lb K_2O/ac treatments. Tissue-K concentrations at the PTRS-D20 location ranged from 0.80–1.82% and followed a similar pattern to that of the PTRS-C3 location. Except for the highest fertilizer-K rate, all fertilizer-K treatments would have been below the suggested 1.75% K threshold. Regardless of the location, yield-maximizing fertilizer-K rate treatments had no distinct visual K deficiency symptoms. Severe stunting was observed in the non-treated control of the PTRS-C3 and PTRS-D20 locations. The significant increase in corn grain yields at the NERREC and PTRS-C3 locations and numerical differences observed at PTRS-D20 appear to coincide with increasing tissue-K concentrations, suggesting that a correlation of tissue-K concentrations with corn grain yields is possible and may aid with in-season nutrient management decisions.

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 indicates that soil-test K is a good predictor of sites that will require K fertilization to maximize corn grain yield and that sites with sub-optimal K availability show significant yield increases (up to 172 bu./ac) with adequate K management. Preliminary results of corn tissue-K show that there is a relation between earleaf-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 different growth stages similar to what has been developed for irrigated soybean (Slaton et al., 2021).

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Table 1. Mean (n = 4) soil pH and Mehlich-3 extractable nutrients in the 0–6-in. depth prior to treatment application and planting at four corn K response trials conducted during 2023.

	Location			
Soil property	**SAREC[†]**	**NERREC**	**PTRS–C3**	**PTRS–D20**
Soil pH	6.2	6.0	7.5	7.0
P (ppm)	30	51	13	10
K (ppm)	146	69	39	65
Ca (ppm)	813	790	1517	1164
Mg (ppm)	41	178	263	282
S (ppm)	11	12	10	7
Fe (ppm)	193	297	219	120
Mn (ppm)	67	24	318	445
Cu (ppm)	0.9	0.9	1.3	1.0
Zn (ppm)	4.6	4.0	1.4	1.8
B (ppm)	0.3	0.4	0.3	0.5

[†] SAREC = Milo J. Shult Agricultural Research and Extension Center, Fayetteville, Ark.; NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.; PTRS = Pine Tree Research Station, Colt, Ark. (sites “C3” and “D20”).

Table 2. Influence of potassium (K) fertilizer rate on mean (n = 4) corn grain yield (bu./ac) at four locations during 2023.

	Locations			
K Fertilizer Rates	**SAREC[†]**	**NERREC**	**PTRS–C3**	**PTRS–D20**
(lb K_2O/ac)	------------------------------ **(bu./ac)**	------------------------------		
0	223	103 c[‡]	47 b	154
40	204	139 bc	149 ab	172
80	203	173 ab	208 a	188
120	223	167 ab	203 a	186
160	204	187 a	216 a	184
200	201	193 a	219 a	179
P-Value	0.3927	0.0005	0.0005	0.3911
C.V. (%)[§]	8.7	10.9	39.0	11.9

[†] SAREC = Milo J. Shult Agricultural Research and Extension Center, Fayetteville, Ark.; NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.; PTRS = Pine Tree Research Station, Colt, Ark. (sites “C3” and “D20”).

[‡] Means within a column followed by the same letter are significantly different ($P < 0.05$).

[§] Coefficient of variation.

Table 3. Influence of potassium (K) fertilizer rate on mean (n = 4) corn earleaf-K concentration at the VT growth stage at four locations during 2023.

	Locations			
K Fertilizer Rates	**SAREC**[†]	**NERREC**	**PTRS–C3**	**PTRS–D20**
(lb K_2O/ac)	(%K)			
0	2.34	1.32 c[‡]	0.48 c	0.80 e
40	2.36	1.42 c	0.89 bc	1.14 d
80	2.44	1.66 bc	1.08 ab	1.39 c
120	2.43	1.71 abc	1.23 ab	1.49 bc
160	2.56	1.94 ab	1.23 ab	1.61 b
200	2.48	2.20 a	1.53 a	1.82 a
P-Value	0.1366	0.0004	<0.0001	<0.0001
C.V. (%)[§]	5.2	21.5	35.3	25.0

[†] SAREC = Milo J. Shult Agricultural Research and Extension Center, Fayetteville, Ark.; NERREC = Northeast Rice Research and Extension Center, Harrisburg, Ark.; PTRS = Pine Tree Research Station, Colt, Ark. (sites “C3” and “D20”).

[‡] Means within a column followed by the same letter are significantly different ($P < 0.05$).

[§] Coefficient of variation.

Impact of Plant Population, Nitrogen Rate, and Hybrid on Irrigated Corn Yield

J.P. Kelley,[1] T.D. Keene,[1] T.L. Roberts,[2] and H. Biram[3]

Abstract

Identifying the optimum corn (*Zea mays* L.) plant population and nitrogen rate is critical for growing high-yielding corn. Field trials evaluating the impact of corn plant population in conjunction with nitrogen rate on yield and late season lodging were conducted in 2023 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station near Marianna, Ark., the Rohwer Research Station near Rohwer, Ark., and the Jackson County Extension Center, near Newport, Ark. Approximate plant populations of 22,000, 27,000, 32000, 37,000, and 42,000 plants/ac were evaluated with nitrogen (N) rates of 0, 150, 200, 250, and 300 lb N/ac. Nitrogen was split applied at the V1–V2, V4–6, and V10 growth stages. Two commercially grown 115–118-day relative maturity hybrids were planted at each location. At maturity, plots were harvested with a small plot combine. Corn yield at all locations responded positively to increasing plant populations and nitrogen rates but at different levels. At Marianna, corn yield did not respond to nitrogen rates higher than 200 lb N/ac, while depending on hybrid, corn yields were maximized from populations of 39,000 to 44,000 plants/ac. At Rohwer, corn grain yields did not increase above 250 lb N/ac, and plant populations needed to achieve maximum yields varied by hybrid and ranged from 26,900 to 33,100 plants/ac. At Newport, corn yields were less responsive to nitrogen rate, and yields were maximized by only 150 lb N/ac due to high soil residual levels. However, corn yield did increase with increasing plant populations of up to 43,000 plants/ac.

Introduction

Arkansas average corn yields have steadily increased from approximately 118 bu./ac in 1993 to 183 bu./ac in 2023 (USDA-NASS, 2024), an average increase of nearly 2.1 bu./ac/yr. There are likely several reasons why yields are increasing, but irrigation plays a significant role in increasing yields. Approximately 95% of the corn grown in Arkansas is irrigated (USDA-FSA, 2024), which helps provide consistent yields over the years with varying growing season rainfall but also encourages producers to use more intensive management practices that can lead to higher yields, such as increasing plant populations and high nitrogen rates. Corn plant populations have been gradually increasing as new hybrids are developed that are more adapted to higher plant populations, thus providing higher grain yields. Iowa's average corn plant population increased from 23,500 plants/ac in 1993 to 31,950 plants/ac in 2023 (USDA-NASS 2024b), and Arkansas has seen similar plant population increases. However, USDA-NASS does not survey corn plant populations in Arkansas. Increasing plant populations does increase the amount of money spent on seed, and seed cost is now generally the second highest input cost for corn, behind fertilizer costs in many fields (Watkins, 2024). The recommended nitrogen rate for high-yielding irrigated corn is 220 lb N/ac (Kelley, 2024). However, some Arkansas corn growers apply higher nitrogen rates where high yield potential can be realized.

Previous Arkansas irrigated corn research (Kelley 2022) has shown grain yield was responsive to increasing plant populations generally up to 30,000 plants/ac, then yields tend to plateau at populations higher than 30,000 to 35,000 plants/ac. Many producers utilizing high plant populations are asking whether higher nitrogen rates are needed to achieve maximum yields when plant populations are increased. More unbiased data is needed to support increasing nitrogen rates when corn plant populations are increased. More local information on plant population responses for full-season corn hybrids commonly grown in Arkansas is needed to determine if higher nitrogen rates are required as corn plant populations increase on irrigated fields.

Procedures

Field trials evaluated the impact of corn plant population and nitrogen rate on corn grain yield at three locations in 2023. Locations were at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station near Marianna, the Rohwer Research Station near Rohwer, and the Jackson County Extension Center near Newport. Plant populations evaluated included 22,000, 27,000, 32,000, 37,000, and 42,000 plants/ac, with the 32,000 plants/ac rate being a typical recommended plant population for irrigated corn in Arkansas. Nitrogen rates of 0, 150, 200, 250, and 300 lb N/ac were evaluated for a total of 25 treatments of plant population

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by nitrogen rate combinations. At each location, two commonly grown hybrids were evaluated. Each treatment was replicated four times within a split-plot design with nitrogen rate as the main plot and plant population as the subplot. Hybrid was blocked to create side by side trials of each hybrid. Plots were four rows wide by 30 or 35 ft long. Plots were planted with standard vacuum planters on raised beds for furrow irrigation. Row spacing at Marianna and Rohwer was 38 inches and 30 inches at Newport. Corn hybrids evaluated included Dekalb DKC 68-35 and Pioneer 1718VYHR at Rohwer, Dekalb DKC 66-06 and Progeny 2118 at Marianna, and Dekalb DKC 65-99 and Pioneer 1847VYHR at Newport. All hybrids were commercially available with a relative maturity range of 115–118 days. All grain yield data were subjected to analysis of variance using ARM 2024 (GDM Solutions, Inc., Brookings, S.D.) and means separated by least significant difference at $P = 0.05$. Yield component data (Tables 4–5) is from one replication, and only treatment means are presented.

The soil series and textural classification was a Memphis-Calloway silt loam at Marianna, a Hebert silt loam at Rohwer, and a Dexter silt loam at Newport. All sites were conventionally tilled, and the previous crop was soybean. Planting dates ranged from 12 April at Rohwer to 17 April at Newport. All trials were furrow irrigated as needed according to the University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) irrigation scheduler program. Production practices for weed and pest control closely followed current CES recommendations.

Pre-plant potassium, phosphorus, zinc, and sulfur fertilizers were applied at recommended levels before the formation of raised beds and planting. Nitrogen (N) in urea form was split and applied with 50 lb N/ac at the V1–V2 stage for all treatments except the 0 N rate. Sidedress N was applied at the V4–V6 growth stage and consisted of 50, 100, 150, or 200 lb N/ac for the 150, 200, 250, and 300 lb/ac N treatments. A late-sidedress application of 50 lb/ac N was applied at the V10 growth stage to all treatments except the 0 N plots. A urease inhibitor was not used with any urea fertilizer application due to anticipated rainfall shortly after application.

Soon after emergence, plant populations were counted from the center of two rows of each plot to estimate the final plant population (Tables 1–3), and populations did vary slightly from the desired populations of 22,000, 27,000, 32,000, 37,000, and 42,000 plants/ac. Before harvest, mature plant height, percent lodging, and greensnap were estimated. Additionally, at Marianna, 10 representative ears from all treatments were hand-harvested from 1 replication to estimate kernels/ear and kernel weight. At corn maturity, the center two rows of each plot were harvested at each location with a small plot combine, and yields were adjusted to 15.5% grain moisture.

Results and Discussion

Corn yield averaged across hybrid, plant population, and nitrogen rates (excluding 0 lb N/ac rate) was 185.5, 202.5, and 268.0 bu./ac at Rohwer, Marianna, and Newport, respectively. The 0 N rate yields, averaged across hybrid and plant populations, varied considerably and were 57.5, 85.5, and 169.0 bu./ac at Rohwer, Marianna, and Newport, respectively, indicating a large difference in residual nitrogen between locations, even though all trials followed soybean. Overall yields were good due to an excellent growing season. Yields at Rohwer were lower than the other two sites and can be attributed to a delay in the initial irrigation due to irrigation system failure but they were irrigated adequately once the system was operational. Corn yields from Marianna, Rohwer, and Newport are found in Tables 1–3.

At Marianna, both DKC 66-06 and Progeny 2118 showed significant effects of nitrogen and plant population on grain yield (Table 1). When averaged across nitrogen rates, Dekalb DKC 66-06 yield was maximized by plant populations of 44,000 plants/ac, compared to 39,000 plants/ac for Progeny 2118. Nitrogen rates needed to achieve maximum yields at Marianna were similar for both hybrids, and there was little difference between 200, 250, and 300 lb N/ac rates. Increasing nitrogen rates beyond 150 lb N/ac on plant populations of 22,000 plants/ac did not increase yields, indicating that the plant cannot compensate for low plant populations, even if more than adequate nitrogen is supplied. Overall, at Marianna, increasing plant populations tended to have a greater increase in yield than increasing nitrogen rates, and DKC 66-06 tended to be more responsive to plant populations than Progeny 2118. Late-season lodging or greensnap was not observed for any treatments at Marianna. Plant height at Marianna was not influenced by plant population, and only the 0 N rate reduced plant height compared to other nitrogen rates (data not shown).

Corn yields at Rohwer were also influenced by plant population and nitrogen rate (Table 2). Yields of the 0 nitrogen rate plots were very low and overall decreased as the plant population increased, indicating the soil residual nitrogen was low and the low population was likely able to gather more nitrogen per plant because of a more extensive root system. The early season drought stress may have also contributed to lower yields when the irrigation system failed prior to reproductive stages. Averaged across nitrogen rates, DKC 68-35 yields were nearly identical for plant populations ranging from 33,100 to 42,500 plants/ac, while Pioneer 1718VYHR yields were similar for populations of 26,900 to 42,100. Pioneer 1718VYHR, in previous work, has not been as plant population responsive as other hybrids. Averaged across plant populations, yields of both DKC 68-35 and Pioneer 1718VYHR were maximized by 250 lb N/ac. Like Marianna, plant height was not influenced by plant population, but plants in the 0-nitrogen rate were shorter than the 150, 200, 250, or 300 lb N/ac rates. No late-season lodging or greensnap was observed at Rohwer (data not shown).

Corn yields at Newport (Table 3) were greater than the other two locations and were influenced by nitrogen and plant populations. The soil residual nitrogen at this site was high, possibly because this field has only been cropped approximately the last k years and previously was in pasture or fallow. Corn yields, when averaged over plant population, were maximized by 150 lb N/ac for both hybrids. Plots with 0 nitrogen applied averaged 187 and 151 bu./ac for DKC 65-99 and Pioneer 1847VYHR. Corn yields increased with increasing plant populations, and the highest DKC 65-99 yields were obtained at 43,800 plants/ac and 43,000 plants/ac for Pioneer 1847VYHR. These high plant populations to achieve maximum yield are much higher than would be recommended on commercial fields and were higher populations than Marianna or Rohwer needed to achieve maximum yields. Corn yields at Newport tended to be more variable than those at Marianna or Rohwer due to mid-season greensnap from a thunderstorm in June that caused severe damage to certain areas of the field. Yield determinations were only taken from plots with less than 5% total greensnap. Nitrogen rate did have an impact on greensnap, with greensnap only being 1% for plots that received 0 nitrogen when averaged across hybrids and ranged from 10–16% for nitrogen rates of 150 to 300 lb N/ac when averaged across plant populations and hybrid with no consistent trend of damage between the 150 to 300 lb N/ac rates. Averaged across nitrogen rates and hybrid, greensnap ranged from 6–16% with no consistent plant population trend. There was more greensnap in Pioneer 1847VYHR (14.5%) when averaged across nitrogen rates and plant population compared to DKC 65–99 (6.5%). Late-season stalk lodging was not observed for any treatment at Newport.

Detailed yield components information of kernels/ear and kernel weight (grams/125 kernels) were collected at Marianna (Tables 4 and 5) immediately prior to harvest. As plant populations increase, the number of kernels per ear the plant can support decreases. The lowest plant populations had the greatest number of kernels/ear, 703 or 666 for DKC 66-06 and Progeny 2118, and kernel numbers steadily decreased as the plant population increased when averaged across nitrogen rates. When averaged across plant populations, nitrogen rates of 150, 200, 250, and 300 lb N/ac produced similar numbers of kernels/ear. Kernel weight was also evaluated, and a similar trend was observed for kernels/ear. Kernel weight was the least from plots having 0 nitrogen applied (34 or 36 grams/125 kernels) when averaged across plant populations compared to plots that received 150 lb N/ac or more (41–44 grams/125 kernels), but weights did not increase with nitrogen rates above 200 lb N/ac. The lack of an increasing number of kernels or increasing kernel weight with increasing nitrogen rates indicates that added nitrogen beyond what is needed does not increase yields. Kernels/ear and kernel weight data closely follow yield data obtained from Marianna, which shows that high nitrogen rates did not increase yield compared to normal recommended rates.

Practical Applications

Results from these irrigated corn trials demonstrate that the plant population needed to reach maximum corn yield can vary between hybrids and the environment, but the currently recommended plant populations of 32,000 to 34,000 plants/ac for irrigated fields appear to be appropriate in most situations. The lack of late-season lodging with high plant populations in these trials is encouraging. However, hybrid, weather conditions, and harvest timing all play important roles, and lodging can still be a concern with high plant populations. In these trials, yields increased more with increasing plant populations than with increasing nitrogen rate, indicating that current nitrogen recommendations for corn are appropriate. For producers considering increasing corn plant populations, adding extra nitrogen beyond a normal nitrogen program does not appear to be needed, even for very high plant populations.

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Table 1. Impact of corn hybrid, plant population, and nitrogen rate on corn yield (bu./ac), University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, 2023.

Dekalb DKC 66-06							Progeny 2118 VT2						
Plants/ac	0	150	200	250	300	Mean[a]	Plants/ac	0	150	200	250	300	Mean[a]
	--------------lb N/ac--------------							--------------lb N/ac--------------					
22,000	84	165	164	162	162	147	21,000	91	144	147	151	151	137
27,600	87	202	208	208	217	184	27,200	92	184	188	193	188	169
32,800	81	219	224	230	226	196	32,400	93	198	208	206	205	182
38,400	73	231	231	235	233	201	39,000	82	211	212	214	212	186
44,000	80	228	239	242	237	205	44,300	90	205	211	206	210	184
LSD 0.05	---------------13.5---------------					---	LSD 0.05	---------------13.0---------------					---
Mean[b]	81	209	213	215	215	---	Mean[b]	90	188	193	194	193	---

[a] Mean corn yield for each plant population averaged across five nitrogen rates.

[b] Mean corn yield for each nitrogen rate, averaged across five plant populations.

Table 2. Impact of corn hybrid, plant population, and nitrogen rate on corn yield (bu./ac), University of Arkansas System Division of Agriculture's Rohwer Research Station, Rohwer, 2023.

Dekalb DKC 68-35							Pioneer 1718VYHR						
Plants/ac	0	150	200	250	300	Mean[a]	Plants/ac	0	150	200	250	300	Mean[a]
	-------------lb N/ac--------------							--------------lb N/ac-------------					
21,400	69	149	161	158	162	140	20,300	63	158	172	174	172	148
27,400	69	163	188	187	189	159	26,900	56	169	185	182	181	155
33,100	61	189	203	213	215	176	32,900	53	162	182	190	190	155
37,500	60	188	205	215	211	176	38,100	45	162	182	194	195	156
42,500	56	188	210	221	215	178	42,100	41	169	179	200	196	157
LSD 0.05	---------------20.2---------------					---	LSD 0.05	---------------19.9---------------					---
Mean[b]	63	175	193	199	198	---	Mean[b]	52	164	180	188	187	---

[a] Mean corn yield for each plant population averaged across five nitrogen rates.

[b] Mean corn yield for each nitrogen rate, averaged across five plant populations.

Table 3. Impact of corn hybrid, plant population, and nitrogen rate on corn yield (bu./ac), University of Arkansas System Division of Agriculture's Jackson County Extension Center, Newport, 2023.

Dekalb DKC 65-99							Pioneer 1847VYHR						
Plants/ac	0	150	200	250	300	Mean[a]	Plants/ac	0	150	200	250	300	Mean[a]
	--------------lb N/ac--------------							--------------lb N/ac--------------					
22,300	167	213	230	232	228	214	22,300	139	233	251	245	250	224
27,700	183	244	271	264	269	246	28,300	155	262	258	261	276	242
33,700	188	258	291	284	281	260	33,400	153	269	280	265	262	246
39,300	199	276	279	283	287	265	38,800	151	259	282	285	266	249
43,800	197	292	304	303	302	280	43,000	157	277	277	281	288	256
LSD 0.05	----------------32.0----------------					---	LSD 0.05	----------------28.4----------------					---
Mean[b]	187	257	275	273	273	---	Mean[b]	151	260	270	267	268	---

[a] Mean corn yield for each plant population averaged across five nitrogen rates.

[b] Mean corn yield for each nitrogen rate, averaged across five plant populations.

Table 4. Impact of corn hybrid, plant population, and nitrogen rate on corn kernels/ear, University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, 2023.

Dekalb DKC 66-06							Progeny 2118VT2						
Plants/ac	**0**	**150**	**200**	**250**	**300**	**Mean**[a]	**Plants/ac**	**0**	**150**	**200**	**250**	**300**	**Mean**[a]
	--------------**lb N/ac**--------------							--------------**lb N/ac**--------------					
22,300	415	779	734	782	804	703	22,300	312	727	708	790	795	666
27,700	413	692	696	695	672	634	28,300	253	641	663	699	680	587
33,700	259	561	622	600	620	532	33,400	232	571	577	520	515	483
39,300	233	505	624	589	558	502	38,800	295	472	396	401	535	420
43,800	284	420	438	460	455	411	43,000	191	352	378	411	443	355
LSD 0.05			---			---	LSD 0.05			---			---
Mean[b]	321	591	623	615	622	---	Mean[b]	257	553	544	564	594	---

[a] Mean kernels/ear for each plant population averaged across five nitrogen rates.

[b] Mean kernels/ear for each nitrogen rate, averaged across five plant populations.

Table 5. Impact of corn hybrid, plant population, and nitrogen rate on corn kernel weight (grams/125 kernels), University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, 2023.

Dekalb DKC 66-06							Progeny 2118VT2						
Plants/ac	**0**	**150**	**200**	**250**	**300**	**Mean**[a]	**Plants/ac**	**0**	**150**	**200**	**250**	**300**	**Mean**[a]
	--------------**lb N/ac**--------------							-------------**lb N/ac**--------------					
22,300	35	42	43	47	45	42	22,300	36	40	45	45	45	42
27,700	34	44	44	45	43	42	28,300	34	41	46	45	45	42
33,700	35	42	46	44	43	42	33,400	36	46	46	45	45	44
39,300	34	41	45	42	44	41	38,800	40	42	44	44	44	43
43,800	31	41	40	44	42	40	43,000	36	36	40	43	42	39
LSD 0.05			---			---	LSD 0.05			---			---
Mean[b]	34	42	44	44	43	---	Mean[b]	36	41	44	44	44	---

[a] Mean kernel weight for each plant population averaged across five nitrogen rates.

[b] Mean kernel weight for each nitrogen rate, averaged across five plant populations.

A Web-Tool Prototype to Assess Mid-Season Corn Nitrogen Status with Drones

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Abstract

Optimized mid-season corn nitrogen (N) fertilizer rate selection is a key component of farm profitability. Yet, site-specific needs are difficult to predict because of complex interactions between genetic, management, and environmental factors. While tissue analysis is increasingly used to assess mid-season corn N status, fine-resolution characterization of in-field variability is needed to optimize tissue sampling strategy. Fortunately, such information may be collected using inexpensive drone systems. Previous research demonstrated that the difference between field canopy greenness and that of a high-N reference can be used to predict yield loss from N deficiency and inform mid-season corn N fertilizer management. Canopy greenness is quantified using the dark green color index (DGCI), and calibration equations were developed to relate field and high-N DGCI values collected between V8 (eight expanded leaves) and VT (tasseling) corn growth stages to a predicted relative grain yield and mid-season corn N status. Data processing that leverages these equations was automated and integrated into a web tool prototype. This report demonstrates how the created web tool prototype can be used for mid-season corn N fertilizer management. The final product will deliver remote sensing-based site-specific mid-season N fertilizer rate recommendations and help producers determine where to collect leaf tissue samples for ground reference. The intent is for this web tool to be used in the field to define corn nitrogen status and optimize traditional tissue sampling strategies. The final product will be deployed by 2027 to help Arkansas corn producers increase profitability with optimized mid-season N fertilizer management.

Introduction

Corn (*Zea mays* L.) requires more nitrogen (N) per unit area than any other crops cultivated in Arkansas, and optimized corn N fertilizer management is a critical component of farm profitability (Meisinger et al., 2008). The recommended corn N fertilizer rates vary according to soil texture and yield goal, and N fertilizer is typically applied in two- or three-split applications (Roberts et al., 2016). Three-split strategies are implemented to better match N fertilizer application with crop needs and increase N fertilizer use efficiency (Slaton et al., 2014). The increased N fertilizer use efficiency helps increase profitability by reducing yield loss from N deficiency with the same or less total N fertilizer amounts. Benefits from three-split applications are greater when unfavorable weather conditions (e.g., excess rainfall) increase early-season N loss from leaching, runoff, denitrification, or volatilization.

Corn uptakes most of its N between the V8 (eight expanded leaves) and R2 (blister) growth stages, and at least 75% to 85% of the total recommended N fertilizer rate is normally applied before V8 to support the crop vegetative growth (Slaton et al., 2014). In typical three-split application setups, the remaining 15% to 25% of N fertilizer is applied pre-tassel to complement the soil N supply and minimize the incidence of yield-limiting N deficiencies during the crop reproductive stages (Dos Santos et al., 2020). However, the specific pre-tassel N fertilizer requirements are likely to vary between fields because of differences in how the previously applied N fertilizer was utilized by the crop. Yet, spatial changes in N fertilizer use and site-specific pre-tassel N fertilizer needs are difficult to predict because of the complexity of interactions occurring among production factors, including genotype, soil properties, weather, and management history (Dos Santos et al., 2021).

Field assessment of mid-season corn N status is needed to fine-tune pre-tassel N fertilizer rates to crop needs, and the N-STaR program recommends leaf tissue sampling for total N analysis to help diagnose and address yield-limiting N deficiencies (Greub et al., 2018). While research shows that pre-tassel N fertilizer application should be considered when the total leaf N is less than 3% (Dos Santos et al., 2020), the cost of tissue analysis may be prohibitive, and little information is available to help producers determine where samples should be collected in a field. The creation of a tool that assesses mid-season corn N status and defines leaf tissue sampling strategies is needed to overcome the economic and practical barriers to data collection, maximize scouting efficiency, and help promote the adoption of optimized mid-season corn N fertilizer management strategies (Morris et al., 2018).

Nitrogen is required for chlorophyll synthesis, and strong correlations exist between leaf N concentration and canopy greenness. Previous research quantified canopy greenness using the dark green color index (DGCI) (Karcher and Richardson, 2003) computed from drone images collected using affordable red, green, and blue (RGB) cameras. Calibration equations were

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established to relate pre-tassel field DGCI values to mid-season crop N status (Purcell et al., 2013; 2015). Comparison between field DGCI values to that of a known high-N reference allowed for the estimation of relative grain yield (RGY) loss from N deficiency independently from lighting conditions at the time of flight (Rorie et al., 2011). Pre-tassel N fertilizer should be considered if more than a specific RGY loss threshold—typically 5%—is expected. An algorithm was created to automate RGB drone image processing (Poncet et al., 2022). The objective of this study was to integrate the created algorithm into a user-friendly interface to make the research findings more accessible to producers.

Procedures

The created web tool assesses mid-season corn N status by comparing the crop canopy greenness to that of a high-N reference. The high-N reference should be established at sidedress. The high-N reference rate should be selected so that approximately 120% of the total recommended N rate is applied between pre-planting and sidedress to maximize the chances of N sufficiency independently from weather conditions. The minimum dimensions of the high-N reference should be around 150 ft x 150 ft, but further research is needed to determine how many, how large, and where the high-N reference area(s) should be established to maximize benefits from web tool use. Canopy greenness is quantified from overhead RGB drone images collected between the V8 and VT (tasseling) corn growth stages using the DGCI. RGY predictions are made by comparing the field DGCI values to that of a high-N reference. Mid-season corn N status is determined by comparing the field RGY values to a user-defined threshold. At least one high-N reference should be established in the field prior to drone image collection, and the tassels should not be visible in the collected drone images. The corn tassels change the canopy greenness, and images should be collected prior to tassel appearance to ensure that the identified variations in field DGCI values are caused by spatial changes in mid-season corn N status rather than corn growth stage.

Images are uploaded into the tool by the user and processed individually (no stitching required). Only images that feature at least part of the high-N reference should be used to generate findings. The user is asked to delineate the high-N reference within each image, which is then processed individually (no stitching required). Image analysis is automated. The user may adjust three image processing parameters: non-canopy filtering, nitrogen deficiency threshold, and image scale. The non-canopy filter excludes the pixels that do not describe the crop canopy from the image analysis. Pixel classification (e.g., crop canopy or not crop canopy) is made by comparing the green pixel radiometric values to their blue and red counterparts. The greater the pixel radiometric value, the greater the amount of sunlight reflected in the associated color. Pixels that have a maximum radiometric value in the blue or red bands are considered non-canopy and excluded from image processing when the non-canopy filter is used. The nitrogen deficiency threshold determines the estimated RGY threshold below which the crop is considered to be nitrogen deficient. By default, yield-limiting N deficiencies are expected when the predicted RGY values are less than 95%. Image scale may be adjusted to resample the processed images at coarser spatial resolutions. The dimensions of the re-scaled processed images are determined by the original image dimensions times a scaling factor ranging from 0.05 to 1.00. For instance, if an image with 128 x 96 pixels is resampled using a scaling factor of 0.5, the dimensions of the new re-scaled image are 128/2 = 64 pixels wide and 96/2 = 48 pixels tall. Web tool development was performed using open-source software.

Results and Discussion

A step-by-step demonstration of the created web-tool prototype is provided in Figs. 1 to 9. Figures 1 to 4 describe drone image upload. The user is prompted to browse one or multiple images from their device (Figs. 1 and 2). The selected images are uploaded into the created web tool and displayed in a table (Fig. 3). New images may be browsed, selected, and added to the web tool. Duplicates are automatically excluded. Uploaded image size can be fine-tuned to accommodate device screen size or resolution and personal preferences (Fig. 4). Uploaded images may also be selected and removed as needed.

Figures 5 and 6 describe the high-N reference delineation process. A high-N reference must be delineated in each image to allow for data processing. A sidebar menu and toolbar allow the user to navigate between images and draw within an image (Fig. 5). The names of the images in which the high-N reference still needs to be delineated are provided in the sidebar menu (Fig. 6). Once a high-N reference has been identified within each image, the user may proceed with image processing and analysis (Fig. 7). A pop-up window will remind the user to define a high-N reference in all images if needed.

Image processing is fully automated, providing that the user initiates the process (Fig. 7). Canopy greenness quantified using the DGCI, RGY, and corn nitrogen status results are displayed among their respective tabs (Figs. 7 and 8). By default, non-canopy pixels are excluded, <95% RGY defines yield-limiting N deficiencies, and the processed images are not resampled. If any of these parameters are changed, the user must update the information displayed within the web tool. A demonstration of the re-scaling functionality is provided in Fig. 9.

The drone images used for illustration in this article were collected in 2022 at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (Colt, Ark.). A high-N reference was established at sidedress within a N-deficient production corn field. Overhead drone images were collected at the V10 (10 expanded leaves) growth stage using a DJI Mavic Air 2 (SZ DJI Technology Co., Ltd, Shenzhen, China) aircraft equipped with an RGB camera. Flight altitude was 200 ft above ground level.

Practical Applications

A web-tool prototype was developed to help producers assess mid-season corn N status with inexpensive RGB drone systems. No stitching is required, and the intent is for the web tool to be used on the turnrow. The current web tool prototype is still in development, and additional functionalities are being added to increase user-friendliness and promote widespread adoption.

Web tool deployment for on-farm use is planned for 2026 to 2027, and the following additions are currently in the pipeline:

- Automation of high-N reference area delineation across images from coordinates.
- Delineation of a virtual high-N reference as a substitute from the establishment of a physical high-N reference at sidedress.
- Determination of a mid-season agronomic and economic N fertilizer rate recommendation to optimize corn N fertilizer management.
- Combination of algorithm outputs into a single image or product.
- Development of an algorithm that will identify the best tissue sampling locations for ground reference.

The final product will help producers fine-tune pre-tassel N fertilizer applications to site-specific field conditions using inexpensive drone systems. For instance, it will be possible to use the created web tool to prioritize tissue sampling and mid-season N fertilizer application in fields where yield-limiting N deficiency occurs and determine where and when the ground reference tissue samples should be collected. Ultimately, web tool use will help optimize corn production in Arkansas through increased efficiency, profitability, and sustainability.

Acknowledgments

Project funding was provided by the Arkansas Corn and Grain Sorghum Checkoff Program administered by the Arkansas Corn and Grain Sorghum Promotion Board. This work was also supported in part by the University of Arkansas System Division of Agriculture and the USDA National Institute of Food and Agriculture, Hatch project ARK 2734.

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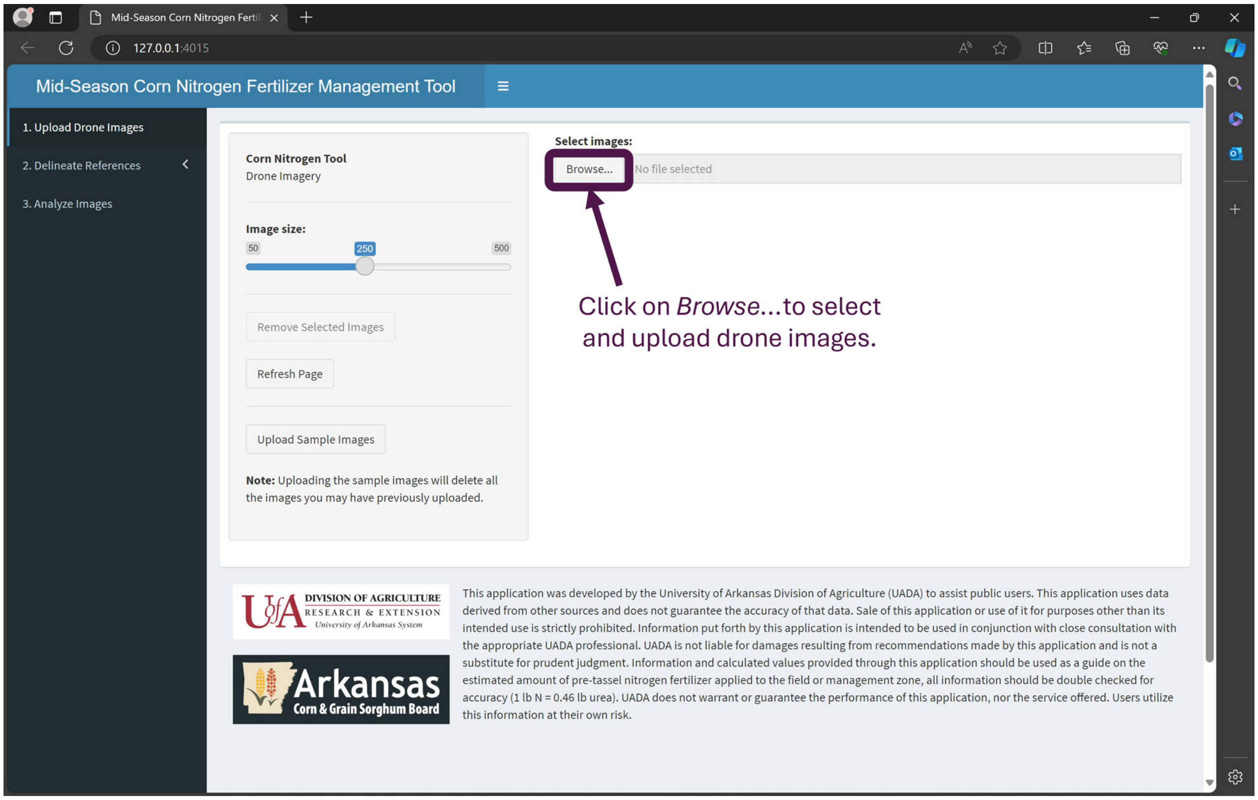

Note: Uploading the sample images will delete all the images you may have previously uploaded.

Click on *Browse*...to select and upload drone images.

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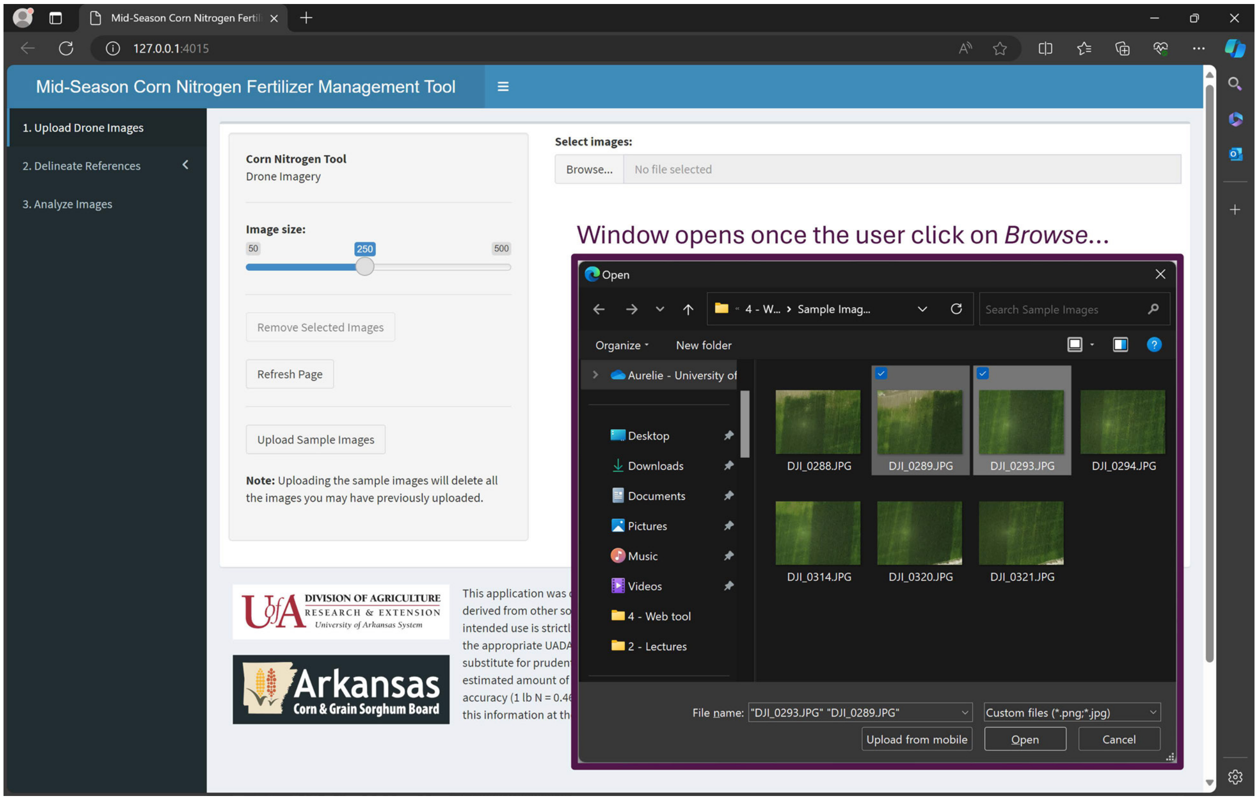
Fig. 1. User interface of the web tool prototype. The Upload Drone Images menu is selected by default. Users are expected to upload drone images before they can proceed to the next step.

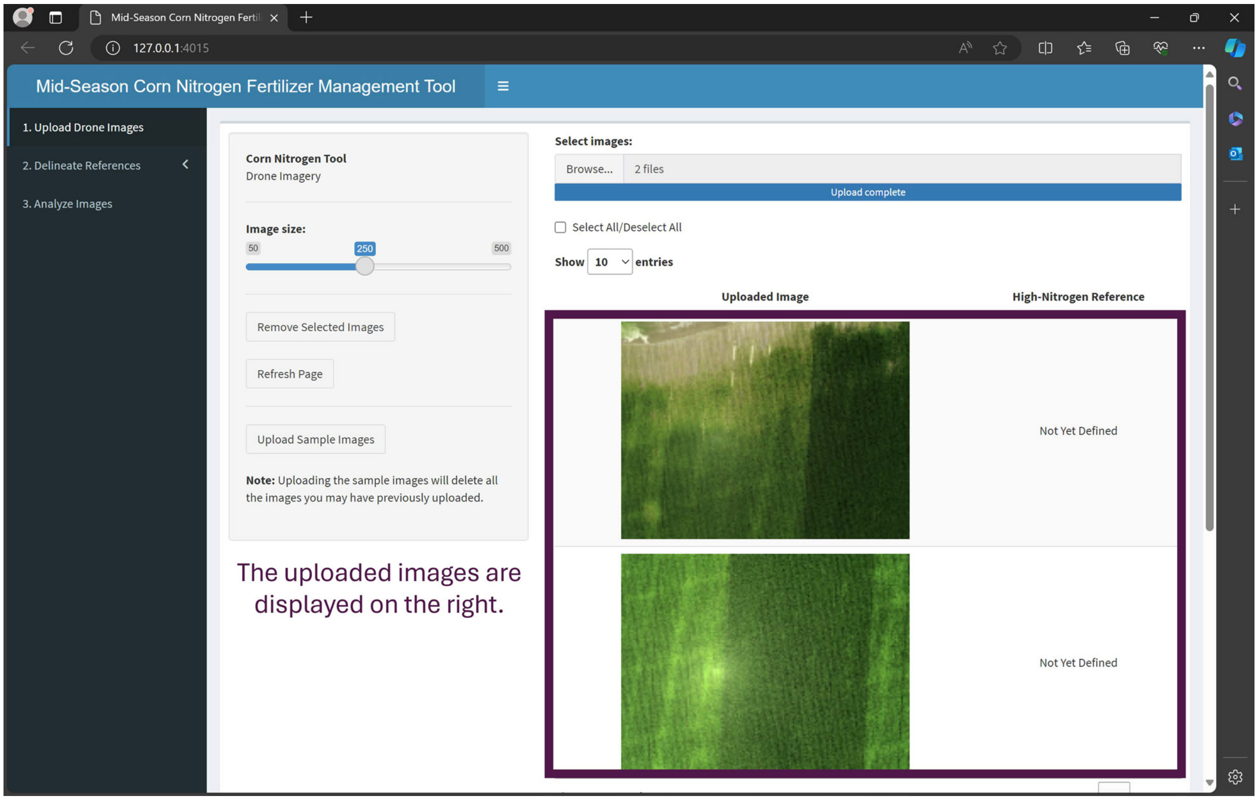


Note: Uploading the sample images will delete all the images you may have previously uploaded.

Window opens once the user click on *Browse*...

File name: "DJI_0293.JPG" "DJI_0289.JPG"

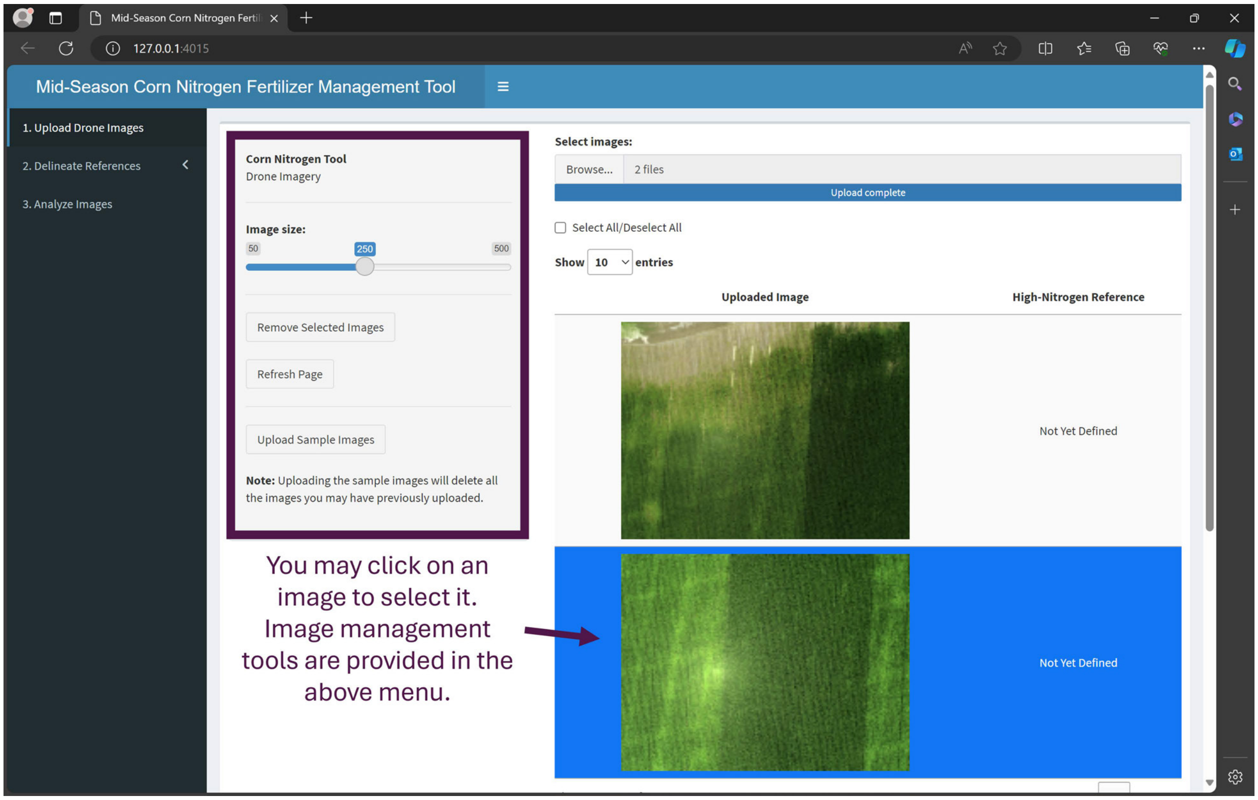
Fig. 2. The browsing window prompts the user to find and select drone images. Multiple images may be selected.



Note: Uploading the sample images will delete all the images you may have previously uploaded.

The uploaded images are displayed on the right.

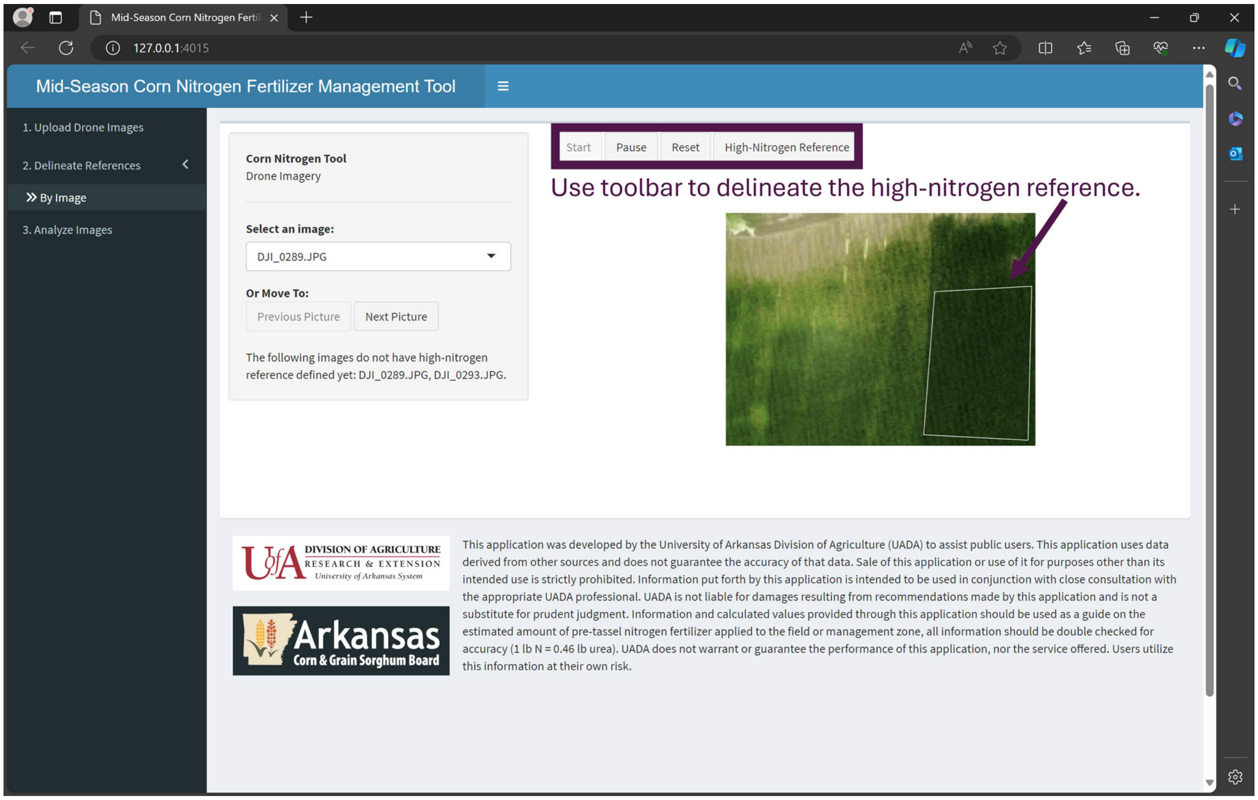
Fig. 3. Uploaded drone images are displayed in the web tool user interface.



Note: Uploading the sample images will delete all the images you may have previously uploaded.

You may click on an image to select it. Image management tools are provided in the above menu.

Fig. 4. The user may change image size to adjust the display to different screen sizes, select (appears in blue) and remove one or more images, or refresh the page. The user may also upload sample images to practice using the created web tool prototype. If all uploaded images are removed at once, image manipulation settings are refreshed.



Corn Nitrogen Tool
Drone Imagery

Select an image: DJI_0289.JPG

Or Move To:

The following images do not have high-nitrogen reference defined yet: DJI_0289.JPG, DJI_0293.JPG.

Use toolbar to delineate the high-nitrogen reference.

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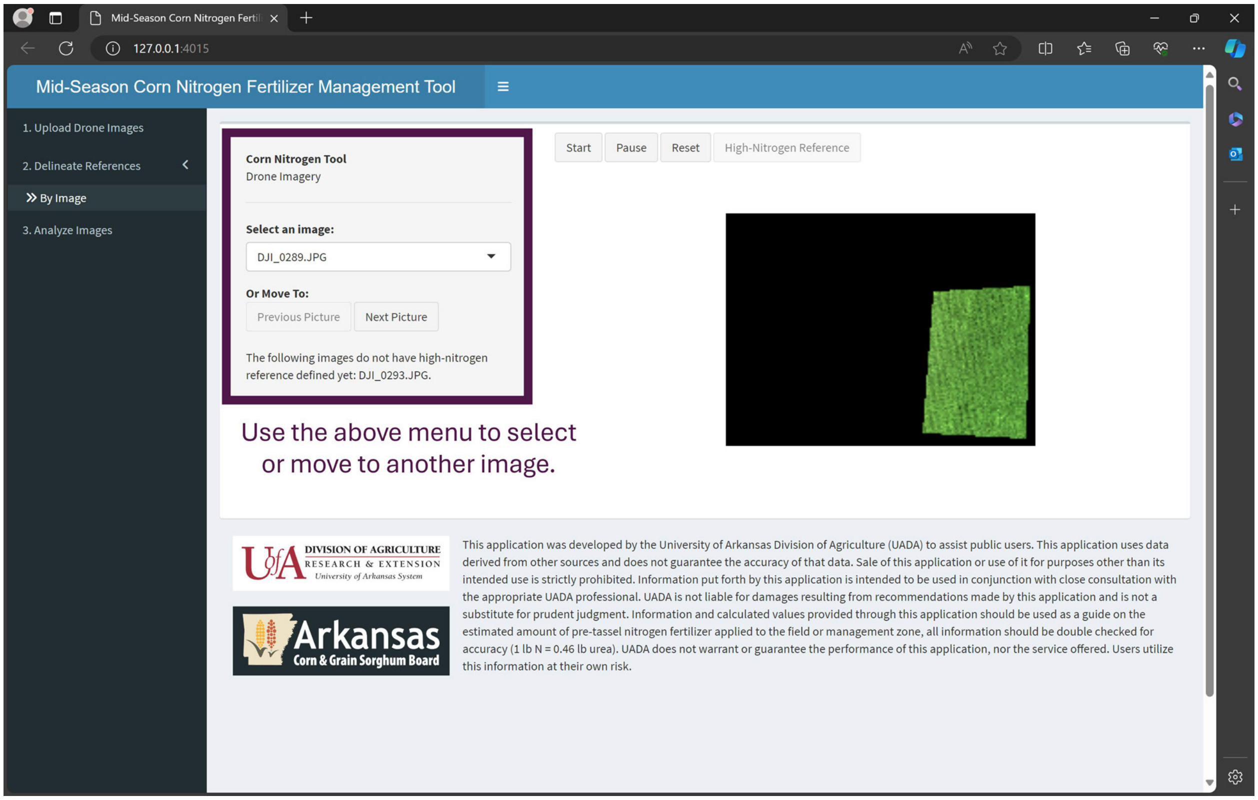
Fig. 5. The user may select the Start, Pause, and Reset tools as needed to delineate the high-nitrogen reference area in each image. The Start button starts the delineation process. The delineated area, determined by where the user clicks on the image, appears as a white polygon overlayed on the selected drone image. Clicking on the High-Nitrogen Reference button completes the process. The reset button allows for the user to start over.



Corn Nitrogen Tool
Drone Imagery

Select an image: DJI_0289.JPG

Or Move To:

The following images do not have high-nitrogen reference defined yet: DJI_0293.JPG.

Use the above menu to select or move to another image.

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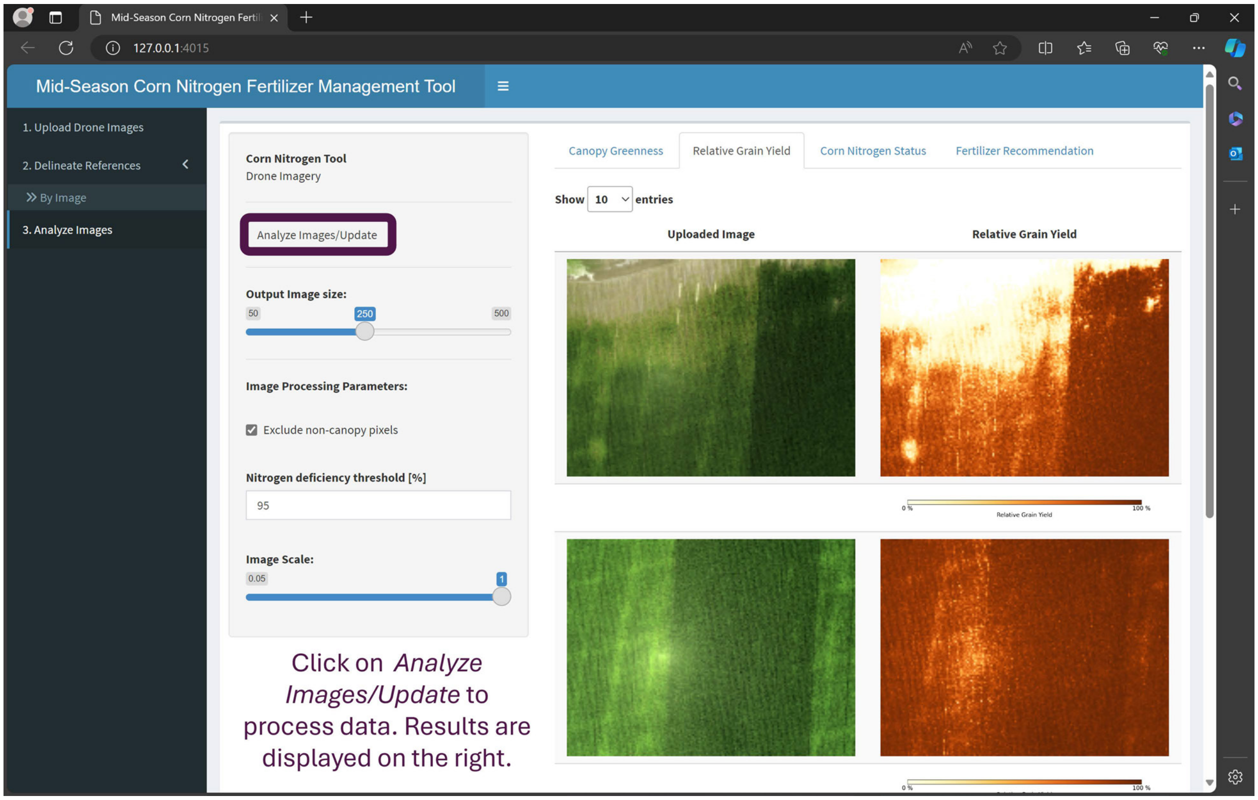
Fig. 6. Once a high-nitrogen reference has been delineated, the rest of the image is blacked out. The user may then select or move to another image using the tools provided on the sidebar menu. A high-nitrogen reference must be selected in each image before the user can proceed with processing.



Corn Nitrogen Tool
Drone Imagery

Output Image size: 250

Image Processing Parameters:

☑ Exclude non-canopy pixels

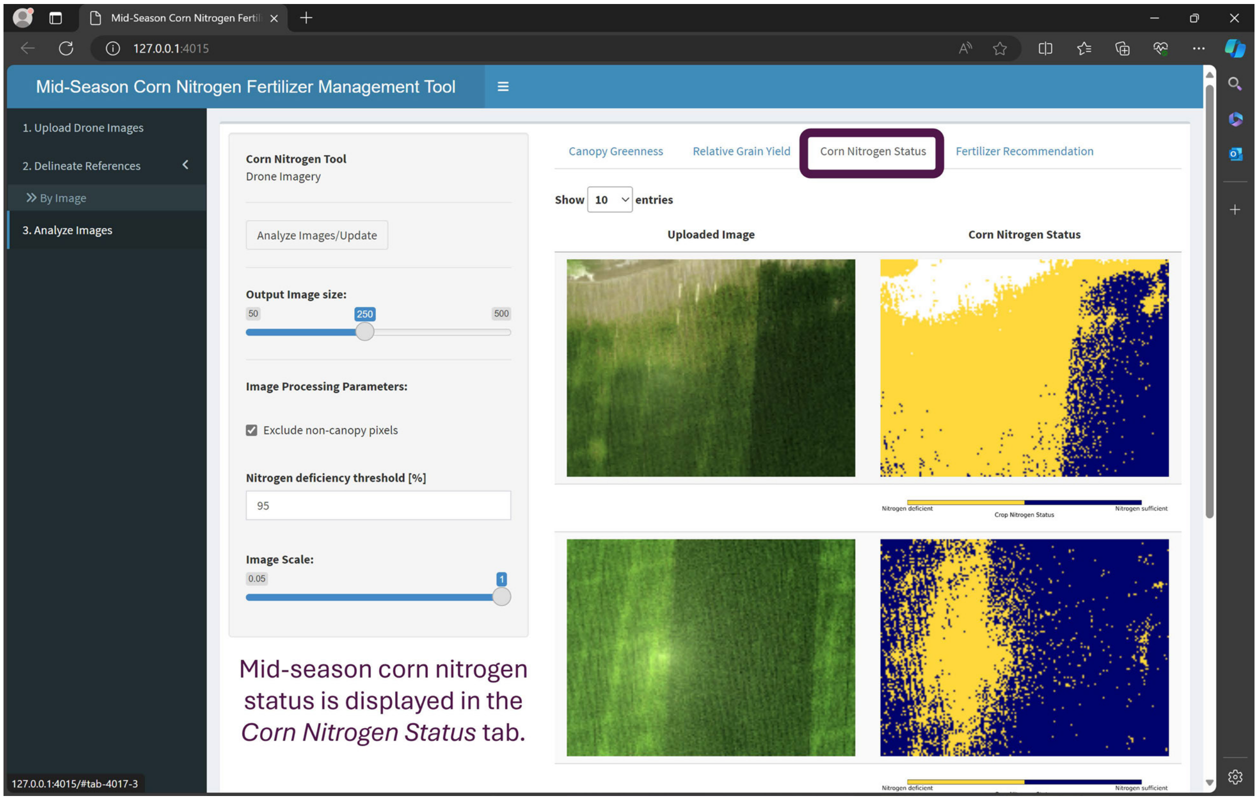
Nitrogen deficiency threshold [%]: 95

Image Scale: 1

Show 10 entries

Click on *Analyze Images/Update* to process data. Results are displayed on the right.

Fig. 7. The user clicks on Analyze Images/Update to process the uploaded images. Outputs from the algorithm integrated into the created web tool prototype are displayed within a set of relevant tabs. The relative grain yield prediction is shown by default side-by-side with the uploaded drone images.



Corn Nitrogen Tool
Drone Imagery

Output Image size: 250

Image Processing Parameters:

☑ Exclude non-canopy pixels

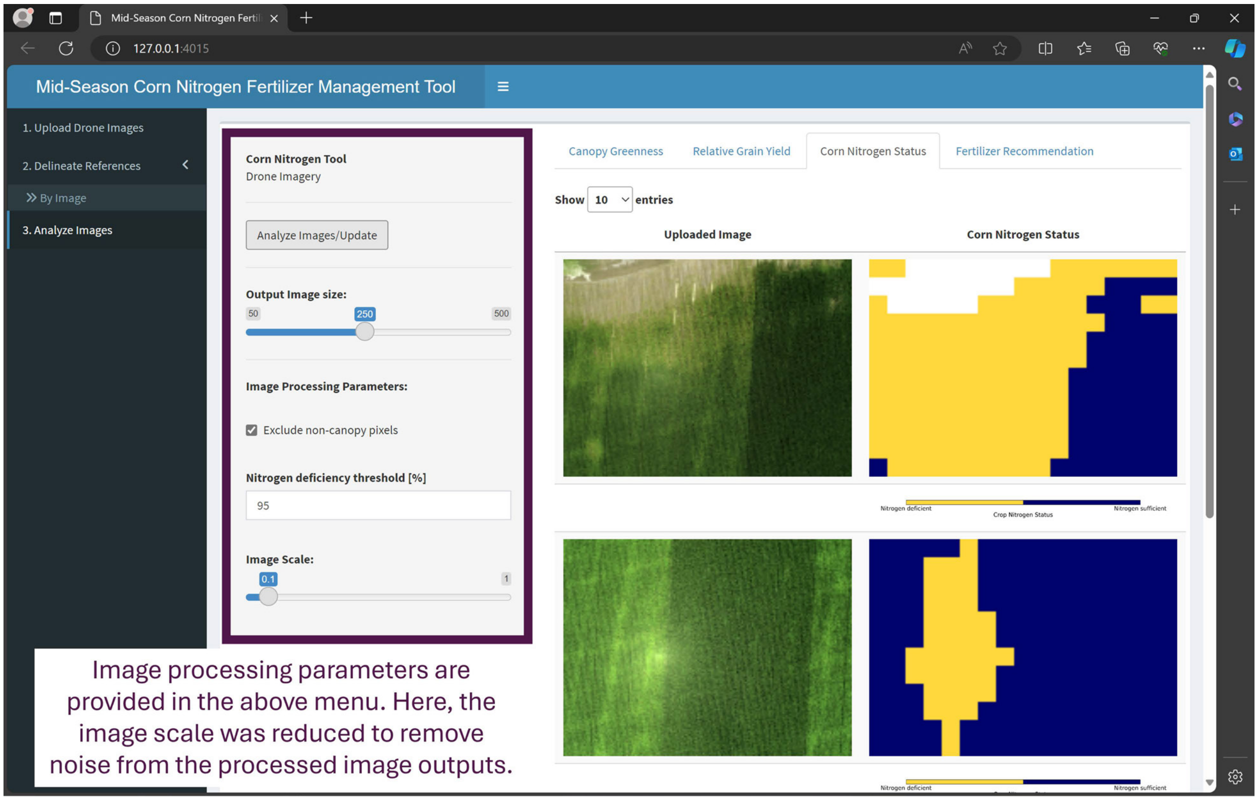
Nitrogen deficiency threshold [%]: 95

Image Scale: 1

Show 10 entries

Mid-season corn nitrogen status is displayed in the *Corn Nitrogen Status* tab.

Fig. 8. Mid-season corn nitrogen status assessment. The user may move between tabs without having to re-process images.



Output Image size: 250

☑ Exclude non-canopy pixels

Nitrogen deficiency threshold [%]: 95

Image Scale: 0.1

Show 10 entries

Image processing parameters are provided in the above menu. Here, the image scale was reduced to remove noise from the processed image outputs.

Fig. 9. The user may change the processed image size to adjust the display to different screen sizes. The user may also determine whether the non-canopy pixels should be excluded during the data processing. When excluded, the non-canopy pixels appear as white in the processed image outputs. Moreover, the user may change the relative grain yield threshold for yield-limiting nitrogen deficiency detection (95% by default) and re-scale the image to a coarser resolution to minimize noise.

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 pursuing agriculture-related majors across the state of Arkansas. Agriculture and agriculture-related professions are the largest employers in the state. This one-week experience enhances students' leadership and employability skills, provides first-hand networking opportunities with potential employers, and highlights Arkansas' agriculture industry's vast resources, services, and careers. The call for applications goes out to all colleges with agriculture-related academic departments. Institutions with agriculture departments will be guaranteed a set number of seats if they designate participants by a specified date. Following the initial application deadline, the remaining unfilled seats will be open to any interested applicants, regardless of institutional affiliation.

Introduction

Agriculture is Arkansas' largest industry, adding around $16 billion to the state's economy in 2020. Of Arkansas's many agricultural products, 23 products ranked in the top 25 in the United States (ADA-NRD, 2021). According to the U.S. Bureau of Labor Statistics (BLS), employment opportunities between 2020 and 2025 will remain strong for new college graduates interested in food, agriculture, renewable natural resources, and the environment across the United States. 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. Employment opportunities in occupations related to food, agriculture, renewable natural resources, and the environment are expected to grow 2.6% between 2020 and 2025 for college graduates with a bachelor's or higher degree.

As new graduates enter the workforce, there is a training gap between technical skills and knowledge and soft skills employers desire. Among the career readiness competencies identified by the National Association of Colleges and Employers (NACE), graduates who successfully transition into the workplace possess professionalism. The NACE defines professionalism as demonstrating personal accountability and effective work habits, e.g., punctuality, working productively with others, time workload management, and understanding the impact of non-verbal communication on professional work image.

Procedures

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

Participants engage in leadership and team-building activities 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, participants travel across the state to pre-arranged tour sites to visit facilities and network with professionals. The tour allows students to experience firsthand the diversity of opportunities within Arkansas' agriculture industry. Growers, producers, processors, manufacturers, educators, and research facilities will host students across Arkansas.

During the week of 15–19 May 2023, twelve college juniors and seniors participated in the Arkansas Future Ag Leaders Tour. Students enrolled at five Arkansas institutions and three out-of-state institutions participated, including the following institutions:

- University of Arkansas – Fayetteville (3 students)
- Southern Arkansas University (2 students)
- Arkansas State University – Jonesboro (2 students)
- Arkansas State University – Beebe (1 student)
- University of Central Arkansas (1 student)
- Central State University, Ohio (1 student)
- Oklahoma State University, Oklahoma (1 student)
- Texas A&M University-Commerce, Texas (1 student)
- Majors of the tour participants included:
- Agriculture Business (4 students)
- Agriculture Education (4 students)
- Animal Science (1 student)
- Sustainable Agriculture and Food Systems (1 student)
- Family and Consumer Science (1 student)
- Plant and Soil Science (1 student)

The 5-day professional development opportunity included professionalism skills and team building to kick off the week on Monday, 15 May. On Tuesday, 16 May, participants traveled across the state of Arkansas on a tour bus to visit and hear from representatives from many areas of the agriculture industry, including:

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

- Anheuser-Busch, Jonesboro
- Cooperative Extension Service, Little Rock, and White County
- Woodruff County Electric Coop, Forrest City
- Farm Credit, Hope
- Evergreen Packing, Pine Bluff
- Riceland, Stuttgart
- Farm Bureau, White County
- Peco Foods, Batesville
- RiceTech, Harrisburg
- Greenway Equipment, Newport
- Dabbs Farm, Stuttgart
- Arkansas Department of Agriculture, Little Rock
- Natural Resources Conservation Services (NRCS), Little Rock

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). Participants 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.

Practical Applications

The Arkansas Future Ag Leaders Tour gives a broad view of the agriculture industry in Arkansas and just a few of the many employment opportunities available. As the aging workforce retires, many vacancies are waiting to be filled. The Ag Leaders Tour introduces college students to employers and career opportunities they may be unaware of or reinforces preexisting career goals. As participants travel around the state, they are also introduced to different communities where they may want to live. To keep Arkansans students working in their home state, the Ag Leaders Tour helps participants understand the vast opportunities and support systems already in place for careers in agriculture. The Ag Leaders Tour also prepares participants with professional and soft skills often overlooked by educators and assumed to exist by employers, such as networking, professionalism, verbal communication, interview skills, resume development, and understanding company culture. The Ag Leaders Tour is the first opportunity for many participants to network with other agriculture students their age outside of their home institution, beginning lifelong friendships and working relationships. Lastly, participants in the Ag Leaders Tour discuss issues and policies impacting Arkansas farmers and the agriculture industry. This awareness helps them to be better prepared to support and contribute to the success of Arkansas agriculture.

Acknowledgments

This educational project was made possible with corn and grain sorghum check-off funds administered by the Arkansas Corn and Grain Sorghum Board through a partnership with the University of Arkansas System Division of Agriculture and the Cooperative Extension Service.

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Table 1. Participants were asked to write one thought per piece of paper and place their responses on a sticky wall. The question was, “What did you learn from participating in the 2023 Arkansas Future Ag Leaders Tour?”

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

Table 2. Participants were asked to write one thought per piece of paper and place their responses on a sticky wall. The question was, “What will you apply in the future as a result of your participation in the 2023 Arkansas Future Ag Leaders Tour?”

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

Application of Supercritical Carbon Dioxide to Enhance the Aroma of Whole Sorghum Flour for Use in Sorghum Cookies

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

Abstract

Sorghum is a promising ingredient for new food products due to its high fiber content, slow digestibility, drought resistance, and gluten-free nature. One of the main challenges in sorghum-based products is the unpleasant aroma compounds found in grain sorghum. Therefore, in this study, sorghum flour was treated via supercritical carbon dioxide (SC-CO_2) to remove undesired aroma compounds. The resulting SC-CO_2-treated flours were used to generate dough for 3D food printing. At the optimized conditions, sorghum cookies were 3D-printed using 60% water and a nozzle diameter of 0.059 in. All dough samples produced with untreated and SC-CO_2-treated sorghum flours exhibited shear-thinning behavior. Changing the treatment pressure (1160–2176 psi) or temperature (104, 140 °F) did not significantly affect the viscosity of the dough samples. Moreover, the sorghum cookie doughs had higher G' and G'' values after the SC-CO_2 treatments (G' > G''). Doughs generated from flours treated at 2176 psi, 104 °F and 1160 psi, 140 °F showed lower adhesiveness compared to the ones produced from untreated flour, whereas 2176 psi, 140 °F treatment did not affect the adhesiveness. After baking, the 3D-printed cookies from SC-CO_2-treated flour exhibited significantly lower redness (a^*), but the hardness of the cookies was not affected by SC-CO_2 treatment. Overall, the SC-CO_2 treatment of sorghum flour did not negatively affect the quality parameters of the 3D-printed cookies while enhancing the aroma of the flour.

Introduction

The severe effects of global warming, such as droughts and floods, as well as the growing demand for sustainable sourcing, make searching for drought-resistant crops essential. Such crops could serve as sustainable alternatives to commercial staple grains. In the summer of 2023, several states in the United States (i.e., Tennessee and Mississippi) were categorized as "D4: Exceptional drought" areas (USDA, 2023). This poses a significant concern for the future of agriculture, which deems it essential to investigate crops that can thrive in arid conditions and serve as a sustainable alternative to commonly cultivated grains.

Grain sorghum is a cereal crop that originates from Sub-Saharan Africa, which makes it highly valued in semiarid and arid regions due to its drought-resistant nature (Kapanigowda et al., 2013). Moreover, owing to its astonishing natural diversity, sorghum can thrive on over 80% of the world's arable land, even on those unsuitable for other crops (Stefoska-Needham and Tapsell, 2020). According to the Food and Agricultural Organization of the United Nations (FAO), the United States was the largest sorghum producer in 2021, with approximately 24912.235 million lb, followed by Nigeria and India with 14770.971 and 10582.188 million lb, respectively (FAO, 2021). Although sorghum is directly consumed in the human diet in Asia and Africa either by incorporating it with other grains or plainly (porridge, couscous, beer, tortilla, popped sorghum, etc.), the vast majority is used for ethanol production and livestock feed in the United States (Alvarenga et al., 2018; Appiah-Nkansah et al., 2018; Vázquez-Araújo et al., 2012).

Sorghum has been studied as a gluten-free alternative to wheat for staple bakery products such as breads, cakes, and cookies (Curti et al., 2022). Cookies are one of the most popular baked goods due to their convenience, nutritional value, simple ingredients, and availability of various types at reasonable prices (Dayakar Rao et al., 2016). In addition, economic evaluations demonstrated that sorghum is an affordable grain, making it a cost-effective and high-value option (Ciacci et al., 2007; Olawoye et al., 2017). Nevertheless, one of the biggest challenges in sorghum-based goods is its unpleasant aroma due to the naturally occurring odor-active compounds (i.e., alcohols, aldehydes, benzene derivatives) released by grain sorghum. Several attempts have been made to remediate the aroma and flavor handicap of sorghum by either masking or removing the off-aroma contributing compounds to enhance its palatability and customer acceptance (Tuhanioglu et al., 2023).

Supercritical carbon dioxide (SC-CO_2) technology provides a green extraction method that utilizes carbon dioxide (CO_2) as a solvent. CO_2 is preferred due to its abundance, inertness, non-toxic nature, and mild critical temperature (87.8 °F) and pressure (1073 psi). Moreover, SC-CO_2 has been shown to be effective in extracting volatile compounds (VC) from various plant materials (Díaz-Maroto et al., 2002; Vatansever and Hall, 2020). Our previous study showed that about 89% of the total VCs were removed from white whole sorghum flour through pure SC-CO_2 at the optimized conditions (2176 psi, 140 °F, 2 h) (Tuhanioglu et al., 2023). As discussed above, one application of the SC-CO_2-treated sorghum flours can be in the

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generation of gluten-free cookies. However, to the best of our knowledge, no study has investigated the effects of SC-CO_2 treatment on the quality parameters of cookies generated from sorghum flour. Therefore, the aim of this study was to investigate the effects of SC-CO_2 treatments on the 3D printability and quality parameters of sorghum flour cookies. Furthermore, the microstructure of the SC-CO_2-treated flours and the rheological, textural, and color properties of the cookies were determined.

Procedures

SC-CO_2 Treatment

All volatile extractions were performed using a lab-scale SC-CO_2 extractor (Supercritical Fluid Technologies, Inc., Del., USA) according to our previous study (Tuhanioglu et al., 2023). The processing variables (pressure, temperature, and time) were chosen based on our previous study (Tuhanioglu et al., 2023). A pressure of 2176 psi and a temperature of 140 °F were tested as the optimal extraction conditions. In addition, two other sets of conditions were tested to evaluate the effects of pressure and temperature (1160 psi, 140 °F and 2176 psi, 104 °F) on the performance of sorghum flour.

Microstructure of the SC-CO_2-Treated Sorghum Flours

The method described by (Kaur and Ubeyitogullari, 2023) was used to determine the morphology of the sorghum flour samples. Scanning electron microscopy (SEM) imaging of the samples was carried out using an FEI NovaNanolab200 Dual Beam system equipped with a 30 kV SEM FEG column and a 30 kV FIB column (FEI Company, Ore., USA). The samples were coated with a layer of gold using the EMITECH Sputter Coater (Mass., USA).

Rheological Properties of Cookie Dough

Rheological behaviors of the cookie doughs were carried out by a modular compact rheometer (model MCR 302e, Anton Paar, Graz, Austria) equipped with a parallel plate geometry of 1.968 in diameter (PP50). The distance between the parallel plate and the surface was adjusted to 0.078 in. Apparent viscosity was monitored at a 0.1–100 s^{-1} shear rate interval.

Cookie Formation

The cookie dough recipe was adapted from (Rai et al., 2014) with minor adjustments. The cookie dough was prepared by combining whole grain sorghum flour (100%), granulated sugar (58%), shortening (28%), baking soda (1%), salt (0.9%), and water (40%, 60%, or 80%) in a mixing cup, where the concentration (w/w) of ingredients are presented as wet flour basis. For consistent cookie formation, the cookies were generated using an extrusion-based 3D food printer (Foodini, Natural Machines, Spain). The printability of the ink was optimized by adjusting the water content, namely to 40%, 60%, and 80%. The cookies were baked in a conventional oven at 400 °F for 16 min immediately after 3D printing. Texture analyses were performed via a Texture Analyzer Model TA-XT2i (Texture Technologies Corp., N.Y., USA). The color values of the cookies were determined using a colorimeter.

Statistical Analysis

The data were analyzed on JMP Pro software v. 17.0.0 (SAS Institute, Inc., Cary, N.C., USA) and presented as mean ± standard deviation. Tukey's multiple comparison test was used to compare means at $\alpha = 0.05$ significance level based on duplicates.

Results and Discussion

Microstructure of the SC-CO_2-Treated Flours

The application of SC-CO_2 on sorghum flours at different pressures and temperatures caused notable alterations on the surfaces of the particles (Fig. 1). The surface of the sorghum particles that were not treated with SC-CO_2 appears to be smooth with some minor fractures, as seen in Fig. 1A. The optimal treatment application (2176 psi, 140 °F) resulted in surface deformations with noticeable cracks (Fig. 1B). Furthermore, at 104 °F and 2176 psi, the granules suffered severe damage, resulting in the formation of cracks and protrusions (Fig. 1C). This caused the granules to lose their original structure and become almost irregular in appearance. At low temperature (104 °F) and high pressure (2176 psi) conditions, CO_2 was at its densest level in comparison to other conditions, which probably led to more efficient extraction of lipids. Consequently, the defatted flours became more susceptible to deform induced by physical impacts. On the other hand, the similarity between the untreated sample and those treated at 1160 psi, 140 °F is striking (Fig. 1D). This could be attributed to the fact that the surface of the flour particles potentially remained unaltered under low pressure (1160 psi) conditions.

Rheological Properties of Cookie Dough

Figure 2 depicts the apparent viscosity of sorghum cookie dough samples as a function of shear rate. SC-CO_2 treatment resulted in measurable changes in rheological behaviors. All samples display a shear-thinning behavior (pseudoplastic fluid) that helps in the extrusion of ink from nozzles with smaller diameters (i.e., 0.059 in) (Liu et al., 2021). Although the viscosity curves of the samples overlapped until a shear rate of 3 s^{-1}, they began to diverge afterward. The viscosity of the untreated sample plummeted after 10 s^{-1} (at 0.0013 lbf·s/in.^{2} viscosity), displaying an erratic behavior between the rates of 10–40 s^{-1}. This pattern may have occurred due to a break in the dough's network structure or a measurement error caused by the rheometer. Furthermore, the viscosity of the samples treated with SC-CO_2 started declining sharply after 35 s^{-1}, which was higher than the shear rate observed in the untreated sample.

3D Printability of the Doughs Generated from SC-CO_2-Treated Flours

It is crucial to understand the impact of food processing (i.e., SC-CO_2 extraction) on their 3D printing properties to expand its potential use. Ensuring a homogenous ink and removing air pockets is vital for successful 3D printing (Ahmadzadeh et al., 2024). 3D printing was used to generate cookies as it can produce objects with high precision, which is critical for further measurements such as texture analysis. The amount of water added to the dough significantly affected its 3D printability, as shown in Fig. 3A–F. When 60% (wet sorghum flour basis, w/w) of water was added to the dough, it appeared to be homogenous and smoothly printable (Fig. 3B–E). Moreover, if the water content was too low, the dough became too firm to print. This was observed when the dough had a 40% water content and was found to be unprintable (Fig. 3A). On the other hand, excessive water addition makes the dough less cohesive for 3D printing. Increasing the water content to 80% made the dough printable despite appearing sloppy and prone to deformation (Fig. 3F). Considering the targeted geometry, a water content of 60% was selected as the ideal amount for printing the dough and producing cookies.

Texture and Color Analyses

Texture evaluation is crucial to determine the sensory qualities of food, which helps in making informed decisions for high-quality products that meet consumer expectations. Table 1 illustrates the textural properties of the 3D-printed cookie dough samples and the hardness of the baked cookies. The treated dough samples and cookies exhibited similar levels of hardness ($P > 0.05$). Furthermore, samples treated at 2176 psi, 140 °F displayed similar springiness, cohesiveness, chewiness, and gumminess compared to the other samples, as the differences were not statistically significant ($P > 0.05$).

During the baking process, the surface color of cookies changes due to the Maillard reaction between reducing sugars and amino acids, as well as starch dextrinization and sugar caramelization (Broyart et al., 1998). The surface colors of the cookies are displayed as L^*, a^*, and b^* values in Table 2. The surface color of a baked product is crucial for its initial appeal, along with texture and taste. In spite of the significant differences between the redness (a^*) of cookies made of untreated flours and SC-CO_2-treated flours (2176 psi, 140 °F) ($P < 0.05$), there were no significant differences in lightness (L^*) and yellowness (b^*) between the cookies ($P > 0.05$).

Practical Applications

The undesired volatile compounds of sorghum flour were significantly reduced by SC-CO_2 extraction. The 3D printability of the sorghum flour cookie dough was not significantly affected by the SC-CO_2 treatment. Therefore, grain sorghum could become popular by implementing green aroma-enhancing technologies to create gluten-free alternative products with improved flavor. This study has the potential to increase the consumption of grain sorghum, which in turn could boost demand and profitability for Arkansas sorghum producers. Overall, the developed SC-CO_2 aroma enhancement approach coupled with 3D food printing can help enhance the appeal of foods without negatively affecting their quality parameters.

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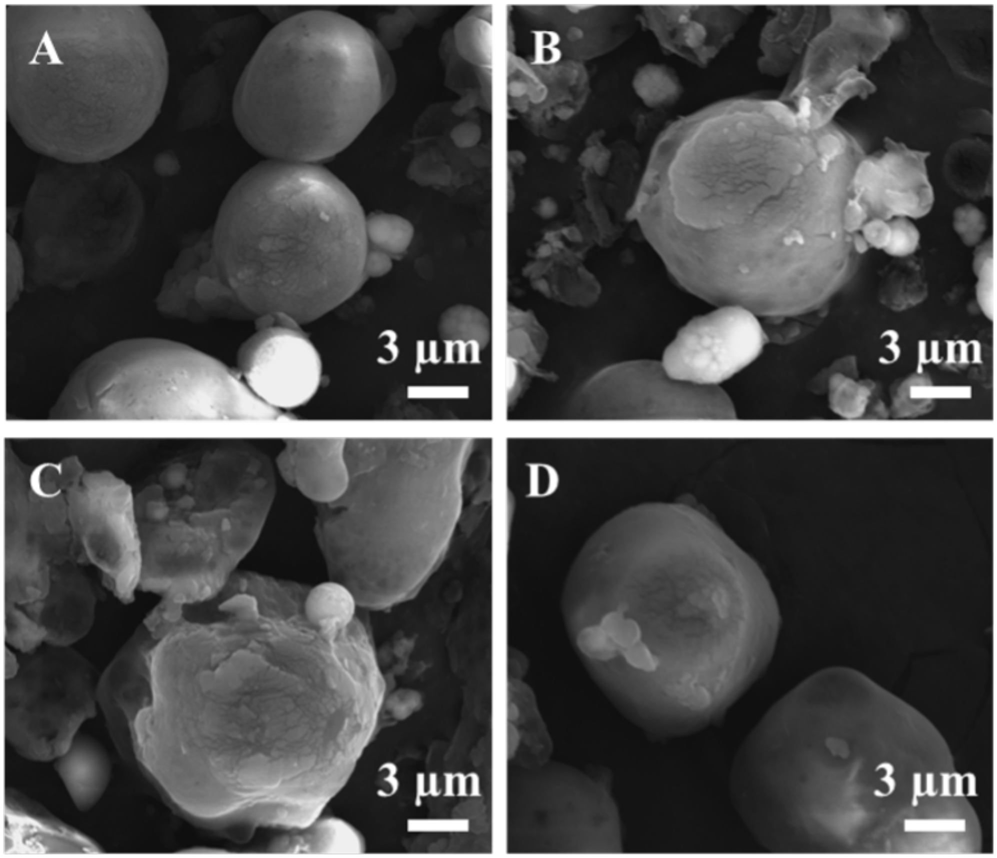

Fig. 1. The scanning electron microscopy images of the untreated (A) and supercritical carbon dioxide (SC-CO_2)-treated white whole sorghum flours (B: 2176 psi – 140 °F, C: 2176 psi – 104 °F, D: 1160 psi – 140 °F).

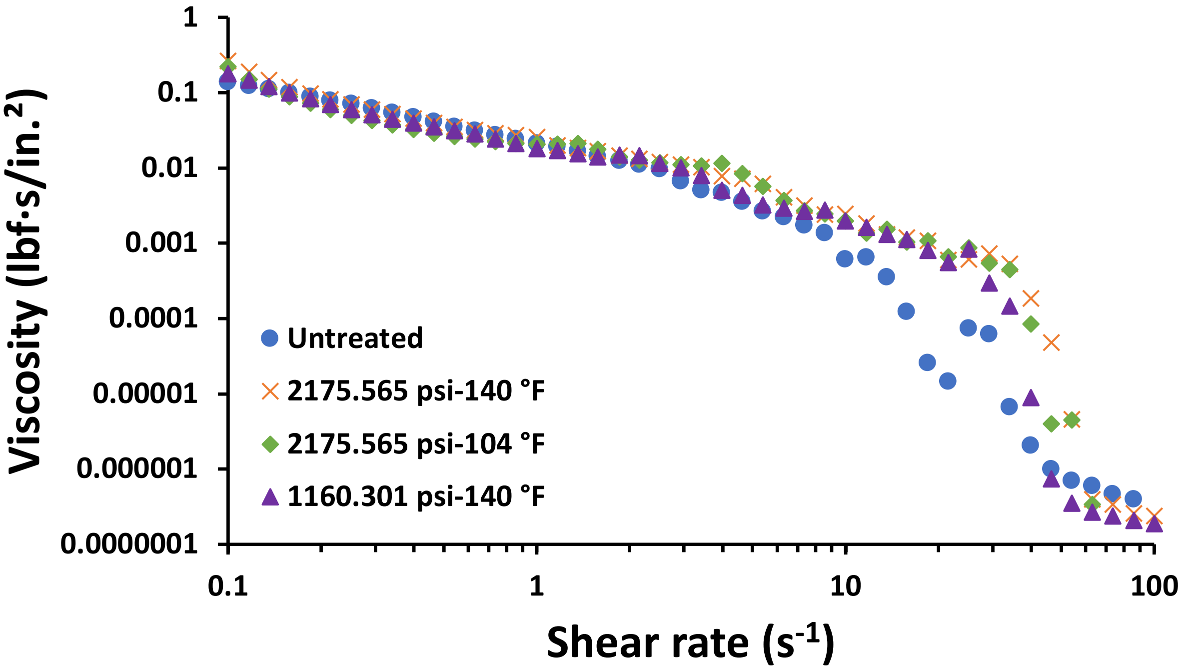

Fig. 2. Apparent viscosities of sorghum cookie dough samples at 77 °F.

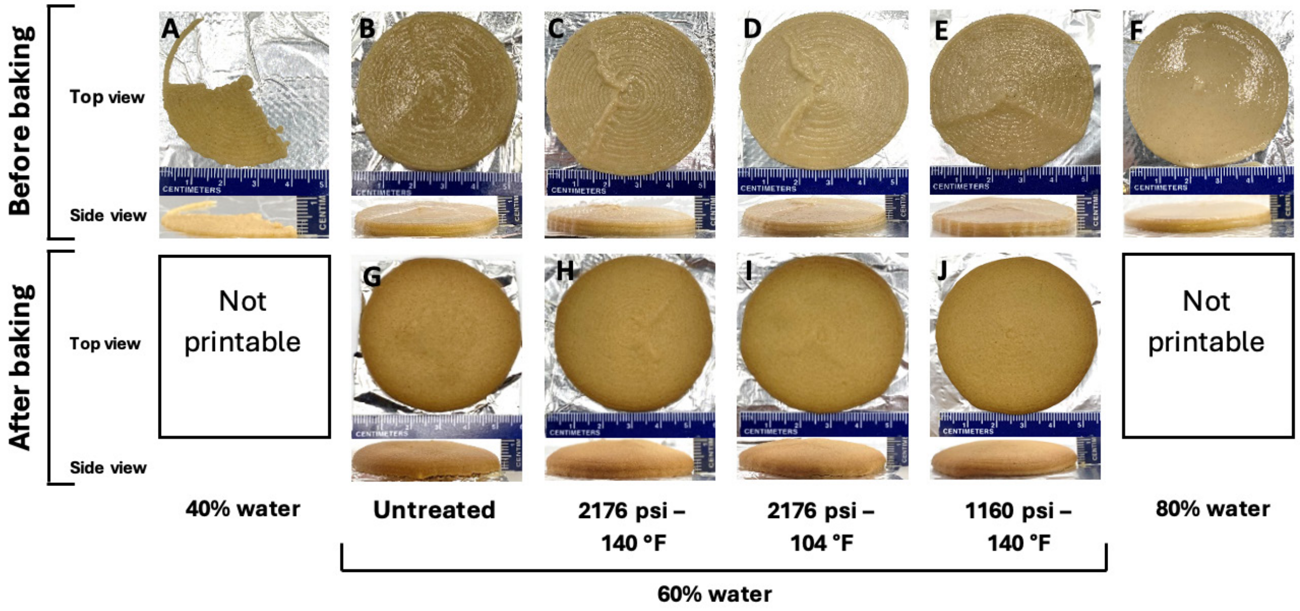

Fig. 3. The top and side views of the 3D-printed sorghum cookie samples before (A–F) and after (G–J) baking.

Table 1. Textural characteristics of the cookie doughs before and after baking.

	Cookie dough samples						Baked cookies
	Hardness	Adhesiveness	Springiness	Cohesiveness	Chewiness	Gumminess	Hardness
	(lb)	(lb x s)					(lb)
Untreated	0.455 ± 0.007 A[†]	-0.063 ± 0.003 A	0.56 ± 0.02 A	0.15 ± 0.03 A	17.77 ± 2.78 A	31.61 ± 5.99 A	1.892 ± 0.140 A
2175.565 psi – 140 °F	0.480 ± 0.044 A	-0.057 ± 0.004 A	0.45 ± 0.15 A	0.20 ± 0.01 A	20.68 ± 10.37 A	44.74 ± 7.21 A	2.578 ± 0.485 A
2175.565 psi – 104 °F	0.585 ± 0.078 A	-0.038 ± 0.000 B	0.38 ± 0.05 A	0.15 ± 0.01 A	15.50 ± 0.38 A	41.20 ± 6.72 A	2.193 ± 0.304 A
1160.301 psi – 140 °F	0.480 ± 0.033 A	-17.20 ± -0.037 B	0.39 ± 0.02 A	0.15 ± 0.01 A	13.03 ± 1.01 A	33.25 ± 0.84 A	2.369 ± 0.161 A

[†] Means within the same column that are not connected by the same letter are significantly different (*P* < 0.05).

Table 2. Surface color measurement results of sorghum cookies after baking.

	*L**	*a**	*b**
Untreated	63.18 ± 1.00 A[†]	7.77 ± 0.55 A	24.99 ± 0.20 A
2176 psi – 140 °F	64.18 ± 0.08 A	6.48 ± 0.09 B	24.45 ± 0.11 A
2176 psi – 104 °F	65.49 ± 0.21 A	6.48 ± 0.23 AB	25.84 ± 1.22 A
1160 psi – 140 °F	64.10 ± 1.75 A	6.94 ± 0.10 AB	24.07 ± 0.38 A

[†] Means within the same column that are not connected by the same letter are significantly different (*P* < 0.05).

Corn and Grain Sorghum Enterprise Budgets and Production Economic Analysis

B.J. Watkins[1]

Abstract

Corn and Grain Sorghum enterprise budgets have been developed that are flexible for representing alternative production practices and cropping systems of Arkansas producers. Interactive budget programs apply consistent methods across major field crops grown in Arkansas. Production practices for base budgets represent the University of Arkansas System Division of Agriculture Cooperative Extension recommendations from crop specialists and the Corn and Grain Sorghum Research Verification Program. Users can customize unique budgets based on 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 and research verification trials. The crop enterprise budgets are designed to give producers the ability to estimate the types of costs associated with production and potential returns. Cost and returns analysis within the budgets investigate factors impacting farm profitability by allowing users to update various field activities associated with one's unique farming techniques and operations. Currently, 9 corn and grain sorghum budgets are released each winter, with updates in the spring. Corn is divided into two seed types: conventional and stacked gene, and further by irrigation practice. Grain sorghum's only distinction is based on irrigation practice: furrow, pivot, and no irrigation.

Introduction

2023 saw its fair share of challenges for Arkansas corn and grain sorghum producers. Input price volatility and supply issues of certain products were ongoing challenges for producers in maintaining profitability. In 2023, commodity prices recouped some of the losses witnessed during the last two years, with a $1.25/bu. increase in price for corn and a $1.10/bu. increase for grain sorghum. Urea prices were down $50/ton, but diesel fuel was up nearly $2/gal from $2.60/gal to $4.50/gal. Herbicide costs were down $12.12/ac in 2023 for stacked gene corn, $7.80/ac for conventional corn, and $5.07/ac for grain sorghum. Overall, net returns for stacked-gene corn increased by $220.26/ac, $214.48/ac for conventional corn, and $72.16/acre for grain sorghum compared to 2022. With price volatility and ever-changing profitability potential, it is essential that producers have a tool to calculate costs and returns for various production techniques and alternatives to estimate potential net profitability scenarios. This profitability measure also needs to encompass changes in input costs and production practices producers seek to adopt for their unique operations. The objective of this project is to develop an interactive, computational program that will enable the 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 estimated directly from information available from suppliers, producers, and knowledgeable sources, as well as costs calculated from engineering formulas developed by the American Society of Agricultural and Biological Engineers. Input costs for fertilizers and chemicals are determined by applying prices for typical input rates. Input prices, custom hire rates, and fees are estimated using information from industry contacts and bids from local suppliers. Methods of calculating the operating expenses presented in crop enterprise budgets reflect producers' methods for obtaining price information for their farms. A survey of local retailers, producers, and professionals within the ag sector is conducted to obtain the prices used in the budgets. However, the prices used in the budgets fail to factor in discounts from buying products in bulk, preordering items for a lower price, and other promotions that may be available at the point of purchase.

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

The capital recovery method determines machinery's ownership costs, 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 and actual cash expenses for machinery. Amortization factors applied for capital recovery estimation coincide with prevailing long-term interest rates (Edwards, 2005).

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Interest rates in this report are from Arkansas lenders, as reported in the fall of 2023. Representative prices for machinery and equipment are based on contacts with Arkansas dealers, manufacturer's suggested retail prices (MSRP), and reference sources (Deere & Company 2023; MSU 2023). Revenue in crop enterprise budgets is the product of expected yields from following Extension recommended practices under optimal growing conditions combined with actual yield data from research verification plot trials and commodity prices received data from the National Agricultural Statistics Service (USDA-NASS).

Results and Discussion

The University of Arkansas System Division of Agriculture's Department of Agricultural Economics and Agribusiness (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 Extension 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 among individual farms due to management preferences believed to be the best methods for the greatest success as land stewards. Analyses are for generalized circumstances focusing on consistent and coordinated application of budget methods for all field crops. This approach results in meaningful costs and returns comparisons for decision-making regarding acreage allocations among field crops. Results should be regarded only as a guide, and individual farmers should develop budgets for their specific production practices, soil types, and various unique circumstances for their farms.

Table 1 presents an example of the 2023 budget developed for furrow irrigated corn utilizing field activities associated with a stacked gene production system in Arkansas. Costs are presented on a per-acre basis and with an assumed 1,000 acres. Program flexibility allows users to alter all variables to uniquely represent many farm situations. Returns to total specified expenses were $479.70/acre. Net returns for 2023 were estimated to be within $10 dollars of expected 2022 returns. The budget program includes similar capabilities for center pivot irrigated and non-irrigated corn, stacked gene and conventional corn evaluation, and grain sorghum production. Table 2 presents the 2023 grain sorghum non-irrigated enterprise budget. The budgets assume grower-owned land, and costs are given on a per-acre basis. In 2023, net returns from non-irrigated sorghum were expected to be -$45.78 compared to last year's expected net returns of -$27.68/ac. Net returns decreased due to decreasing commodity prices over the past year, plus a slight increase in 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, enter the term "crop budgets" in the search box, and the first option available is the crop enterprise budget page. Here, on the Crop Enterprise Budgets for Arkansas website, users can find a list of the available crop budgets. The interactive budgets utilize Microsoft Excel. An updated accessible tool is in the development stage and will be available once it is complete. (The current estimated release is in the fall/winter of 2024.) The benefits provided by the economic analysis of alternative corn and grain sorghum production methods offer a significant reduction in financial risk faced by producers. Arkansas producers can develop economic analyses of their individual production activities with the budget program. Unique crop enterprise budgets developed for individual farms are helpful in determining credit requirements and for planning production methods with the most significant potential for financial success. Flexible budgets enable farm financial outlooks to be revised during the production season as inputs, input prices, yield expectations, and commodity prices change. For the 2023 crop budgets, an update reflecting changes in fuel and fertilizer prices was made in the spring. The update also included changes in commodity pricing with an increase in expected net revenue. Incorporating changing information and circumstances into budget analysis assists producers and lenders in making decisions that manage financial risks inherent in agricultural production.

Acknowledgments

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Table 1. 2023 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	6.50	1,397.50
Operating Expenses		**Unit**	**Quantity**	**Price/Unit[b]**	**Costs**
Seed, Includes Applicable Fees	100%	ac	1	123.52	123.52
Nitrogen (Urea 46-0-0)	100%	lb/ac	435	0.29	126.15
Phosphate (0-46-0)	100%	lb/ac	130	0.38	49.40
Potash (0-0-60)	100%	lb/ac	175	0.29	51.28
Ammonium Sulfate (21-0-0-24)	100%	lb/ac	100	0.26	26.30
Zinc Sulfate	100%	lb/ac	29.00	1.73	50.17
Other Nutrients, Including Poultry Litter	100%	ac	1.00	0.00	0.00
Herbicide	100%	ac	1	81.09	81.09
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	3	8.00	24.00
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	8.00	0.00
Machinery and Equipment					
Diesel Fuel, Pre-Post Harvest	100%	gal	3.800	3.85	14.63
Repairs and Maintenance, Pre-Post Harvest	100%	ac	1	7.99	7.99
Diesel Fuel, Harvest	100%	gal	2.027	3.85	7.81
Repairs and Maintenance, Harvest	100%	ac	1	8.58	8.58
Irrigation Energy Cost	100%	ac-in.	14	4.55	63.66
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%	hr	0.800	12.45	9.97
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 %	8.00	681.94	27.28
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					**$805.96**
Returns to Operating Expenses					**$591.54**
Capital Recovery and Fixed Costs					
Machinery and Equipment		ac	1	80.79	80.79
Irrigation Equipment		ac	1	27.01	27.01
Farm Overhead[c]		ac	1	4.04	4.04
Total Capital Recovery and Fixed Costs					**$111.84**
Total Specified Expenses					**$917.80**
Net Returns					**$479.70**

[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. 2023 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	6.00	390.00
Operating Expenses		**Unit**	**Quantity**	**Price/Unit[b]**	**Costs**
Seed, per acre	100%	lb	5	3.72	16.74
Nitrogen (Urea, 46-0-0)	100%	lb	200	0.29	58.00
Phosphate (0-46-0)	100%	lb	110	0.38	41.80
Potash (0-0-60)	100%	lb	100	0.29	29.30
Ammonium Sulfate (21-0-0-24)	100%	lb	0	0.26	0.00
Boron 15%	100%	lb	0.00	1.73	0.00
Other Nutrients, Including Poultry Litter	100%	ac	1.00	0.00	0.00
Herbicide	100%	ac	1	48.27	48.27
Insecticide	100%	ac	1	32.68	32.68
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	5	8.00	40.00
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	8.00	0.00
Machinery and Equipment					
Diesel Fuel, Pre-Post Harvest	100%	gal	2.742	3.85	10.56
Repairs and Maintenance, Pre-Post Harvest	100%	ac	1	7.65	7.65
Diesel Fuel, Harvest	100%	gal	2.027	3.85	7.81
Repairs and Maintenance, Harvest	100%	ac	1	7.41	7.41
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%	hr	0.529	12.45	6.59
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 %	8.00	337.53	13.50
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					**$367.93**
Returns to Operating Expenses					**$22.07**
Capital Recovery and Fixed Costs					
Machinery and Equipment		ac	1	64.62	64.62
Irrigation Equipment		ac	1	0.00	0.00
Farm Overhead[c]		ac	1	3.23	3.23
Total Capital Recovery and Fixed Costs					**$67.85**
Total Specified Expenses					**$435.78**
Net Returns					**-$45.78**

[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

2023–2024 Corn and Grain Sorghum Research Proposals

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	$80,616
L. Connor		Performance Crop Insurance as a Risk Management Tool for Corn and Grain Sorghum Producers in Arkansas	2 of 3	$29,810
M. Daniels		The Arkansas Discovery Farm Program	2 of 3	$5,000
T. Faske	D. Rivera	Assessing Management Options for Corn Nematodes in Arkansas	2 of 3	$53,713
V. Ford	B. Watkins	Corn and Grain Sorghum Enterprise Budgets and Production Economic Analysis	Ongoing	$10,000
J. Kelley	T. Roberts	Optimizing Plant Population and Nitrogen Rate in Corn	1 of 3	$31,000
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	$4,498
J. Kelley	T. Faske, T. Spurlock, T. Roberts, T. Barber, G. Studebaker, and C.G. Henry	Corn and Grain Sorghum Research Verification Program	3 of 3	$126,000
T. Roberts	J. Kelley and G. Drescher	Fine-Tuning Potassium Recommendations and Investigating Intensive Tissue Analysis for Sustainable Corn Production	2 of 3	$55,934
T. Roberts	J. Kelley and G. Drescher	Comparing the Effects of Nitrogen Sources and Application Strategies on Corn Performance	3 of 3	$75,188
G. Studebaker	N. Bateman, B. Thrash, and N. Joshi	Assessing Susceptibility of Insect Pests of Corn in Storage to Selected Insecticides	2 of 3	$40,563
A. Ubeyitogullari		Developing a Green Integrated Approach to Enhance the Utilization of Grain Sorghum in Foods	3 of 3	$42,205
B. Deaton		Economic Analysis of Corn and Grain Sorghum Production and Marketing Practices	1 of 3	$5,713
T. Spurlock	J. Kelley and J. Davis	Determining the Value Added of Starter Fertilizer with In-Furrow Fungicide on Corn	3 of 3	$26,000
B. Littlejohn		Use of Gossypol to Inhibit Reproduction in Domestic Hogs as a Model for Feral Hog Control	1 of 3	$30,000
A. Poncet	L. Purcell, T. Roberts, and J. Kelley	A Web Tool to Assess Mid-Season Nitrogen Fertilizer Needs from Aerial Imagery	3 of 3	$54,000
T. Roberts	A. Rojas and J. Kelley	Cover Crops in Corn Rotations–What Works and What Doesn't?	1 of 3	$46,599
B. Bluhm		Towards a Comprehensive Aflatoxin Solution: Creating and Integrating Novel Aflatoxin Control Resources for an Effective, Sustainable Management Strategy	1 of 3	$45,000

Continued

2023–2024 Corn and Grain Sorghum Research Proposals, continued

Principle Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
C. Henry	T. Spurlock and J. Kelley	Improving Irrigation Technology for Corn Production in Arkansas	1 of 3	$185,281
C. Henry		The Arkansas Irrigation Yield Contest	Year 6	$10,000
J. Robinson		Arkansas Future Ag Leaders Tour	2 of 3	$5,000
		Total Awards		**$962,120**
Projects Completed and Not Resubmitted This Year				
J. Kelley	*T. Roberts, T. Faske, G. Studebaker, and T. Barber*	Developing Profitable Irrigated Rotational Cropping Systems for Arkansas (Final year completing 9th year of project)	Completed	$0
S. Sadaka	*G. Atungulu and N. Joshi*	Utilization of Ozone Fumigation to Reduce Aflatoxin Contamination and Suppress Insects in Stored Corn (Year 3 of 3)	Completed	$0
L. Espinoza	*A. Poncet and C.G. Henry*	Implementation of Remote and Proximal Sensing Driven Practices in Corn Production (Year 3 of 3)	Completed	$0
L. Purcell	*T. Roberts and A. Poncet*	Calibrating Mid-Season N Fertilizer Rates Based Upon Leaf N Concentration and Remote Sensing (Year 3 of 3)	Completed	$0
B. Bluhm		Gene Editing: A New Approach to Overcome Mycotoxins and Environmental Stress in Arkansas Corn Production (Phase II) (Year 3 of 3)	Completed	$0
T. Roberts	*T. Spurlock, T. Faske, A. Rojas, and J. Kelley*	Implementing Cover Crops into Corn Rotations and the Impact on Soil Health (Year 3 of 3)	Completed	$0

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