Arkansas
Corn and Grain Sorghum Research Studies 2021

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

DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

ARKANSAS AGRICULTURAL EXPERIMENT STATION

July 2022

Research Series 687

This publication is available on the internet at: https://aaes.uada.edu/communications/publications/

Cover: Zinc deficiency of corn at Marianna, Arkansas, University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station.

Photograph by: Jason Kelley, University of Arkansas System Division of Agriculture, Cooperative Extension Service, Little Rock.

Layout and editing by Gail Halleck.

Arkansas Agricultural Experiment Station (AAES), University of Arkansas System Division of Agriculture, Fayetteville. Deacue Fields, Vice President for Agriculture; Jean-François Meullenet, AAES Director and Senior Associate Vice-President for Agriculture–Research. WWW/CC2022.

ISSN: 2692-1715 CODEN: AKAMA6

ARKANSAS
CORN AND GRAIN SORGHUM
RESEARCH STUDIES
– 2021 –

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

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

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

INTRODUCTION

The 2021 edition of the Arkansas Corn and Grain Sorghum Research Studies Series includes research results on topics pertaining to corn and grain sorghum production, including weed, disease, and insect management; economics; sustainability; irrigation; post-harvest drying; soil fertility; mycotoxins; cover crop management; and research verification program results.

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

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

The use of products and trade names in any of the research reports does not constitute a guarantee or warranty of the products named and does not signify that these products are endorsed or approved to the exclusion of comparable products. All authors are either current or former faculty, staff, or students of the University of Arkansas System Division of Agriculture or scientists with the United States Department of Agriculture, Agriculture Research Service.

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

Victor Ford, Jason Kelley, and Nathan McKinney II, Editors
University of Arkansas System Division of Agriculture,
Little Rock and Fayetteville, Arkansas

ACKNOWLEDGMENTS

The research results in this publication were made possible through funding provided by the Corn and Grain Sorghum producers of Arkansas and administered by the Arkansas Corn and Grain Sorghum Promotion Board. We express sincere appreciation to the producers and the Arkansas Corn and Grain Sorghum Promotion Board members for their vital financial support of these programs.

The Arkansas Corn and Grain Sorghum Promotion Board Members 2021–2022

Jacob Appleberry	Tillar, Arkansas
Jon Carroll	Moro, Arkansas
Trent Dabbs	Stuttgart, Arkansas
Kenny Falwell	Newport, Arkansas
Jason Felton	Marianna, Arkansas
David Gammill	Tyronza, Arkansas
Tommy Young	Tuckerman, Arkansas (Chairman)
Mark Lambert	Little Rock, Arkansas (Coordinator)

CONTENTS

VERIFICATION

DISEASES

INSECTS

WEED CONTROL

IRRIGATION

SOIL FERTILITY

AGRONOMY

MISCELLANEOUS

ENVIRONMENT AND SUSTAINABILITY

ECONOMICS

APPENDIX: CORN AND GRAIN SORGHUM RESEARCH PROPOSALS

2021 Corn and Grain Sorghum Research Verification Program

C. Capps,[1] J.P. Kelley,[2] B.J. Watkins,[3] and C.R. Stark Jr.[4]

Abstract

In 2021, the Corn and Grain Sorghum Research Verification Program (CGSRVP) conducted trials on 9 irrigated corn fields. Participating counties included Ashley, Desha (2 fields), Drew, Lonoke, Mississippi, Monroe, Poinsett, and Prairie. Corn grain yields averaged 226 bu./ac across the 9 fields. The Arkansas state average corn grain yield for 2021 was 184 bu./ac compared to the national average of 177 bu./ac (USDA-NASS, 2022). Fields were planted between 9 March and 16 April, with an average planting date of 2 April. Plant populations averaged 34,621 plants/ac. Fields were furrow irrigated between 3 to 6 times, and soil moisture sensors were used to assist with irrigation scheduling. Preplant fertilizer applied averaged 41-48-72-15-2 lb/ac of nitrogen, phosphorus, potassium, sulfur, and zinc, respectively. Total in-season fertilizer applied was 229-48-79-31-2 lb/ac of nitrogen, phosphorus, potassium, sulfur, and zinc, respectively. The resulting nitrogen fertilization program achieved 1 bu. of corn grain for every 1.01 lb/ac of nitrogen fertilizer applied. Economic returns to total costs/ac were $596.91 when no land charges were applied. Fertilizer/nutrients and seed cost were the largest input costs at $138.82 and $124.58 and accounted for 27% and 24% of total expenses, respectively.

Introduction

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

The CGSRVP started in 2000 after the initiation of a statewide checkoff program for corn and grain sorghum, which is distributed by the Arkansas Corn and Grain Sorghum Promotion Board. Since the inception of the program, there have been 167 corn or grain sorghum fields enrolled in the program in 35 counties.

Procedures

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

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

[1] Program Associate, Department of Crop, Soil, and Environmental Sciences, Monticello.
[2] Professor, Department of Crop, Soil, and Environmental Sciences, Little Rock.
[3] Instructor, Department of Agricultural Economics and Agribusiness, Conservation and Crop Budget Economist, Jonesboro.
[4] Professor Emeritus, College of Forestry, Agriculture & Natural Resources, University of Arkansas at Monticello.

Results and Discussions

Overall corn yields during the 2021 growing season ranged from 181.0 bu./ac in Desha County 1 to a high of 259.4 bu./ac in Desha County 2 (Table 1). The overall average yield of corn fields was 226 bu./ac. The state average corn yield for 2021 was 184 bu./ac (USDA-NASS, 2022). All corn fields were planted within the recommended planting date ranges from 9 March in Desha Co. 2 to 21 April in Poinsett Co., with an average planting date of 2 April. Harvest dates ranged from 19 August to 25 September. Plant populations averaged 34,621 plants/ac, which would be at a recommended level for most irrigated fields and hybrids.

Fertilizer application to fields closely followed current University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) recommendations and were based on soil analysis and yield goals (Table 2). Preplant fertilizer applied to corn fields averaged 41-48-72-15-2 lb/ac of nitrogen-phosphorus-potassium-sulfur-zinc, where nitrogen applied preplant or at planting totaled approximately 18% of the total nitrogen applied during the growing season. Side-dress nitrogen applied at the V4–V8 growth stage averaged 140 lb of nitrogen/ac with a nitrogen source of urea, ammonium sulfate, urea-ammonium nitrate, or a combination of those sources. A pre-tassel application of nitrogen, typically 100 lb of urea/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 229 lb N/ac when averaged across all fields. Applied nitrogen fertilizer resulted in an average yield of 226 bu./ac, which led to 1 bushel of corn grain for every 1.01 lb of nitrogen fertilizer applied.

Pest management practices followed current CES recommendations. None of the corn fields met thresholds requiring an insecticide application during the season, and 4 fields were aerially sprayed with a foliar fungicide at the R2 stage for southern rust (*Puccinia polysora*) control. Herbicides applied to corn fields varied but most commonly consisted of a combination of glyphosate, metolachlor, atrazine, and mesotrione that was applied in a one- or two-pass program.

Irrigation is an important management practice for Arkansas corn. Statewide, approximately 95% of the corn grown in the state in 2021 was irrigated (USDA-FSA, 2021). Irrigation initiation, frequency, and termination were scheduled with the help of the Arkansas Irrigation Scheduler program and the use of soil moisture sensors to determine soil moisture content. During 2021, overall irrigation requirements for corn were generally less than in previous years due to timely rains on some fields, and each field was furrow irrigated 4.8 times on average (Table 3) from ground, surface water, or a combination of each. Each furrow irrigation was estimated to provide 2 ac-in. of irrigation water. Average rainfall on corn fields in 2021 from planting to maturity was 21.89 in. demonstrating that total rainfall during the growing season may be adequate for corn production, but the poor distribution of rainfall throughout the season is one of the reasons that such a high percentage of Arkansas corn is irrigated.

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

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

with a maximum air temperature set at 86 °F and 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 2021 average GDDs accumulated at each field to reach the growth stages listed. These values align closely with reported GDDs needed to reach maturity for full-season hybrids (110–120 days) that are typically grown in Arkansas. The use of GDDs can accurately predict corn growth stages and assist in management decisions such as irrigation termination.

Economic Analysis

Records of field operations and inputs on each field were compiled by the CGSRVP coordinator, county extension agent, and producer and serve as the basis for estimating costs and economic returns that are discussed in this section. Production data from the 9 irrigated corn fields were applied to determine costs and returns above operating costs, as well as total specified costs. Operating costs and total costs per bushel indicate the commodity price needed to meet each cost type.

Production expenses are expenditures that would generally require annual cash outlays and would be included on an annual operating loan application. Actual quantities of all production inputs as reported by the cooperators are used in this analysis. Input prices are determined by data from the 2021 Crop Enterprise Budgets published by the Cooperative Extension Service and information provided by the producer cooperators. Fuel and repair costs for machinery are calculated using a budget calculator based on parameters and standards established by the American Society of Agricultural and Biological Engineers. Machinery repair costs are estimated values for full-service repairs, and actual cash outlays will differ as producers utilize employee labor or provide unpaid labor for equipment maintenance.

Operating expenses include production expenses, as well as interest paid on operating capital and all post-harvest expenses. Post-harvest expenses include hauling, drying, check-off fees, and other expenses typically incurred after harvest. Post-harvest expenses vary according to corn yield.

Ownership costs of machinery are determined by a capital recovery method that determines the amount of money that should be set aside each year to replace the value of equipment used in production. Machinery costs are estimated by applying engineering formulas to represent the prices of new equipment. This measure differs from typical depreciation methods, as well as actual annual cash expenses for machinery, but establishes a benchmark that estimates farm profitability.

Operating costs, total costs, costs per bushel, and returns are presented in Tables 5 and 6. Costs in this report do not include land costs, management, or other expenses and fees not associated with production. Corn grain price used for economic calculations was $5.38/bu. and was calculated from Arkansas Daily Grain reports published by the Agricultural Marketing Service-U.S. Department of Agriculture. The price is a simple average of Arkansas 2021 crop booking and cash prices from 4 January through 31 August 2021. The average corn grain yield from the 9 irrigated corn verification fields was 226 bu./ac.

The production expenses for irrigated corn fields harvested for grain were $523.41/ac in 2021. On average, fertilizers and nutrients were the largest expense category at $138.82/ac or 27% of production expenses for irrigated corn fields. Seed costs averaged $124.58/ac which was 24% of production expenses on irrigated corn fields.

With an average corn yield of 226 bu./ac for all irrigated corn fields, operating costs were $523.41/ac for 2021. The return to operating costs for all irrigated corn fields for 2021 was $692.23/ac. Fixed costs for irrigated fields were $95.32/ac. Returns to total cost for irrigated fields was $596.91/ac. Total specified costs for all irrigated corn fields during 2021 averaged $2.77/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 make adjustments or define areas that may need more research in the future. The program results are assembled into a database to allow long-term monitoring of agronomic and economic trends of Arkansas corn and grain sorghum production. The program also aids in educating new county agents, consultants, and producers who are less familiar with current production recommendations.

Areas of ongoing research that are being evaluated in the corn and grain sorghum research verification program fields include the use of foliar tissue testing during the season to evaluate whether current fertilizer recommendations for corn provide adequate levels of nutrients in the plants. Tissue samples are taken during the V10-tassel stage to determine whether nitrogen levels in the plant are adequate and if a pre-tassel nitrogen application is needed. End-of-season corn stalk nitrate samples were also collected to determine if nitrogen was adequate during the season and to evaluate overall nitrogen efficiency. Soil moisture sensors were used in all corn fields to track soil moisture levels and will help serve as a testing program for using soil moisture sensors for irrigation timing. The verification fields also serve as a pest management monitoring program for foliar diseases in corn such as southern rust and sugarcane aphids in grain sorghum 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 that the published research-based recommendations for corn production are reliable for profitable and sustainable production. The extension recommendations will be revised according to new findings and used in the verification program to ensure high-yielding and profitable corn production for Arkansas 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 were enrolled in the program. Support was also provided by the University of Arkansas System Division of Agriculture.

Literature Cited

USDA-NASS. 2022. United States Department of Agriculture National Agricultural Statistics Service. Accessed 29 March 2022. Available at: https://quickstats.nass.usda.gov/

USDA-FSA. 2021. United States Department of Agriculture Farm Service Agency. Accessed 29 March 2022. Available at: https://www.fsa.usda.gov/news-room/efoia/electronic-reading-room/frequently-requested-information/crop-acreage-data/index

Table 1. 2021 Corn Research Verification Program locations, hybrid planted, field size, row spacing, previous crop, plants per acre, plant date, harvest date, and yield.

County	Hybrid	Field Size	Row Space	Previous Crop	Plants Per Acre	Plant Date	Harvest Date	Yield
		(ac)	(in.)					(bu./ac)
Ashley	Local 1577 VT2P	80	38	soybean	35,700	3/13	8/27	215.0
Desha 1[a]	DeKalb 70-27 VT2P	22	38	soybean	30,540	4/5	8/30	181.0[b]
Desha 2	AgriGold A647-35-3330	45	38	soybean	33,200	3/9	8/19	259.4
Drew	Croplan 5678VT2P	120	38	soybean	35,400	4/21	9/20	233.5
Lonoke	Croplan 5550VT2P	63	30	soybean	35,875	4/6	9/1	246.0
Mississippi	DeKalb 70-27 VT2P	80	38	soybean	36,500	4/6	9/24	199.1
Monroe	DeKalb DKC 65-99	30	30	soybean	33,800	4/6	9/3	204.6
Poinsett	Pioneer 1847VYHR	80	30	soybean	33,375	4/7	9/25	247.0
Prairie	Dyna-Gro 57VC51	120	30	soybean	37,200	4/5	9/14	252.0
Mean	---	**71.1**	**---**	**---**	**34,621**	**4/2**	**9/8**	**226.0**

[a] The field received 13 inches of rainfall and suffered severe wind damage from early June storms.

[b] The final yield does not include about 25% loss from early June storm damage.

Table 2. 2021 Corn Research Verification Program locations, preplant, sidedress, pre-tassel, 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---------------------				
Ashley	45-90-120-13-5	165-0-0-0-0	0-0-0-0-0	210-90-120-13-5	Calhoun Silt Loam
Desha 1	23-46-100-0-3	142-0-0-12-0	46-0-0-0-0	211-46-100-12-3	Hebert Silt Loam
Desha 2	40-0-30-20-1	93-0-0-17-0	93-0-0-17-0	226-0-30-54-1	Herbert Silt Loam
Drew	20-46-30-12-0	154-0-60-12-0	46-0-0-0-0	220-46-90-24-0	Calhoun Silt Loam
Lonoke	58-0-0-24-0	124-0-0-0-0	46-0-0-0-0	228-0-0-24-0	Hebert Silt Loam
Mississippi	60-0-90-12-5	161-0-0-0-0	60-0-0-0-0	281-0-90-12-5	Sharkey-Steele Clay
Monroe	43-93-75-23-2	123-0-0-36-0	46-0-0-0-0	212-93-75-59-2	Calhoun Silt Loam
Poinsett	29-80-80-10-1	170-0-0-36-0	46-0-0-0-0	245-80-80-46-1	Calloway Silt Loam
Prairie	47-80-120-20-2	126-0-0-12-0	46-0-0-0-0	219-80-120-32-2	Calhoun Silt Loam
Mean	**41-48-72-15-2**	**140-0-7-14-0**	**48-0-0-2-0**	**229-48-79-31-2**	**---**

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

Table 3. 2021 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.)
Ashley	Furrow	5	21.36
Desha 1	Furrow	5	31.07
Desha 2	Furrow	3	28.78
Drew	Furrow	5	19.20
Lonoke	Furrow	5	21.35
Mississippi	Furrow	4	18.13
Monroe	Furrow	5	21.57
Poinsett	Furrow	6	15.40
Prairie	Furrow	5	20.14
Mean	**-**	**4.8**	**21.89**

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

Table 4. Corn growth stage and corresponding average accumulated growing degree days determined by weekly field visits in all cornfields in 2021.

Corn Growth Stage	Accumulated Growing Degree Days From Planting
VE–Emergence	149
V2	279
V4	440
V6	614
V8	793
V10	944
V12	1081
V14	1191
V16	1313
R1–Silking	1498
R2–Blister	1670
R3–Milk	1855
R4–Dough	2044
R5–Dent	2243
R6–Physiological Maturity (Black Layer)	2873

Table 5. Operating costs, total costs, and returns for corn research verification program fields, 2021.

County	Operating Costs	Operating Costs	Returns to Operating	Fixed Costs	Total Costs	Returns to Total Costs	Total Costs per Bushel
	($/ac)	($/bu.)	($/ac)	($/ac)	($/ac)	($/ac)	($/bu.)
Ashley	486.80	2.26	669.90	87.77	574.57	582.13	2.67
Desha 1	462.80	2.56	510.98	97.81	560.61	413.17	3.10
Desha 2	480.83	1.85	914.74	96.62	577.44	818.13	2.23
Drew	565.13	2.42	691.10	88.83	653.97	602.26	2.80
Lonoke	502.74	2.04	820.74	121.35	624.09	699.39	2.54
Mississippi	493.56	2.48	577.60	86.56	580.13	491.03	2.91
Monroe	553.57	2.76	525.66	87.69	641.26	437.97	3.20
Poinsett	616.75	2.50	712.11	99.33	716.08	612.78	2.90
Prairie	548.53	2.18	807.23	91.88	640.41	715.35	2.54
Mean	**523.41**	**2.34**	**692.23**	**95.32**	**618.73**	**596.91**	**2.77**

Table 6. Summary of operating costs, total costs, and returns for corn research verification program fields, 2021.

	Ashley	Desha1	Desha2	Drew	Lonoke
Yield (bu./ac)	215.0	181.0	259.4	233.5	246.0
Price ($/bu.)	5.38	5.38	5.38	5.38	5.38
Total Crop Revenue ($/ac)	**1,156.70**	**973.78**	**1,395.57**	**1,256.23**	**1,323.48**
Expenses			----$/ac----		
Seed	126.00	119.21	122.50	127.05	126.00
Fertilizers & Nutrients	144.20	126.59	107.22	173.00	90.38
Herbicides	35.12	49.97	49.26	36.68	36.45
Fungicide	0.00	0.00	0.00	20.81	14.93
Custom Application	0.00	0.00	0.00	14.00	28.00
Diesel Fuel, Field Activities	10.40	12.03	9.95	10.68	13.95
Irrigation Energy Costs	13.17	10.54	14.43	14.43	15.12
Other Inputs, Pre-harvest	3.88	3.88	3.88	3.88	3.88
Input Costs					
Fees	6.00	6.00	6.00	6.00	6.00
Crop Insurance	16.15	16.15	16.15	16.15	16.15
Repairs & Maint.	17.48	18.76	18.40	17.97	22.99
Labor, Field Activities	9.16	9.92	8.39	9.40	9.67
Production Expenses					
Interest	8.49	8.30	7.92	10.01	8.53
Post-harvest Expenses	96.75	81.45	116.73	105.08	110.70
Total Operating Expenses	**486.80**	**462.80**	**480.83**	**565.13**	**502.74**
Returns to Operating Expenses	**669.90**	**510.98**	**914.74**	**691.10**	**624.09**
Capital Recovery & Fixed Costs	87.77	97.81	96.62	88.83	121.35
Total Specified Expenses	**574.57**	**560.61**	**577.44**	**653.97**	**624.09**
Returns to Specified Expenses	**582.13**	**413.17**	**818.13**	**602.26**	**699.39**
Operating Expenses Per bu.	2.26	2.56	1.85	2.42	2.04
Total Specified Expenses Per bu.	2.67	3.10	2.23	2.80	2.54

Continued

Table 6. Continued.

	Mississippi	Monroe	Poinsett	Prairie	Mean
Yield (bu./ac)	199.1	200.6	247.0	252.0	**225.96**
Price ($/bu.)	5.38	5.38	5.38	5.38	**5.38**
Total Crop Revenue ($/ac)	**1,071.16**	**1,079.23**	**1,328.86**	**1,355.76**	**1,215.64**
Expenses	------------------------------------		**$/ac**		--
Seed	127.75	119.00	122.50	131.25	**124.58**
Fertilizers & Nutrients	128.98	167.16	179.23	132.63	**138.82**
Herbicides	58.33	33.30	43.75	33.24	**40.71**
Fungicide	0.00	20.50	0.00	20.50	**8.53**
Custom Application	7.00	35.00	42.00	28.00	**17.11**
Diesel Fuel, Field Activities	10.49	10.67	12.78	12.11	**11.45**
Irrigation Energy Costs	10.54	14.43	17.31	14.43	**13.82**
Other Inputs, Pre-harvest	3.88	3.88	3.88	3.88	**3.88**
Input Costs					
Fees	6.00	6.00	6.00	6.00	**6.00**
Crop Insurance	16.15	16.15	16.15	16.15	**16.15**
Repairs & Maint.	17.88	18.56	20.67	18.21	**18.99**
Labor, Field Activities	8.18	8.57	9.36	9.28	**9.10**
Production Expenses					
Interest	8.79	10.08	11.00	9.47	**9.18**
Post-harvest Expenses	89.60	90.27	111.15	113.40	**101.68**
Total Operating Expenses	**493.56**	**553.57**	**616.75**	**548.53**	**523.41**
Returns to Operating Expenses	**577.60**	**525.66**	**712.11**	**807.23**	**670.38**
Capital Recovery & Fixed Costs	86.56	87.69	99.33	91.88	**95.32**
Total Specified Expenses	**580.13**	**641.26**	**716.08**	**640.41**	**618.73**
Returns to Specified Expenses	**491.03**	**437.97**	**612.78**	**715.35**	**596.91**
Operating Expenses Per bu.	2.48	2.76	2.50	2.18	**2.34**
Total Specified Expenses Per bu.	2.91	3.20	2.90	2.54	**2.77**

Gene Editing: A New Approach to Overcome Mycotoxins and Environmental Stress in Arkansas Corn Production, 2021

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

Abstract

Mycotoxins are chemical compounds produced by fungal pathogens that are harmful to humans and animals. Certain mycotoxins, such as aflatoxin produced by *Aspergillus flavus*, are a serious economic concern for Arkansas corn growers. Aflatoxin accumulation in corn grain is commonly associated with environmental stress during the growing season, particularly during the onset and progression of reproductive development. While many environmental stresses can predispose corn to aflatoxin contamination, heat and drought stress are the most common and harmful in Arkansas production conditions. Conventional breeding strategies have not provided adequate resistance to aflatoxin contamination and environmental stress in southern-adapted corn hybrids. In recent years, gene editing has emerged as a powerful, non-GMO tool to modify genes in corn and other crops. In this research, we are utilizing gene editing to create corn lines that are simultaneously resistant to environmental stress and aflatoxin contamination. Building on previous work supported by the Arkansas Corn and Grain Sorghum Board, we are exploring the association between genes that regulate heat stress responses in corn and aflatoxin resistance. We have identified a set of corn genes involved in heat stress response that are linked to aflatoxin susceptibility. We are utilizing gene editing to determine exactly how these genes predispose corn to aflatoxin contamination and to bolster aflatoxin resistance without incurring a yield penalty.

Introduction

Mycotoxin contamination in corn has proven to be a serious risk factor for Arkansas corn producers. Typical Arkansas growing seasons often include periods of high heat and drought, both of which predispose corn to aflatoxin contamination. Aflatoxin is an organic chemical compound produced by the fungus *Aspergillus flavus*. Aflatoxin is the most carcinogenic, naturally occurring compound known to humankind, and its presence in corn grain, animal feed, and human foodstuffs is highly regulated worldwide (Anukul et al., 2013). In human food and animal feeds, the U.S. regulatory limit for aflatoxin is 20 ppb (Sarma et al., 2017). During heat and/or drought stress, aflatoxin levels exceeding 1000 ppm have been recorded in Arkansas corn, which is 50,000 times over the regulatory limit. Thus, even low levels of aflatoxin contamination in corn are highly problematic.

A lack of effective management strategies for aflatoxin accumulation further exacerbates the problem for Arkansas corn growers. Fungicides, which effectively control many foliar diseases of corn, are largely ineffective for aflatoxin management in field conditions. Genetic resistance to aflatoxin accumulation is essentially unavailable in commercial corn hybrids despite decades of public and commercial breeding efforts, primarily because of yield reductions and other negative traits associated with linkage drag. Biological control products, such as Afla-Guard®, are promising but not individually sufficient to mitigate risk. For example, Afla-Guard®, under ideal conditions, can reduce aflatoxin levels by as much as 90% (Dorner, 2010). While impressive, the extremely low aflatoxin tolerance levels of 20 ppb offset the efficacy of biological control. If the potential for aflatoxin contamination exceeds 200 ppb, which is frequently the case in Arkansas production conditions, biological control products cannot provide sufficient suppression of aflatoxin. Thus, novel aflatoxin management techniques are urgently needed for the sustainable production of corn in Arkansas and other Southern states.

In recent years, gene editing has emerged as a powerful new tool to accelerate the deployment of improved crop varieties (Pandey et al., 2022). In essence, the gene-editing approach utilizes 'molecular scissors' to precisely cut specific plant genes, with the result of changing or removing sequence information (Cong et al., 2013). When informed by knowledge about how specific gene sequences convey desired traits, gene editing can be used to improve crop production much more quickly and precisely than conventional breeding. Additionally, gene editing can be performed in ways that do not result in a genetically modified organism (GMO), thus avoiding costs, regulatory delays, and public perception issues associated with the release of GMO crop varieties/hybrids.

A key roadblock to using gene editing to improve aflatoxin resistance in corn is the lack of fundamental information as to what makes corn susceptible at the cellular/molecular level. Although the environmental stresses that predispose corn to aflatoxin accumulation are well documented (Fountain et al., 2014), it is unclear exactly what cellular processes and events are directly accountable for increased susceptibility or what specific genes regulate those processes. Thus, research is urgently needed that focuses on dissecting cellular-level responses in corn to environmental stress.

An intriguing area of study into how corn responds to environmental stress is the heat stress response (HSR) and un-

[1] Professor and Research Associate, Department of Entomology and Plant Pathology, Fayetteville.

folded protein response (UPR). Excessive heat disrupts protein folding, processing, and subcellular localization in plants, which is crucial for proper protein function (Wang et al., 2004). Misfolded proteins are often non-functional or even toxic to plant cells; thus, plants have evolved intricate pathways within the HSR and UPR to enable correct folding during heat stress and inactivate/recycle misfolded proteins (Liu et al., 2010; Mittler et al., 2012). Elements of the HSR and UPR are broadly conserved in plants and have been documented to play an active role in how corn responds to heat stress (Li et al., 2020). It is important to note that the HSR and UPR have their limits; in their current capacity, neither sufficiently protects corn against extreme heat stress. However, these pathways are excellent targets for improvement via gene editing.

The research objectives of this project are to 1) use gene editing for non-transgenic, precision manipulation of corn genes involved in resistance (or susceptibility) to aflatoxin and environmental stress, and 2) genetically map genes/pathways in corn underlying resistance and/or susceptibility to aflatoxin and environmental stress to identify high-priority targets for gene editing.

Procedures

Objective 1

Gene editing is a recent yet broadly utilized tool for crop improvement, and as a result, new refinements of gene-editing techniques are continually emerging from research groups across the world. In the initial phase of this project, fundamental techniques for gene editing in corn were established, including a system to propagate corn tissue culture cells (analogous to stem cells in other organisms); the ability to create and regenerate protoplasts; efficient delivery of gene-editing constructs into corn protoplasts and tissue culture cells; the ability to efficiently regenerate non-transgenic, edited plants; and high-throughput screening for gene editing events. Due to the constant flow of new information from other published studies, elements of the gene-editing pipeline described above were refined to increase efficiency and save time at various steps of the process.

In addition to the technical considerations described above, a key element of successful gene editing is determining the best strategy to change the sequence—and thus the function—of a given gene. In previous work, we explored strategies to create DNA/RNA constructs for gene editing that inactivated genes, altered their expression, and changed specific domains within genes to alter their function. Recently, the focus of this work has narrowed to focus on altering the expression profile of genes via gene editing as the most immediate and fruitful way to enhance resistance to aflatoxin accumulation.

Objective 2

Perhaps the biggest challenge of utilizing gene editing to improve resistance to aflatoxin is knowing which genes to target for editing. The corn genome contains approximately 32,000 genes, nearly twice as many as the human genome (Llaca et al., 2011; Nurk et al., 2022). Many genes in the corn genome arose through duplication and duplicates then evolved to either serve a redundant function, a similar supporting function, or an entirely new function compared to the original gene. This pattern of duplication and divergent function presents a significant challenge in identifying genes involved in stress tolerance. In previous work, we focused heavily on transcription factors, which regulate other genes that respond directly to environmental stimuli and challenges, such as stress (Meshi and Iwabuchi, 1995). We used various complementary ways to identify target genes, such as mining publicly available gene expression data sets while considering conserved gene function and co-localization of potential stress-related genes with genes known to be involved in other agronomic traits, such as yield. These efforts have steered us to focus on genes involved in the heat stress response (HSR) and unfolded protein response (UPR) pathways, including key transcription factors that represent the regulatory junction between these two stress response pathways.

Results and Discussion

In the initial stages of developing gene-editing strategies to improve aflatoxin resistance, we considered ways to inactivate genes, alter their expression, and change specific domains within genes to alter their function. Regarding gene inactivation, we explored the hypothesis that specific genes in corn function may function as susceptibility genes, which are required for pathogen attack and/or strongly induce the production of aflatoxin. In corn, susceptibility genes could function directly by inducing pathogen growth and aflatoxin production or indirectly by predisposing stress responses that, in turn, promote aflatoxin accumulation. Susceptibility genes for other diseases, such as powdery mildew, have been documented in various plants, and inactivation of susceptibility genes can convey genetic resistance to pathogen attack (Wang et al., 2014). Similarly, if one or more susceptibility genes for aflatoxin contamination were to exist, they would be ideal targets for inactivation via gene editing. We took a three-pronged approach to search for aflatoxin susceptibility genes in corn. First, we analyzed all genes in the corn genome that were transcriptionally activated (or deactivated) by environmental stress. Second, we searched for susceptibility gene orthologs—genes with similar sequences to susceptibility genes previously identified in other crop species—to see if susceptibility might be broadly conserved. Third, we determined whether any predicted susceptibility genes were nearby any corn genes that control desired traits, such as yield, which could be associated with linkage drag. From these analyses, we concluded that if corn possesses aflatoxin susceptibility genes, it is unlikely that they share a similar sequence or function as known susceptibility genes in other systems. Thus, the discovery of such susceptibility genes in corn will require a focused effort that spans association genomics, conventional genetic segregation analyses, mutational analyses, and finally, functional validation. All of these steps will require extensive phenotyping for aflatoxin accumulation under stressful conditions. While this is a worthy avenue of investigation, the scope of such a project would be considerable. Thus, to expedite the delivery of results to growers, we have shifted our focus to other strategies.

Analyses of gene expression data derived from environmentally stressed corn consistently highlighted the involvement of the heat stress response (HSR) and unfolded protein response (UPR) pathways in response to stress. In some data sets, genes from the HSR and UPR pathways showed stronger transcriptional responses to environmental stress than any other genes in the corn genome. Intriguingly, at the highest temperatures evaluated (approximately 95–98 °F), the induction of key genes within the HSR and UPR began to falter, and physiological damage to corn plants was observed at late-vegetative stages and early-reproductive stages of development (Li et al., 2020). This observation is perfectly consistent with high levels of aflatoxin in some eastern Arkansas fields in 2010 and 2011 when drought coupled with early-season heat waves overlapped with the timing of reproductive development in the majority of corn planted in the Arkansas delta. Because we do not typically observe a pronounced uncoupling of aflatoxin accumulation from fungal growth, these observations increasingly point toward a new hypothesis: heat stress at the transition to reproductive growth in corn compromises the HSR and UPR response pathways, which enables the growth of *A. flavus* and the concomitant accumulation of aflatoxin, rather than stress creating an environment in corn kernels that specifically induces susceptibility to aflatoxin accumulation. We are actively testing this hypothesis by performing a full computational analysis in corn of all known genes involved in the HSR and UPR, particularly the convergent point of inductive regulation in response to heat and drought stress. This will allow us to select high-priority candidate genes for gene editing, particularly in regulatory regions of genes, such as promoters, untranslated regions involved in regulation, and other key elements.

Our program's earlier decision to focus on editing gene promoters as the quickest, most fruitful path to generate practical results was recently corroborated by an independent study focused on improving yield in corn. In a study by Liu et al. (2021), grain-related yield traits were enhanced substantially by altering the expression of a family of genes involved in controlling cell growth in corn. The family targeted for gene editing contained over 50 members, making the individual analysis of such genes unfeasible. By randomly and simultaneously targeting the promoters of the entire gene family for editing, they were able to alter expression sufficiently to substantially increase the number of kernels per cob of corn and thus increase yield potential. We have been undertaking a conceptually similar technical approach to modify the expression of key regulatory genes within the HSR and UPR pathways; although Liu et al. (2021) targeted a different biological phenomenon than aflatoxin accumulation, their success validates our approach.

Practical Applications

Environmental stress, particularly heat and drought, is a persistent challenge for corn production in Arkansas and other southern states. The alignment of these stresses with specific growth stages of corn can substantially increase the risk of aflatoxin accumulation in harvested grain. Arkansas growers simply do not have enough tools at their disposal to eliminate the risk that aflatoxin can present in any given year. The most sustainable, reliable, and cost-effective strategy for aflatoxin management would be strong genetic resistance in high-yielding commercial hybrids. However, conventional breeding has so far been unable to deliver this level of resistance. Improving resistance to environmental stress such as heat and drought, while simultaneously conveying increased resistance to aflatoxin accumulation, would eliminate the periodic, potentially devastating risks associated with aflatoxin contamination, while ensuring the long-term sustainability of corn production in the context of climate change. Our overarching goal is to develop novel corn germplasm that can be used to create hybrids that excel in Arkansas production conditions. This will be accomplished by creating gene-edited, stress-tolerant lines that are suitable parents for corn hybrids which will be used in partnership with public- and private-sector corn breeders to create and evaluate new hybrids that are resistant to environmental stress and aflatoxin accumulation. In the long term, the gene-editing pipeline being created in this project can be used to offset the production challenges of tomorrow that are perhaps unseen today.

Acknowledgments

The authors express their gratitude to Arkansas corn and sorghum producers for supporting this research via check-off funds administered by the Arkansas Corn and Grain Sorghum Promotion Board. The University of Arkansas System Division of Agriculture also supported this research. Additionally, this research was supported in part by the USDA National Institute of Food and Agriculture, Hatch project 1024680. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the U.S. Department of Agriculture.

Literature Cited

Anukul, N., V. Kanithaporn, and W. Wahakarnchanakul. 2013. Significance of regulation limits in mycotoxin contamination in Asia and risk management programs at the national level. J. Food Drug Analysis. 21:227-241.

Cong, L., F.A. Ran, D. Cox, S. Lin, R. Barretto, N. Habib, P.D. Hsu, X. Wu, W. Jiang, L.A. Marraffini, and F. Zhang. 2013. Multiplex genome engineering using CRISPR/Cas systems. Science. 339:819-823.

Dorner, J.W. 2010. Efficacy of a biopesticide for control of aflatoxins in corn. J. Food Protection. 73:495-499.

Fountain, J.C., B.T. Scully, X. Ni, R.C. Kemerait, R.D. Lee, Z.Y. Chen, and B. Guo. 2014. Environmental influences on maize-*Aspergillus flavus* interactions and aflatoxin production. Frontiers Microbiol. 5:40.

Li, Z., J. Tang, R. Srivastava, D.C. Bassham, and S.H. Howell. 2020. The transcription factor bZIP60 links the unfolded protein response to the heat stress response in maize. Plant Cell. 32:3559-3575.

Liu, J.X. and S.H. Howell. 2010. Endoplasmic reticulum protein quality control and its relationship to environmental stress responses in plants. Plant Cell. 22:2930-2942.

Llaca, V., M.A. Campbell, and S. Deschamps, 2011. Genome diversity in maize. J. Botany:104172.

Meshi, T. and M. Iwabuchi, 1995. Plant transcription factors. Plant Cell Physiology 36:1405-1420.

Mittler, R., A. Finka, and P. Goloubinoff. 2012. How do plants feel the heat? Trends Biochem. Sci. 37:118-125.

Nurk, S., S. Koren, A. Rhie, M. Rautiainen, A.V. Bzikadze, A. Mikheenko, M.R. Vollger, N. Altemose, L. Uralsky, A. Gershman, S. Aganezov, S.J. Hoyt, M. Diekhans, G.A. Logsdon, M. Alonge, S.E. Antonarakis, M. Borchers, G.G. Bouffard, S.Y. Brooks, G.V. Caldas, N.C. Chen, H. Cheng, C.S. Chin, W. Chow, L.G. de Lima, P.C. Dishuck, R. Durbin, T. Dvorkina, I.T. Fiddes, G. Formenti, R.S. Fulton, A. Fungtammasan, E. Garrison, P.G.S. Grady, T.A. Graves-Lindsay, I.M. Hall, N.F. Hansen, G.A. Hartley, M. Haukness, K. Howe, M.W. Hunkapiller, C. Jain, M. Jain, E.D. Jarvis, P. Kerpedjiev, M. Kirsche, M. Kolmogorov, J. Korlach, M. Kremitzki, H. Li, V.V. Maduro, T. Marschall, A.M. McCartney, J. McDaniel, D.E. Miller, J.C. Mullikin, E.W. Myers, N.D. Olson, B. Paten, P. Peluso, P.A. Pevzner, D. Porubsky, T. Potapova, E.I. Rogaev, J.A. Rosenfeld, S.L. Salzberg, V.A. Schneider, F.J. Sedlazeck, K. Shafin, C.J. Shew, A. Shumate, Y. Sims, A.F.A. Smit, D.C. Soto, I. Sović, J.M. Storer, A. Streets, B.A. Sullivan, F. Thibaud-Nissen, J. Torrance, J. Wagner, B.P. Walenz, A. Wenger, J.M.D. Wood, C. Xiao, S.M. Yan, A.C. Young, S. Zarate, U. Surti, R.C. McCoy, M.Y. Dennis, I.A. Alexandrov, J.L. Gerton, R.J. O'Neill, W. Timp, J.M. Zook, M.C. Schatz, E.E. Eichler, K.H. Miga, and A.M. Phillippy. 2022. The complete sequence of a human genome. Science. 376:44-53.

Pandey, S., A. Singh, S.K. Parida, and M. Prasad. 2022. Combining speed breeding with traditional and genomics-assisted breeding for crop improvement. Plant Breeding, 1–13.

Sarma, U.P., P.J. Bhetaria, P. Devi, and A. Varma. 2017. Aflatoxins: Implications on Health. Indian J. Clinical Biochem. 32:124–133.

Wang, W., B. Vinocur, O. Shoseyov, and A. Altman. 2004. Role of plant heat-shock proteins and molecular chaperones in the abiotic stress response. Trends Plant Sci. 9:244-252.

Wang, Y., X. Cheng, Q. Shan, Y. Zhang, J. Liu, C. Gao, and J.L. Qiu. 2014. Simultaneous editing of three homoeoalleles in hexaploid bread wheat confers heritable resistance to powdery mildew. Nature Biotechnol. 32:947-951.

Field Efficacy of Seed- and Soil-Applied Nematicides in Hybrid Corn

T.R. Faske,[1] M. Emerson,[1] and J. Kelley[1]

Abstract

The field efficacy of four seed-applied nematicides and three soil-applied nematicides were evaluated in a field infested with stubby-root nematodes (*Paratrichodorus* sp.), lesion nematodes (*Pratylenchus* spp.), and southern root-knot nematodes (*Meloidogyne incognita* (Kofoid and White) Chitwood) in Jackson County. One seed- and soil-applied nematicide combination, Trunemco + Velum (*Bacillus amyloliquefaciens* MBI 600 + cis-jasmone), and the soil-applied nematicide, Counter (terbufos), reduced stubby-root and lesion nematode densities compared to the nontreated control. No nematicide suppressed root-knot nematode densities compared to the nontreated control. This suppression did not contribute to a significant grain yield benefit; however, Counter provides the greatest trend in protection (20 bu./ac or 9%) compared to the nontreated control. Overall, these commercially available seed- and soil-applied nematicides were inconsistent in nematode suppression and grain yield protection.

Introduction

Several genera of plant-parasitic nematodes are commonly detected in cornfields (*Zea mays* L.) in Arkansas. Common nematode genera include stubby-root nematodes (*Paratrichodorus* sp.), lesion nematodes (*Pratylenchus* spp.), and root-knot nematodes (*Meloidogyne* spp.). Although plant-patristic nematodes rank among the ten most destructive diseases of corn in the southern U.S. (Mueller et al., 2020), there is little information on the biology and damage of corn nematodes in Arkansas.

The vertical distribution of stubby-root nematode, *Paratrichodorus minor* (Colbran) Siddiqi, and the southern root-knot nematode, *M. incognita,* has been reported to change dramatically during the cropping season on corn in Florida (McSorley and Dickson, 1990). Furthermore, the greatest density of lesion nematode, *P. brachyurus* (Godfrey) Filipjev & Stekhoven, was reported to remain primarily at 6 to 12 in. soil depth on corn in Florida. However, there is currently no information on the vertical distribution of plant-parasitic nematodes on corn in Arkansas.

During the past fifteen years, there has been an increase in the number of seed- and soil-applied nonfumigant nematicides registered on row crops in Arkansas. There has been a general trend to market nematicides that have a lower risk to human safety and impact on non-target organisms. Such nematicides include fluopyram, a succinate dehydrogenase inhibitor (SDHI) fungicide that is marketed as an in-furrow nematicide in corn. There are currently three bionematicides that are various bacterial strains from the genera *Bacillus* or *Burkholderia*. Currently, there is little information on the benefit of these nematicides on corn in Arkansas. Thus, the objectives of this study were to (i) evaluate the vertical distribution of corn nematodes during a cropping season and (ii) evaluate the field efficacy of various seed- and soil-applied nematicides to suppress corn nematodes and protect grain yield potential.

Procedures

The field efficacy of four seed- and three soil-applied nematicides were evaluated in a field experiment in 2021 in Jackson County, Ark. (Table 1). The soil texture was a loamy sand with 76% sand, 20% silt, and 4% clay. The corn hybrid, Local Seed 'LC1577' (Local Seed Co, LLC, Memphis, Tenn.; 115-day maturity) was planted on 13 April at a seeding rate of 32,000 seed/ac. The previous crop was wheat (*Triticum aestivum* L.), and the field was watered with a center pivot irrigation system. Weeds were controlled per recommendations by the University of Arkansas System Division of Agriculture's Cooperative Extension Service. Plots consisted of 4, 30-ft long rows spaced 30-in. apart. The experimental design was a randomized complete block design with 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 0.5-in. diameter poly-tubing using a variable rate AMVAC SmartBox meter. Soil samples were a composite of 8 core samples taken 6 to 8 in. deep, within 3 in. of the plant stalk with a 0.75-in. diameter soil probe. Nematodes were collected with a modified Baermann funnel system and enumerated using a stereoscope. Soil samples were collected at planting (13 April), mid-season (24 May; 41 days after planting (DAP) and V4 growth stage), and at harvest (23 September). In order to determine the changes in nematode distribution at two soil depths, 6 core samples were collected at two depths: 0-6.0 in. and 6.1–12 in. from the same hole in three of the six nontreated control plots at the same three sample times. Stand counts as the number of plants per ten row

[1] Professor/Extension Plant Pathologist, Program Associate, and Program Technician, respectively, Department of Entomology and Plant Pathology, Lonoke Extension Center, Lonoke.

feet were determined at 14 and 28 DAP. A vigor rating was given for the entire plot at 14 and 28 DAP, where 1 = poor growth and 5 = best growth. The two center rows of each plot were harvested on 18 September with an ALMACO SPC40 plot combine (ALMACO, Nevada, Iowa) equipped with a HarvestMaster Single BDS HiCap HM800 weigh system (HarvestMaster Logan, Utah).

Nematode data were subjected to repeated measures analysis and grain yield was subjected to analysis of variance using SPSS 27.0 and mean separation when appropriate at $P = 0.10$ according to Fisher's least significant difference procedure. Nematode data at different sampling depths were subjected to mixed model analysis, with sample depth and sample timing as fixed variables and replications as random variables using the same statistical software and means separation procedure.

Results and Discussion

There was an interaction ($P \leq 0.10$) between the two sample depths and sample time for the stubby-root nematode, lesion nematode, and southern root-knot nematode (Table 2). However, the density of stubby root nematode and lesion nematode were similar between the shallow (0 to 6.0 in.) and deeper (6.1 to 12 in.) soil depths across all sample times. Numerically, 100% more stubby-root nematodes and 80% more lesion nematodes were detected at the shallow depth than at the deeper depth across all sample times. In contrast, a greater ($P = 0.10$) density of southern root-knot nematode was detected at the deeper depth (6.1 to 12 in.) than at the shallower depth at planting and 40 days after planting (V4 growth stage) but not at harvest. Some 151% more ($P = 0.008$) southern root-knot nematodes were detected at 6.1 to 12 in. soil depth than at 0 to 6 in. soil depth across all sample times. Thus, in contrast to the erratic densities of stubby-root nematode and southern root-knot nematode in a study in Florida (McSorley and Dickson, 1990), our data suggest that a greater proportion of stubby-root nematodes remains in the shallow soil depth sampled, while most root-knot nematodes remained in the deeper soil depth sampled.

None of the seed- or soil-applied nematicides had a significant effect at 28 days after planting on seedling emergence or vigor. The average plant density was 21.8 plants per ten ft. of row, and the average vigor rating was 3.6. Fewer ($P = 0.10$) stubby-root nematodes and lesion nematodes were observed with Trunemco + Velum and Counter compared to the nontreated control (Fig. 1). No nematicide or nematicide combinations had a significant ($P = 0.12$) impact on the southern root-knot nematode densities. These nematicides had no ($P = 0.70$) impact on corn grain yield (Fig. 2). A greater grain yield trend was observed with Avicta and Counter compared to the nontreated control. In a similar corn nematicide study, BioST Nematicide 100, Avicta, Propulse, and Counter had a greater yield trend compared to the nontreated control in a silt loam soil in a field infested with similar corn nematodes in Arkansas (Faske et al., 2021).

Practical Applications

No nematicides consistently provide grain yield protection, even when yield-limiting densities of corn nematodes are present.

Acknowledgments

Support was provided by the Arkansas corn and grain sorghum producers through check-off funds administered by the Arkansas Corn and Grain Sorghum Promotion Board. Support was also provided by the University of Arkansas System Division of Agriculture.

Literature Cited

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

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

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

Table 1. Trade names, rates, and active ingredient for nematicides used in a corn nematicide experiment in 2021 in Jackson County.

Trade name and formulation	Rate	App[†]	Active ingredient
Aveo EZ Nematicide	0.2 fl oz/cwt	ST	*Bacillus amyloliquefaciens* PTA 4838
BioST Nematicide 100	7.0 fl oz/cwt	ST	*Burkholderia rinojensis* A396
Trunemco corn/soy	0.30 fl oz/cwt	ST	*B. amyloliquefaciens* MBI 600 + cis-Jasmone
Avicta 500 FS	2.4 fl oz/cwt	ST	abamectin
Averland 0.7 FC	6.0 fl oz/ac	IF	abamectin
Velum 4.16 SC	3.0 fl oz/ac	IF	fluopyram
Propulse 3.34 SC	8.0 fl oz/ac	IF	prothioconazole + fluopyram
Counter 20G	6.5 lb/ac	IF	terbufos

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

Table 2. Density of three corn nematodes at three sample times and two sample depths in a corn nematicide experiment in 2021 in Jackson County.

Sample time (DAP)[†]	Sample depth	Stubby-root nematode	Lesion nematode	Southern root-knot nematode
	(in.)		Nematodes/100 cm^3 soil	
0	0–6.0	18.9 a[‡]	4.5 a	48.3 a
0	6.1–12	12.3 a	14.9 a	236.1 b
40	0–6.0	95.0 b	11.7 a	85.0 a
40	6.1–12	41.7 ab	5.0 a	218.4 b
169	0–6.0	42.2 ab	57.7 b	76.7 a
169	6.1–12	19.7 a	22.2 ab	74.3 a

[†] DAP = days after planting.

[‡] Means with different letters indicate a significant difference at α = 0.10 according to Fisher's least significant difference procedure.

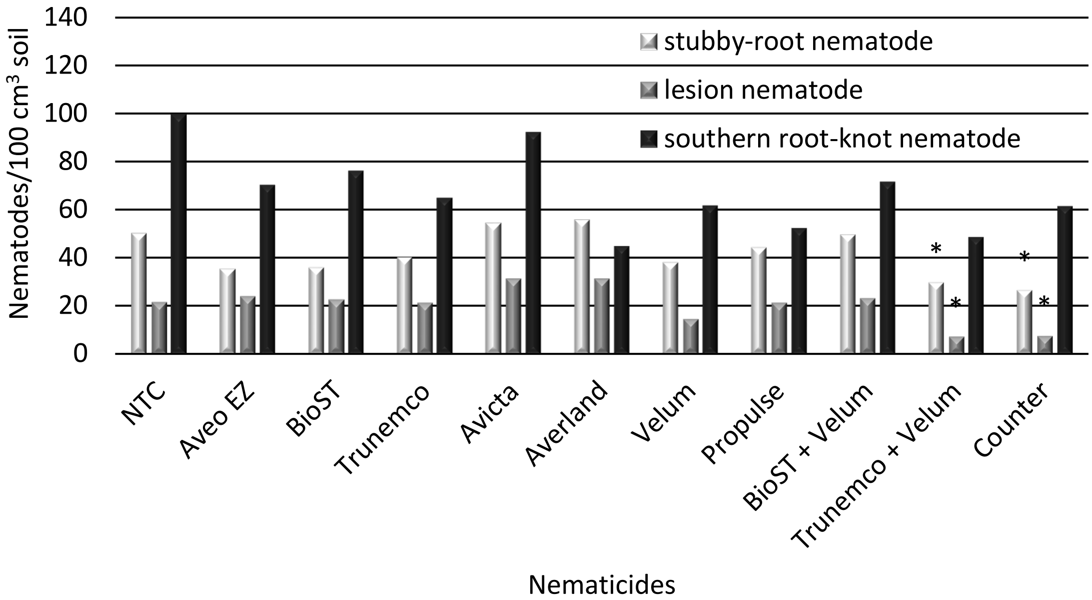

Fig. 1. Suppression of three corn nematodes by ten nematicide combinations in a field experiment in Jackson County. Each bar represents the average nematode density from six replicates collected at planting, 45 days after planting, and at harvest. For nematicide rates, see Table 1. An asterisk above the bar indicates a difference (*P* = 0.01) compared to the nontreated control (NTC) according to Fisher's least significant difference procedure.

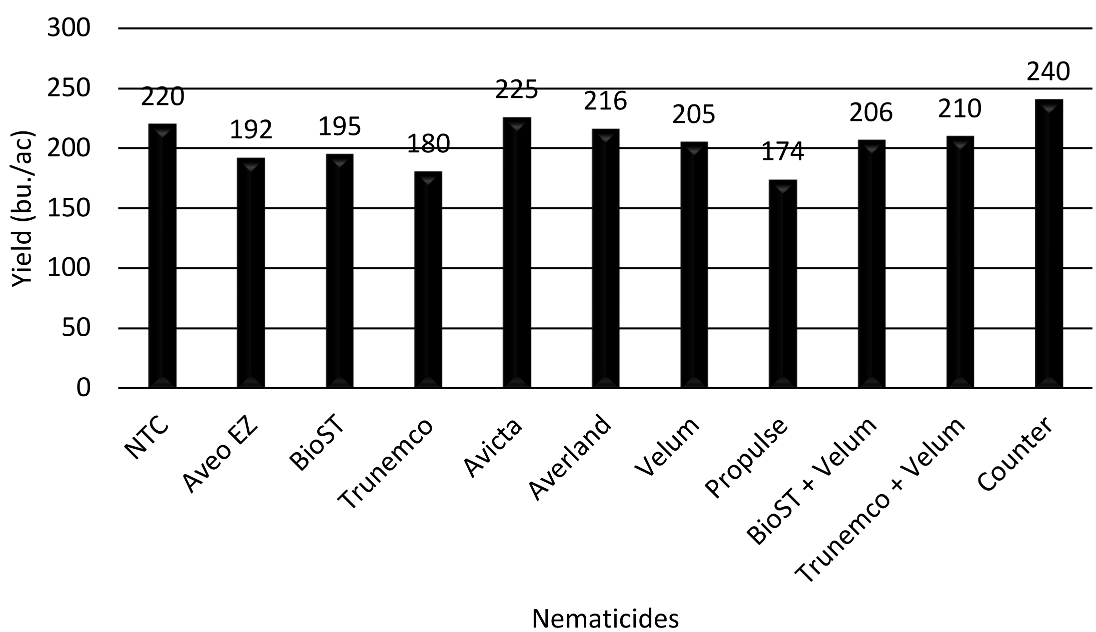

Fig. 2. Yield protection by ten nematicide combinations in a field with stubby-root nematode, lesion nematode, and southern root-knot nematode in Jackson County. Grain yield was adjusted to 15.5% moisture. For rates, see Table 1.

Evaluation of In-furrow Fungicides on Corn, 2021

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

Abstract

In-furrow and foliar fungicide trials on corn were planted on a farm near Grady and at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS), Marianna, in 2021. In the trial at Grady, Xyway LFR applied with in-furrow pop-up starter fertilizer at planting was compared to pop-up starter only in two large unreplicated blocks. Stand counts collected one week after planting found that the Xyway LFR treated block contained 29,000 plants/ac while the untreated had 34,000 plants/ac. No difference was observed with foliar disease levels, mainly southern rust, throughout the season between treatments. Yield data was collected using a weigh wagon measuring three arbitrarily located strips in the Xyway treated block and the nontreated block averaging 190 bu./ac and 226 bu./ac, respectively. At LMCRS, in-furrow fungicide treatments were compared to nontreated, pop-up starter, and foliar fungicides applied at R3. Stands were not different across treatments, but vigor was significantly less in the Xyway LFR treated plots at V3. Southern rust levels in the Xyway LFR treatment were not significantly different from the non-treated or pop-up fertilizer treated plots. There was significantly less southern rust in the in-furrow Quadris treatment at R3 and R5.5 and fungicide treatments at R5.5. Yield was not different among treatments. Early season application of Xyway LFR in the seed furrow seemed to negatively impact vigor at both locations and did not reduce southern rust during reproductive stages later in the growing season nor add value to the crop above any application costs.

Introduction

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

Procedures

At the on-farm location near Grady, a large block fungicide trial was arranged in an unreplicated design, planted on 38-in. rows. Xyway LFR fungicide was applied in-furrow at planting on 7 April 2021 at a rate of 12 fl oz/ac (0.87 fl oz 1000 row feet) in an approximate block of 25 acres. The remaining area of the approximately 99-acre field was left untreated. A 10-34-0 pop-up starter fertilizer was also applied to the entire field at a rate of 4 gal/ac. Stand and vigor (0–9, where 9 would be the most healthy or vigorous) were determined in each block on 15 April 2021. For disease assessments, 15 points were georeferenced approximately equidistant throughout each block in rows of 5, with each row serving as a treatment replicate. Disease severity data, where 0 = no disease and 9 = severe disease, were collected at a 10-ft row length around each point. Percent plant greenness was visually estimated (0–100%) near maturity. Diseases were assessed at R4 and R5.5. The grain was harvested using a commercial combine and weigh wagon where three arbitrarily selected areas were chosen within each block, of approximately equal length and width, and harvested. Grain was weighed after each block was harvested and yield was determined in bushels per acre. Disease ratings from all treatment strips were subjected to analysis of variance (ANOVA) followed by means separation of fixed effects using Tukey's honest significant difference test (HSD) at $P = 0.05$. Satellite imagery was acquired from the Sentinel-2 constellation and used to visualize differences in plant health by near-infrared imagery (Copernicus Sentinel data, 2021). Images were overlayed onto soil survey data (SSURGO, 2021) for visualization of spatial distributions of plant health in relation to changes in soil types within the trial.

A trial was planted at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station on 15 April in a randomized complete block design with three in-furrow treatments applied at 5 gal/ac, Agroliquid Pro-germinator 9-24-3 (pop-up starter), pop-up starter + Quadris at 13.8 fl oz/ac, and pop-up starter + Xyway LFR at 12 fl oz/ac. Two foliar fungicide treatments, Veltyma and Trivapro, were also

[1] Associate Professor, Program Technician, and Program Associate, respectively, Department of Entomology and Plant Pathology, Lonoke and Monticello.
[2] Professor and Program Technician, respectively, Department of Crop, Soil, and Environmental Sciences, Little Rock.
[3] Application Technologist, Agriculture and Natural Resources, Cooperative Extension Service, Newport.

included in the trial and applied at R3 at 7 and 13.7 fl oz/ac, respectively. Stand and vigor data (0–9 scale) were collected on 6 May. Southern rust levels were determined at the time of foliar fungicide application and again at R5.5 on 6 August. Grain was harvested with a small plot combine equipped with a research weigh system. All data were subjected to ANOVA and means separation of fixed effects using Fisher's least significant difference test at $P = 0.05$.

Results and Discussion

In the on-farm trial, the Xyway LFR treated block was slower to emerge than the nontreated areas (Fig. 1). Stand estimates indicated that the Xyway LFR block had approximately 29,000 plants emerged/ac when compared to the nontreated, with approximately 34,000 plants/ac. A visual assessment of vigor indicated the Xyway LFR blocks were less 'healthy' than the nontreated, averaging 3 compared to 9, respectively, and this could be seen using near-infrared satellite imagery captured earlier in the growing season (Fig. 2). Overall, disease incidence and severity were moderate in the test area at R5.5. The predominant disease was southern rust, which was slightly different in the nontreated when compared to the Xyway LFR treated block, 6.5 vs. 7.2, respectively. Disease levels at R4 were low and not at levels suitable for data collection. The Xyway LFR treated plants were significantly greener than the nontreated block, 75% vs. 90%, respectively, at maturity. The Xyway LFR treated block seemed to be slightly behind in growth stage (estimated 3–5 days based on starch line progress). Yield averaged 190 bu./ac in the Xyway LFR block and 226 bu./ac in the nontreated block resulting in an approximate difference of 36 bu./ac where the corn was treated with Xyway LFR. Based on these results, a fungicide application did not add value to the crop above the application cost. It is unclear at this time why a net yield loss occurred, but relatively cooler soil temperatures at the time of planting may have contributed to this effect (Fig. 3).

At the LMCRS trial location, stands were not different across treatments, but vigor was significantly less in the Xyway LFR treated plots (Table 1). Southern rust levels in the Xyway LFR treatment were not significantly different from the nontreated or pop-up fertilizer treated plots. There was significantly less southern rust in the in-furrow Quadris treatment at R3 and R5.5 and foliar fungicide treatments at R5.5. Yield was not different among treatments.

Practical Applications

Xyway LFR was applied in two trial locations and had a similar impact on early season assessments of plant health and vigor. Emergence was delayed at Grady, and the plants seemed less vigorous at LMCRS. The product also did not reduce the latter season impacts of foliar disease sufficient to add value to the crop (by increasing yield) above any application costs. Based on these results, the benefit of in-furrow fungicide application in Arkansas is still unclear. However, Xyway LFR should no longer be applied into the seed furrow, especially in cooler soils. More work is needed to understand if another application method, such as 2 × 2, could be beneficial to a corn crop. Numerous other foliar fungicides are labeled for control of southern rust and are effective when applied properly. These products and their relative efficacy ratings on a number of diseases can be found in MP154 (Faske and Spurlock, 2022).

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 used to complete the objectives of this project.

Literature Cited

Copernicus Sentinel data [2021], processed by the European Space Administration (ESA).

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

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

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Soil Survey Geographic (SSURGO) Database. Accessed 2021. Available at https://sdmdataaccess.sc.egov.usda.gov

Fig. 1. The emergence of corn treated with Xyway LFR at 12 fl oz/ac (right) vs. the nontreated.

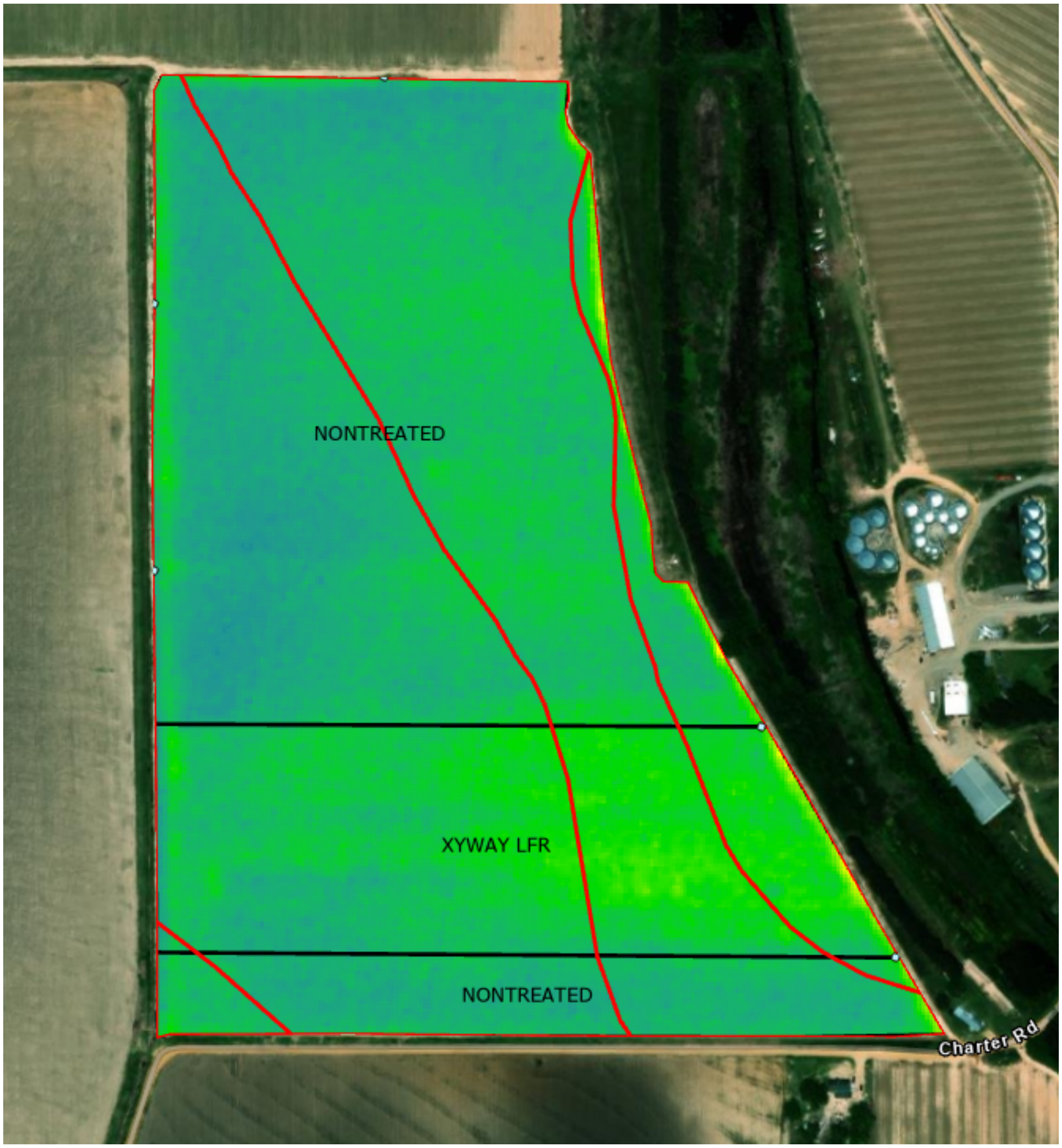

Fig. 2. Near-infrared (NIR) satellite image of the Xyway LFR trial near Grady, Ark. from 15 May 2021. Black lines are plot boundaries. Red lines are different soil series (SSURGO). Lighter green is indicative of lower NIR values which suggest plants were less green or "healthy" in comparison to the nontreated blocks across two soil series, suggesting this plant response was due to the applied product rather than more suitable soil conditions.

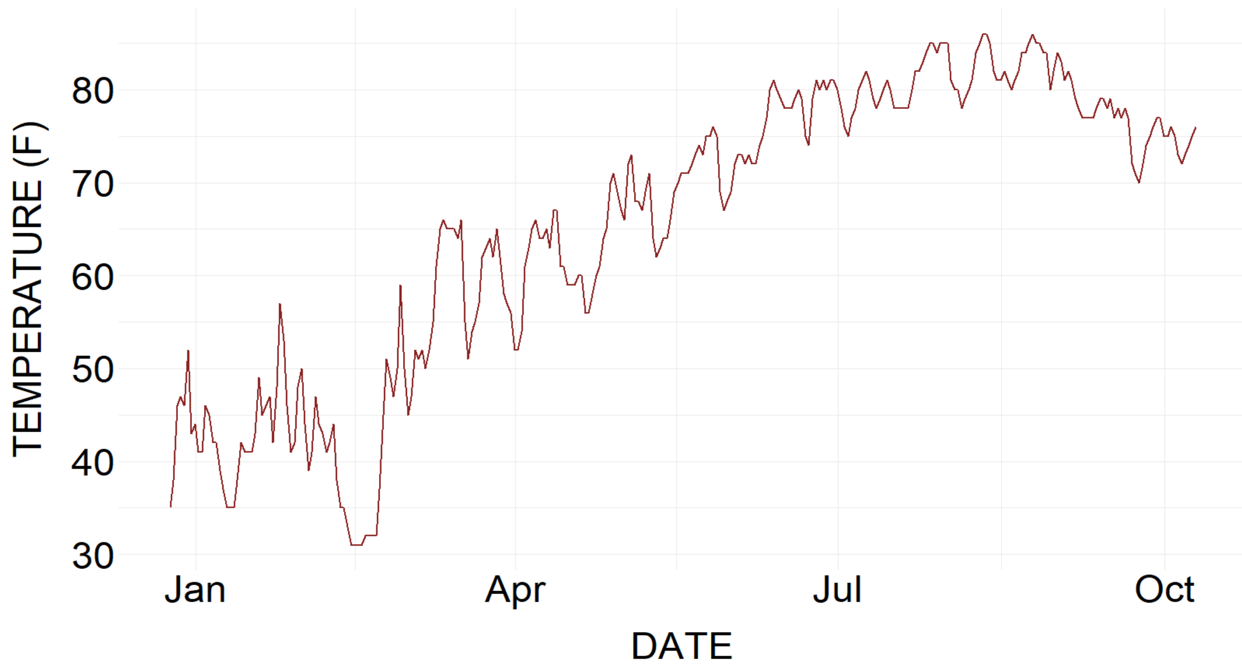

Fig. 3. Estimated soil temperatures at the Grady field trial location. On the day of planting, 7 April, the estimated soil temperature was 52 °F.

Table 1. Data collected from the fungicide trial at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Ark., 2021.

Treatment	Stand	Vigor	Southern rust	Southern rust	Yield
	(plants/ac)	(0-9)	(R3, 0-9)	(R5.5, 0-9)	(bu./ac)
Nontreated	35,000	8.5 a[†]	1.5 a	7.0 b	181.1
In-furrow fertilizer 5 GPA	34,300	8.3 a	0.8 b	8.5 a	194.5
In-furrow fertilizer 5 GPA + Xyway @ 12 fl oz/ac	36,000	5.5 c	1.0 ab	7.8 ab	188.9
In-furrow fertilizer 5 GPA + Quadris @ 13.8 fl oz/ac	35,500	7.8 ab	0.0 c	5.3 c	188.8
Veltyma @ 7 fl oz/ac (R3)	35,800	6.8 bc	1.3 ab	4.5 c	186.3
Trivapro @ 13.7 fl oz/ac (R3)	35,000	7.8 ab	1.5 a	2.0 d	191.3
LSD *P* = 0.10	NS	1.46	0.51	1.48	NS

[†] Means followed by the same letter are not significantly different using Fisher's least significant difference test at *P* = 0.10.

Comparison of Corn Traits for Control of Corn Earworm

N.R. Bateman,[1] G.M. Lorenz,[2] B.C. Thrash,[2] G. Studebaker,[3] W.A. Plummer,[2] S.G. Felts,[1] C.A. Floyd,[4] T.B. Newkirk,[4] C. Rice,[4] T. Harris,[4] A. Whitfield,[4] and Z. Murray[4]

Abstract

Corn earworm is observed on a yearly basis feeding on corn ears and has been documented to cause yield loss in very late-planted corn. Multiple transgenic corn hybrids that produce *Bt* toxins have been introduced to combat pests such as corn borers. These hybrids have also shown some control of corn earworm. Multiple studies were conducted in 2021 to determine the efficacy of DoublePro and corn hybrids containing Vip3a (Viptera, Leptra, and Treceptra) on corn earworm compared to a non-*Bt* hybrid. A strip trial was planted in Marianna, Arkansas, with multiple hybrids containing Vip3a, a DoublePro hybrid, and a non-*Bt* hybrid. Corn ears were sampled for the presence of corn earworm and kernel damage. A general trend was observed that the DoublePro traited hybrid had more corn earworms present than the non-*Bt* hybrid but less kernel damage than the non-*Bt* hybrid. The Vip3a-containing hybrids had less than 2 damaged kernels per 100 ears and less than 1 larvae per 100 ears. A second study was also planted in Marianna, Arkansas, comparing multiple non-*Bt*, DoublePro, and Vip3a hybrids for control of corn earworm. Corn hybrids containing the Vip3a gene had fewer larvae and less damaged kernels per 10 ears compared to non-*Bt* and DoublePro hybrids. Across both studies, corn hybrids containing the Vip3a gene reduced both corn earworm densities and kernel damage. Vip3a-containing hybrids could be an option, if economical, for growers concerned about corn earworm damage.

Introduction

Corn earworm, *Helicoverpa zea* (Boddie), is a minor pest of corn, *Zea mays* (L.), in Arkansas but is observed annually feeding on corn ears. Corn earworm typically feeds only on the tip of the corn ear, which generally does not lead to economic yield loss (Dicke and Guthrie, 1988). Genetically modified corn hybrids were originally introduced to combat the corn borer complex but also have activity on other lepidopterous insects (Koziel et al., 1993). Recent hybrid releases express multiple *Bacillus thuringiensis* (*Bt*) proteins, including the Vip3a protein and show increased efficacy and decreased kernel feeding from corn earworm (Bibb et al., 2018). The objective of this study was to determine the efficacy of multiple *Bt* proteins that are commonly found in Arkansas-grown corn, including DoublePro, Viptera, Leptera, and Trecepta compared to non-*Bt* hybrids.

Procedures

Large Block Study

Studies were conducted in 2021 to determine the efficacy of different *Bt* traits in corn for corn earworm. A non-replicated strip trial was planted on three dates (17 April, 4 May, and 18 May) at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS) near Marianna, Arkansas. Mulitple corn hybrids were planted at each date and consisted of a non-*Bt* (DKC 67-70), a Genuity DoublePro (DKC 67-72), and three Vip3a containing hybrids (P 2042, NK 1677, and DKC 67-94). Plot size was 25.3 ft (8 rows) by 300 ft with 1 replication per planting date. For all plots, the number of corn earworms per 100 ears at the R3 (milk) growth stage and the number of damaged kernels per 100 ears at the R4 (soft dough) growth stage were recorded. Yield was not recorded for this study.

Small Plot Study

An additional study was also planted at the LMCRS to further evaluate the efficacy of multiple *Bt* traits in corn for the control of corn earworm. Multiple non-*Bt*, DoublePro, and Vip3a corn hybrids (Table 1) were planted at an early (1 May) and late planting date (1 June). A randomized complete block design with four replications was used, and plot size was 12.6 ft (4 rows) by 40 ft. At the R3 (milk) growth stage, 10 ears were removed per plot, and the total number of corn earworm larvae present was counted for the early planting. Similarly, at the R4 (soft dough) growth stage, damaged kernel counts were made on 10 ears per plot for both plantings. Data were processed in Agriculture Research Manager v. 10, with an analysis of variance and Duncan's New Multiple Range Test ($P = 0.10$) to separate means.

[1] Extension Entomologist/Assistant Professor and Program Associate, respectively, Department of Entomology and Plant Pathology, Stuttgart.
[2] Extension Entomologist/Distinguished Professor, Extension Entomologist/Assistant Professor, Program Associate, Program Associate, and Program Associate, respectively, Department of Entomology and Plant Pathology, Lonoke.
[3] Extension Entomologist/Professor, Department of Entomology and Plant Pathology, Keiser.
[4] Graduate Assistant, Graduate Assistant, Graduate Assistant, Graduate Assistant, Graduate Assistant, and Graduate Assistant, respectively, Department of Entomology and Plant Pathology, Fayetteville.

Results and Discussion

Large Block Study

A general trend was observed across all planting dates that the non-*Bt* (DKC 67-70) hybrid had more corn earworm present than the other hybrids; however, for the second planting date, the DoublePro hybrid (DKC 67-72) had the highest number of corn earworm present. For all plantings, the non-*Bt* (DKC 67-70) had greater kernel damage than all other hybrids, although damaged kernel counts were similar to the DoublePro hybrid (DKC 67-72). All corn hybrids containing the Vip3a gene averaged less than 2 damaged kernels per 100 ears and less than 1 corn earworm per 100 ears (Table 2).

Small Plot Study

In the early planting date, all hybrids containing Vip3a (DKC 65-99 and P 2089VYHR) had fewer corn earworm present than P 1870YHR (Table 3). Additionally, the hybrids containing Vip3a (DKC 65-99 and P 2089VYHR) had less kernel damage than all other hybrids for the early planting. No yield differences were observed among the different hybrids for the early planting. For the late planting, the P 1870R and P 1870YHR hybrids had more corn earworm present than all other hybrids (Table 3). Both non-*Bt* hybrids (DKC 67-70 and P 1870R) and the P 1870YHR hybrid had more kernel damage than all other hybrids for the late planting. Hybrids containing Vip3a (DKC 65-99 and P 2089VYHR) had fewer corn earworm present and less kernel damage than all other hybrids for the late planting. The Treceptra hybrid (DKC 65-99) yielded higher than P 1870YHR and P 2089VYHR for the late planting.

Practical Applications

In general, the hybrids containing the Vip3a gene had fewer larvae and damaged kernels compared to the DoublePro and non-*Bt* hybrids. Hybrids containing the Vip3a gene are a good option to minimize corn earworm damage in corn; however, it is rare that we observe enough damage in any corn hybrid from corn earworm to reduce yield. Growers should look at the overall yield potential and price of seed to determine what insect trait package is most profitable for their operation.

Acknowledgments

The authors would like to thank the Arkansas Corn Checkoff Program administered by the Arkansas Corn and Grain Sorghum Research and Promotion Board for the funding of this work, and the University of Arkansas System Division of Agriculture.

Literature Cited

Bibb, J.L., D. Cook, A. Catchot, F. Musser, S.D. Stewart, B.R. Leonard, G.D. Buntin, D. Kerns, T.W. Allen, and J. Gore. 2018. Impact of corn earworm (Lepidoptera: Noctuidae) on field corn (Poales: Poaceae) yield and grain quality. J. Econ. Entomol. 111:1249–1255.

Dicke, F.F. and W.D. Guthrie. 1988. The most important corn insects, pp. 767–867. *In*: Corn and corn improvement. Agronomy Monograph 18, 3rd ed. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America, Madison, Wis.

Koziel, M.G., G.L. Beland, C. Bowman, N.B. Carozzi, R. Crenshaw, L. Crossland, J. Dawson, N. Desai, M. Hill, and S. Kadwell. 1993. Field performance of elite transgenic maize plants expressing an insecticidal protein derived from *Bacillus thuringiensis*. Biotechnology. 11:194–200.

Table 1. Corn hybrid names and trait packages used in corn earworm efficacy studies conducted at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, near Marianna, Arkansas, in 2021.

Large Block Study		
Hybrid	**Trait Package**	***Bt* toxins**
DKC 67-70	RR2	None
DKC 67-72	VT2P	Cry1A.105, Cry2Ab2
NK 1677	Viptera	Cry1Ab, Vip3A
P 2042	Leptra	Cry1Ab, Cry1F, Vip3A
DKC 67-94	Treceptra	Cry1A.105, Cry2Ab2, Vip3A
Small Plot Study		
Hybrid	**Trait Package**	***Bt* toxins**
DKC 67-70	RR2	None
DKC 67-72	VT2P	Cry1A.105, Cry2Ab2
DKC 65-99	Treceptra	Cry1A.105, Cry2Ab2, Vip3A
P 1870R	RR2	None
P 1870YHR	YHR	Cry1Ab, Cry1F
P 2089VYHR	Leptra	Cry1Ab, Cry1F, Vip3A

Table 2. Corn earworm densities and kernel damage per 100 ears for multiple corn hybrids and planting dates, at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station Marianna, Arkansas, in 2021.

Planting Date	Hybrid	Trait Package	CEW† Larvae/10 ears	Damaged Kernels/10 ears
17 April				
	DKC 67-70	RR2	2.3	27.8
	DKC 67-72	VT2P	1.0	7.5
	NK 1677	Viptera	0.0	0.0
	P 2042	Leptra	0.0	0.25
	DKC 67-94	Treceptra	0.0	0.0
4 May				
	DKC 67-70	RR2	8.0	6.3
	DKC 67-72	VT2P	14.0	5.1
	NK 1677	Viptera	0.0	0.0
	P 2042	Leptra	0.8	0.9
	DKC 67-94	Treceptra	0.5	0.0
18 May				
	DKC 67-70	RR2	10.0	10.9
	DKC 67-72	VT2P	6.0	10.6
	NK 1677	Viptera	0.0	1.2
	P 2042	Leptra	0.0	0.2
	DKC 67-94	Treceptra	0.0	0.6

† Corn earworm.

Table 3. Corn earworm densities and kernel damage per 10 ears for multiple corn hybrids and planting dates, at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, near Marianna, Arkansas, in 2021.

Planting Date	Hybrid	Trait Package	CEW† Larvae/ 10 ears	Damaged Kernels/ 10 ears	Yield bu./ac
1 May					
	DKC 67-70	RR2	1.5 ab‡	2.8 a	204.1 a
	DKC 67-72	VT2P	1.5 ab	3.8 a	200.9 a
	DKC 65-99	Treceptra	0.0 b	0.2 b	202.0 a
	P 1870R	RR2	0.8 ab	3.8 a	196.4 a
	P 1870YHR	YHR	1.8 a	3.1 a	172.3 a
	P 2089VYHR	Leptra	0.0 b	0.2 b	197.3 a
1 June					
	DKC 67-70	RR2	5.8 b	12.0 a	204.4 ab
	DKC 67-72	VT2P	6.0 b	6.0 b	201.4 ab
	DKC 65-99	Treceptra	0.3 c	0.2 c	213.8 a
	P 1870R	RR2	16.0 a	11.5 a	190.3 ab
	P 1870YHR	YHR	11.8 a	12.4 a	187.1 bc
	P 2089VYHR	Leptra	0.0 c	0.2 c	166.6 c

† Corn earworm.

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

Efficacy of Sivanto Applied In-Furrow for Control of Sugarcane Aphid in Grain Sorghum

B.C. Thrash,[1] G.M. Lorenz,[1] N.R. Bateman,[2] W.A. Plummer,[1] M.G. Mann,[1] J.P. Schafer,[1] S.G. Felts,[2] C.A. Floyd,[3] T.B. Newkirk,[3] C. Rice,[3] T. Harris,[3] A. Whitfield,[3] and Z. Murray[3]

Abstract

Sugarcane aphids (SCA) quickly became the most damaging insect pest of grain sorghum in Arkansas after initially entering the state in 2015. There are multiple management methods for SCA, including resistant and tolerant cultivars, insecticide seed treatments, and foliar insecticide applications. One product commonly used in foliar applications for control of SCA in grain sorghum is Sivanto Prime (flupyradifurone). Because Sivanto Prime has systemic activity, it could potentially be used as an in-furrow application at planting, giving growers another option for control of sugarcane aphids. A study was conducted at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station to evaluate Sivanto Prime applied as an in-furrow treatment at planting for control of SCA in grain sorghum. Treatments containing in-furrow applications of Sivanto Prime provided similar control of SCA and yields similar to those of foliarly applied Transform (sulfoxaflor) and Sivanto Prime.

Introduction

Sugarcane aphids (SCA) first became an issue in Arkansas grain sorghum in 2015. This pest rapidly spread across the state and has become the most damaging insect pest of grain sorghum in Arkansas. Sugarcane aphids have an extremely large reproductive potential. Fields can go from a few SCAs being found along field edges to near 100% of plants being infested within a week. Severe SCA infestations can cause complete yield loss, and the copious amounts of honeydew these insects produce can clog up combines, greatly reducing harvest efficiency. However, there are several options growers have to help manage this pest. Selecting a grain sorghum hybrid that is resistant or tolerant to SCA can reduce the speed at which the aphids infest the crop and reduce the potential yield loss. However, most of these hybrids still require foliar insecticide applications to control this pest. Neonicotinoid seed treatments protect against aphid infestation early in the growing season but are only effective for the first month after planting. Transform (sulfoxaflor) and Sivanto Prime (flupyradifurone) are the currently recommended products for foliar control of SCA in Arkansas. Transform has trans-laminar activity where the product moves into the treated leaf but is not translocated throughout the unsprayed portion of the plant. Sivanto, on the other hand, does have systemic activity and moves with the plant as it grows. The objective of this study is to determine if an in-furrow (IF) application of Sivanto will provide control of SCA throughout the growing season.

Procedures

Grain sorghum (Pioneer 84P80) was planted on 7 May at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station in Marianna, Ark. Plots were 4 rows by 40 ft planted on 38-in. beds, with each treatment being replicated 4 times. Treatments were Sivanto Prime applied IF at 4, 6, and 8 oz/ac, foliar applications of Sivanto Prime at 5 and 8 oz/ac, Transform at 2.75 oz/ac, and an untreated check, for a total of 7 treatments. The number of aphids on 10 upper and 10 lower leaves in each plot was estimated and recorded at 0 (27 July), 3 (30 July), 6 (2 August), 13 (9 August), and 15 (11 August) days after the foliar application (DAA) and 81, 84, 87, 94, and 96 days after the at planting IF application, respectively. The 0 DAA rating was conducted just prior to the foliar insecticide application. No differences were observed between the upper and lower leaf counts, and they were combined for analysis. A honeydew rating of 0 (no honeydew)–5 (severe honeydew) was also recorded for each plot at 3, 13, and 15 DAA. Plots were harvested on 27 September, and yields are reported in bu./ac. All data were processed using Agriculture Research Manager Version 10, AOV, and Duncan's New Multiple Range Test (*P* = 0.10) to separate means.

Results and Discussions

In the untreated check, SCA densities increased throughout the duration of the test (Fig. 1). At the 0 DAA rating, which was prior to the foliar application, all Sivanto Prime IF treatments

[1] Extension Entomologist, Extension Entomologist, Program Associate, Program Associate, and Program Associate, respectively, Department of Entomology and Plant Pathology, Lonoke.
[2] Extension Entomologist and Program Associate, respectively, Department of Entomology and Plant Pathology, Stuttgart.
[3] Graduate Assistant, Graduate Assistant, Graduate Assistant, Graduate Assistant, Graduate Assistant, and Graduate Assistant, respectively, Department of Entomology and Plant Pathology, Fayetteville.

had fewer SCA than the untreated. At 3, 6, 13, and 15 DAA, all treatments reduced SCA densities and provided equally good control at all sample dates. At 3 DAA, all products reduced honeydew severity, but IF applications of Sivanto had the lowest amount of honeydew (Fig. 2). At 13 DAA, all treatments had less honeydew than the untreated, but Sivanto Prime IF at 6 and 8 oz/ac and Sivanto Prime foliar at 5 and 8 oz/ac had the lowest honeydew rating. At 15 DAA, all treatments had less honeydew than the untreated, but Sivanto Prime IF at 6 and 8 oz/ac, and all foliar insecticide treatments had the lowest honeydew rating. All treatments yielded, at a minimum, double the untreated check, but all rates of Sivanto Prime IF and foliar applications of Sivanto Prime at 8 oz/ac and Transform at 2.75 oz/ac yielded the greatest (Fig. 3).

In-furrow applications of Sivanto Prime provided season-long control of SCA and yielded similarly to the currently recommended foliar products. Honeydew ratings were initially lower in the IF treatments when compared to the foliar applications due to SCA never establishing in those plots. However, rainfall washed off much of the honeydew prior to the ratings at 13 and 15 DAA, making the foliar application honeydew ratings similar to those of the IF applications. Overall, IF applications of Sivanto performed comparably to our standard foliar applications.

Practical Applications

In-furrow applications of Sivanto performed comparably to our standard foliar applications and may be a consideration for growers who do not want to make a foliar application for SCA later in the growing season.

Acknowledgments

We want to thank the Arkansas Corn and Grain Sorghum Board and the University of Arkansas System Division of Agriculture for their support. We would also like to thank Bayer Crop Science for funding this research.

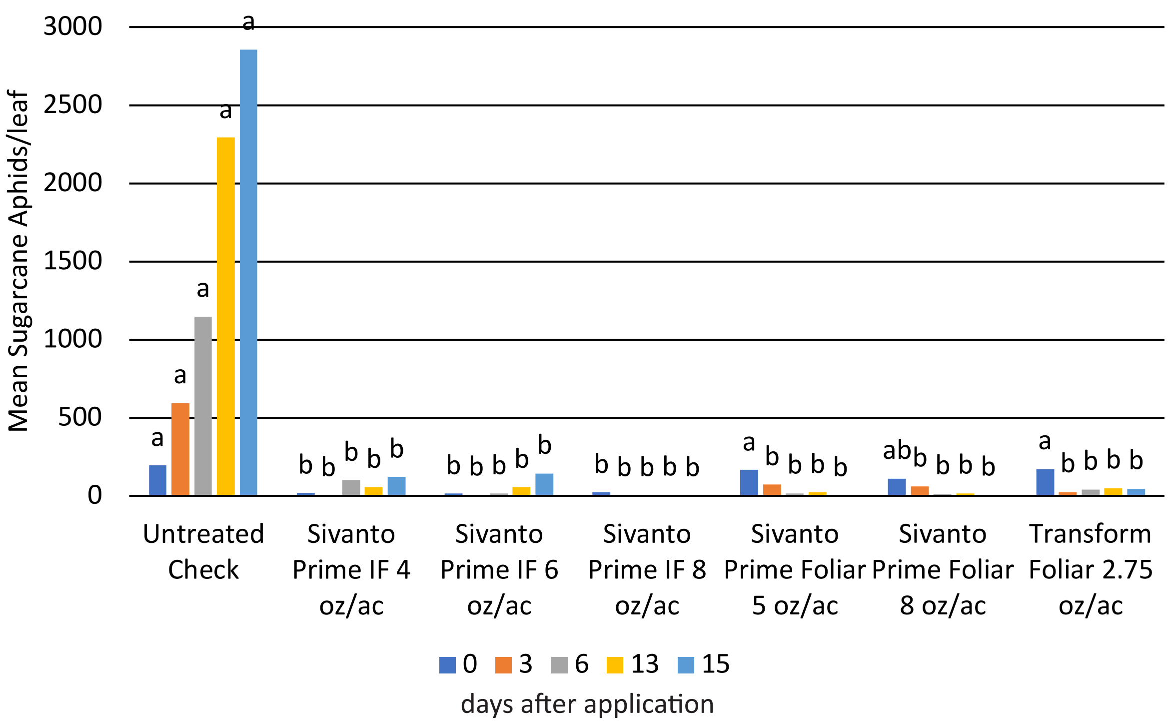

Fig. 1. Mean number of sugarcane aphids per leaf on 10 upper and 10 lower leaves in sorghum treated with in-furrow (IF) and foliar-applied insecticides at 0, 3, 6, 13, and 15 days after application. Means followed by a different letter are significantly different at *P* = 0.10.

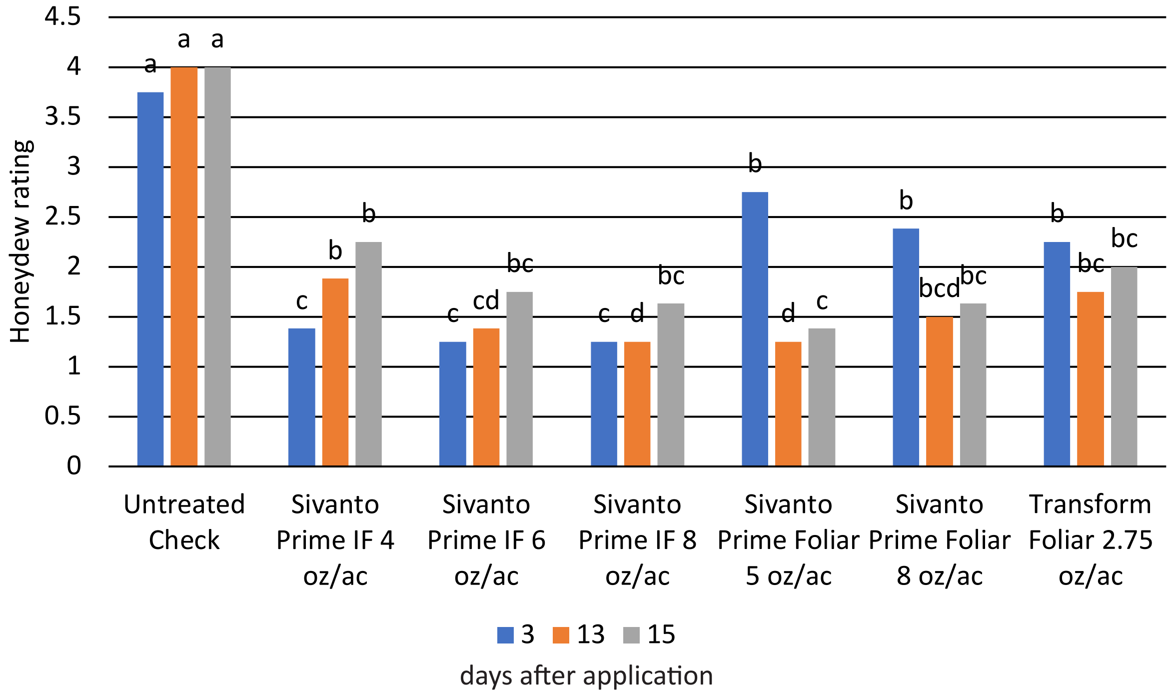

Fig. 2. Mean honeydew rating 0 (no honeydew)–5 (severe honeydew) in sorghum treated with in-furrow (IF) and foliar-applied insecticides at 3, 13, and 15 days after application. Means followed by a different letter are significantly different at *P* = 0.10.

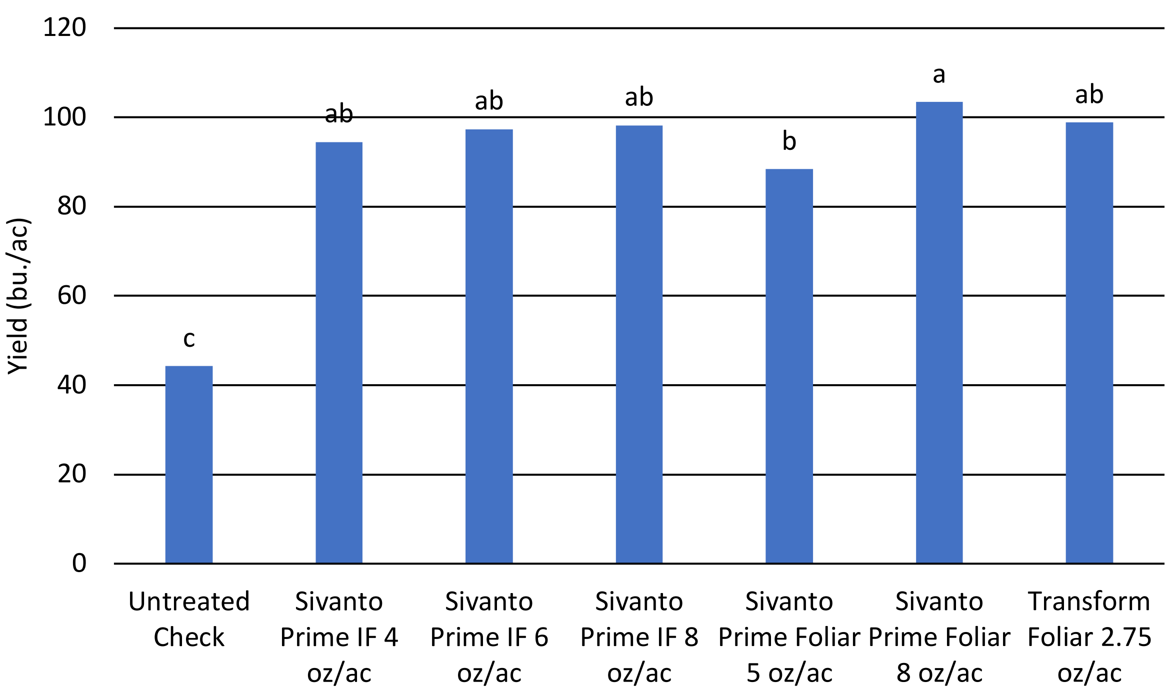

Fig. 3. Mean yield of sorghum treated with in-furrow (IF) and foliar-applied insecticides. Means followed by a different letter are significantly different at *P* = 0.10.

Sensitivity of Arkansas Johnsongrass Populations to Herbicides

J.A. Fleming,[1] J.K. Norsworthy,[1] L.T. Barber,[2] and T.R. Butts[2]

Abstract

Due to genetic similarities between johnsongrass (*Sorghum halepense* L. Pers.) and grain sorghum (*Sorghum bicolor* L. Moench), few herbicides are available to effectively remove the troublesome weed without injuring the crop. In order to combat this issue, multiple new grain sorghum lines are being developed in grain sorghum to help producers by allowing over-the-top applications of herbicides previously unavailable, with some commercialized in 2021. These technologies include resistance to both acetyl CoA carboxylase (ACCase) and acetolactate synthase (ALS) inhibitors. Johnsongrass seed from locations in Arkansas were collected, and a greenhouse study was conducted in Fayetteville, Ark., in 2020 and 2021 to determine the effectiveness of the herbicides that will be labeled in these new technologies. Johnsongrass seeds were collected from 63 fields within six counties in eastern Arkansas. These accessions were threshed and then seeded in the greenhouse, where seedlings were treated with fluazifop at 0.09 lb/ac, quizalofop at 0.04 lb/ac, nicosulfuron at 0.03 lb/ac, and imazamox at 0.05 lb/ac. All herbicides were applied with 1% v/v crop oil concentrate. Overall, the two ACCase inhibitors, quizalofop and fluazifop, provided the highest levels of control, with a percent mortality of greater than 90% across all accessions tested aside from one accession from Crittenden County. These herbicides showed minimal variability in visual johnsongrass control and percent mortality. The lowest percent mortality was for nicosulfuron, which only controlled 87% of the plants treated. Imazamox resulted in 91% mortality of johnsongrass. Imazamox and nicosulfuron showed high levels of variability across all accessions. These findings show that imazamox and nicosulfuron will be ineffective at controlling Arkansas johnsongrass accessions in many fields. If Arkansas grain sorghum producers are planting into areas with known johnsongrass pressure, the best option is to utilize a technology that enables the use of quizalofop.

Introduction

Johnsongrass is a perennial grass that can reproduce both sexually, through seed production, and asexually, through rhizomes. The ability of johnsongrass to grow rapidly and produce greater than 10,000 seeds and 5,000 rhizomes makes the weed detrimental to producers (McWhorter, 1971). When johnsongrass is present, a yield reduction of up to 90% can be observed in upland crops (Klein and Smith, 2020). While many options are available for johnsongrass control in broadleaf crops like cotton (*Gossypium hirsutum* L.) and soybean [*Glycine max* L. Merr.], grass crops are subject to injury caused by many herbicides effective on johnsongrass. Herbicide resistance traits have also been an integral part of johnsongrass control in broadleaf crops and grass crops like corn (*Zea mays* L.), specifically the glyphosate resistance technology released in the 1990s. Conversely, this technology has not been available for grain sorghum producers, leaving them with no safe and effective herbicides for postemergence johnsongrass control. Recently multiple companies and universities have been developing new grain sorghum lines with genetic resistance to herbicides previously unavailable for grass control in grain sorghum. These include two lines with resistance to acetolactate synthase (ALS) inhibitors and two lines with resistance to acetyl coenzyme a carboxylase (ACCase) inhibitors. The ALS-inhibitor technologies include IGROWTH®, developed by UPL and Avanta Seeds which has resistance to imazamox, a commonly used herbicide in Clearfield rice for annual grass control, and INZEN, developed by Corteva, which has resistance to nicosulfuron, a herbicide that was commonly used for johnsongrass control in corn (Pinkerton, 2020). The ACCase-inhibitor technologies include Double Team™ (developed by Adama and S&W Seed Company), which confers resistance to quizalofop, a herbicide utilized in broadleaf crops for grass control, and TamArk™ grain sorghum developed through a collaboration between the University of Arkansas System Division of Agriculture and Texas A&M University with resistance to fluazifop and other herbicides within the aryloxyphenoxypropionate family and the single herbicide within the phenylpyrazolin family of ACCase-inhibitors. With the introduction of new herbicide options for johnsongrass control in grain sorghum, it becomes important to understand which herbicides are effective on Arkansas johnsongrass accessions.

Procedures

A greenhouse study was conducted in 2020 and 2021 in Fayetteville, Arkansas, to evaluate the effectiveness of new grain sorghum herbicides on johnsongrass control. This experiment was a single factor completely randomized design. Seedheads from 63 different johnsongrass populations were collected throughout six counties (Crittenden, Greene, Poinsett, Cross, Mississippi, and

[1] Graduate Assistant and Distinguished Professor, respectively, Department of Crop, Soil, and Environmental Sciences, Fayetteville.
[2] Professor and Assistant Professor, Department of Crop, Soil, and Environmental Sciences, Lonoke.

Craighead) in 2020. The seed was hand-harvested from seedheads and placed into cold storage for two weeks before planting to break seed dormancy. Trays were filled with standard potting mix, and johnsongrass seed was sown at 100 seeds per tray. Five trays were planted per accession, one for each of the four herbicides and one nontreated for comparison (Table 1). Trays of seedlings were sprayed when johnsongrass reached the 2- to 3-leaf stage. Applications were made at 1 mph and 20 gal/ac in a spray chamber using flat fan 1100067 nozzles at 40 psi. Both ACCase herbicides received 1% v/v of crop oil concentrate as recommended by the label. Before application, the total number of plants in each tray was recorded. The final number of living plants was recorded again at 28 days after application (DAA) and used to calculate percent mortality. Visual johnsongrass control was evaluated every 7 days until 28 DAA on a scale of 0 to 100, where 0 represents no johnsongrass injury, and 100 represents no living johnsongrass tissue. Data were analyzed using JMP Pro 16.1, and means were separated using Fisher's protected least significant difference, and boxplots were assembled.

Results and Discussion

All four herbicides evaluated achieved 100% control and mortality of some accessions evaluated, but quizalofop was the only herbicide that controlled all johnsongrass accessions 100%. The two ALS-inhibitors, imazamox and nicosulfuron, resulted in significantly lower visual control levels and percent mortality than the two ACCase-inhibitors, quizalofop and fluazifop, when averaged over accession. This reduction in control with ALS-inhibitors is likely due to the number of outlier control levels present, which are accessions that have much lower levels of control than the majority of the data and are potentially resistant (Figs. 1 and 2). These outlier control levels observed are of the most concern since outliers within this data set are specific accessions that do not fit the majority of the data due to low levels of control. These accessions are also considered potentially resistant. Zero outliers within the ACCase-inhibitors evaluated were observed with quizalofop since all johnsongrass accessions were controlled 100%, and 4 were observed with fluazifop. While 3 of the 4 fluazifop outliers had visual control and percent mortality ratings greater than 90%, one accession from Crittenden County resulted in only 73% mortality (Figs. 1 and 2). The two ALS-inhibitors had the highest level of variation, with control and mortality ranging from 0% to 100%. Of the 63 accessions evaluated, 6 were considered outliers when treated with imazamox and 10 when treated with nicosulfuron. The imazamox outliers were found in Poinsett County, while nicosulfuron outliers were located mainly in Crittenden and Mississippi Counties.

Practical Applications

With johnsongrass populations potentially resistant to new herbicides becoming available for postemergence control in grain sorghum, it will become essential that producers select the proper technology to control johnsongrass and mitigate the spread of resistance successfully. Johnsongrass accessions with potential resistance are of most concern in this study, specifically when looking at the ALS-inhibitors, nicosulfuron and imazamox. Due to the variation in control of the ALS-inhibitors, these herbicide technologies would not be recommended for grain sorghum producers in areas with a history of johnsongrass pressure. Instead, one of the two ACCase-inhibitors, fluazifop or quizalofop, would be recommended for johnsongrass control. It will also be important for producers to utilize these new postemergence options in a program approach with other effective herbicide modes of action and integrated weed management strategies to better control johnsongrass and mitigate an increase in the number of herbicide-resistant johnsongrass populations (Norsworthy et al., 2012).

Acknowledgments

The authors express their gratitude to Arkansas corn and sorghum producers for supporting this research via check-off funds administered by the Arkansas Corn and Grain Sorghum Promotion Board. The authors would like to thank the University of Arkansas Systems Division of Agriculture for their support with this study and the Crittenden, Mississippi, Poinsett, Greene, Cross, and Craighead County agents for their assistance in collecting these johnsongrass samples.

Literature Cited

Klein, P. and C.M. Smith. 2020. Invasive johnsongrass, a threat to native grasslands and agriculture. Biologia 76:413-420.

Mcwhorter, C.G. 1971. Anatomy of johnsongrass. Weed Sci. 19:385-393.

Norsworthy, J.K., S.M. Ward, D.R. Shaw, R.S. Llewellyn, R.L. Nichols, T.M. Webster, and M. Barrett. 2012. Reducing the risks of herbicide resistance: best management practices and recommendations. Weed Sci. 60:31-62.

Pinkerton, S. (2020) Advanced cropping solutions for sorghum coming soon. Accessed 24 February 2022. Available at: https://sorghumgrowers.com/magazine/checkoff-newsletter-spring-2020/

Table 1. Johnsongrass control and mortality of johnsongrass collected in Arkansas by herbicide averaged over accession 21 days after treatment.

Herbicide	lb ai/ac	Visual control	Mortality
		--------------------------(%)--------------------------	
Fluazifop	0.09	99 a[†]	98 a
Quizalofop	0.04	100 a	100 a
Nicosulfuron	0.03	91 b	91 b
Imazamox	0.05	87 b	87 b

[†] Values in each column with different letters are different based on Fisher's protected least significant difference ($\alpha = 0.05$).

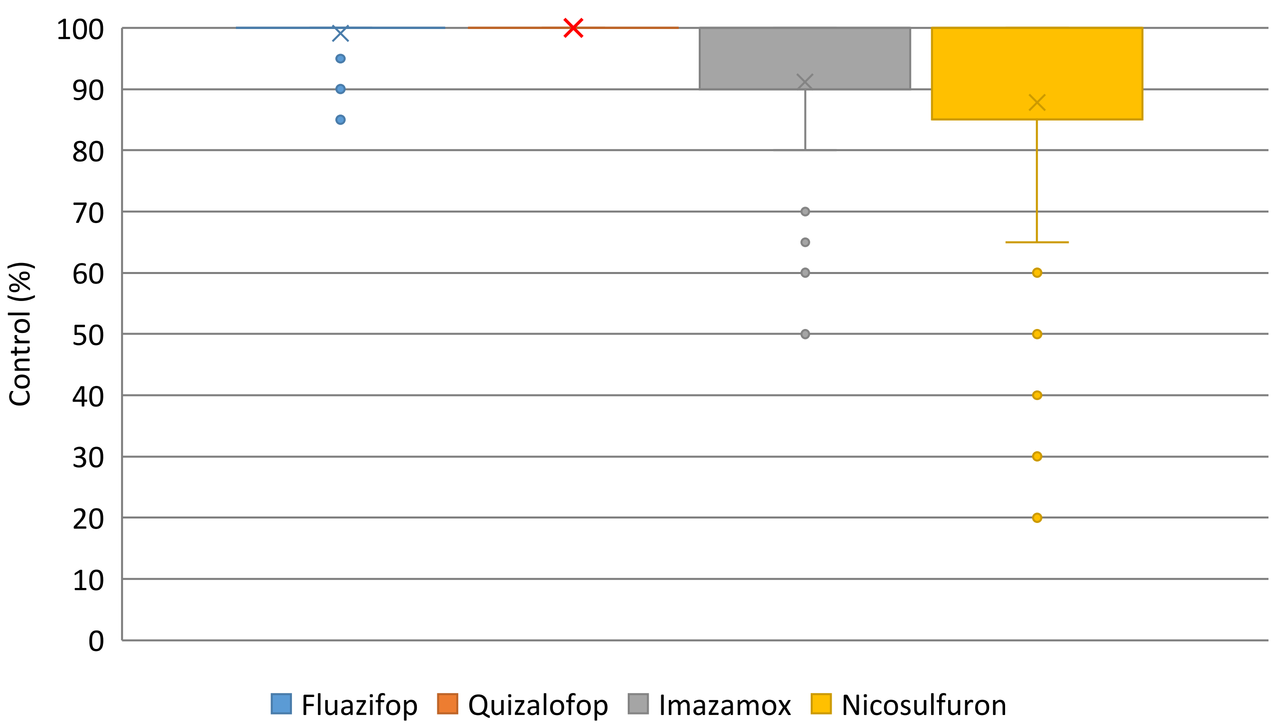

Fig. 1. Box and whisker plots representing visual control of johnsongrass accessions collected in eastern Arkansas in 2020 by herbicide 21 days after treatment. Lines represent the median control level, Xs represent the mean control, and dots represent outlier accessions that do not fall within 90% of the data.

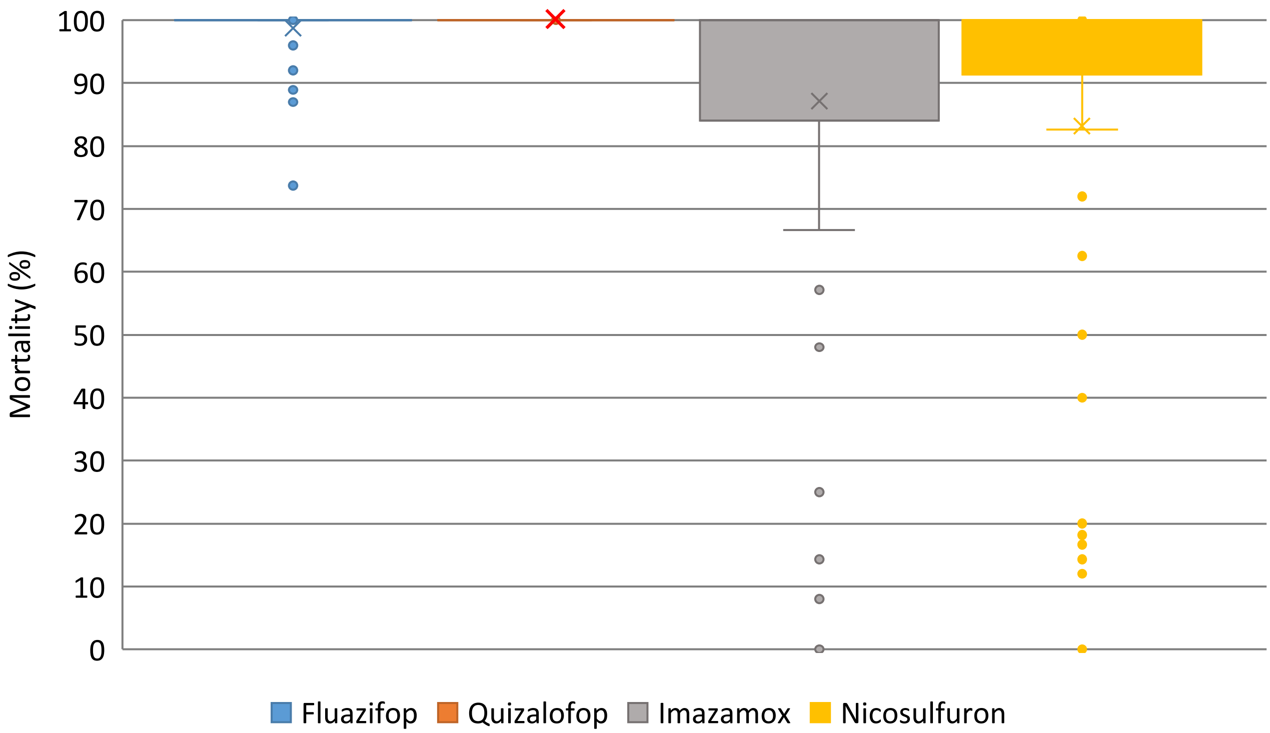

Fig. 2. Box and whisker plots representing percent mortality of johnsongrass accessions collected in eastern Arkansas in 2020 by herbicide 21 days after treatment. Lines represent the median percent mortality, Xs represent the mean percent mortality, and dots represent outlier accessions that do not fall within 90% of the data.

Optimum Cover Crop Termination Timing in Corn Weed Control System

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

Abstract

In 2021, research was conducted to determine the optimum time to terminate a cover crop while also achieving sufficient weed control and optimum corn yield. The test was designed as a randomized complete block with 7 cover crop termination timings: 14 and 7 days prior to planting (DPP), at planting (AP), and 7, 14, 21, and 28 days after planting (DAP). A conventional tillage treatment was added for comparison and was treated with the standard herbicide program used for termination. All termination treatments consisted of glyphosate (Roundup PowerMax 2) applied at 40 oz/ac plus *S*-metolachlor (Dual II Magnum) at 1.3 pt./ac and atrazine (Aatrex) at 1 qt/ac. A standard postemergence (POST) application was made at the V4 corn stage across all treatments utilizing a premix of *S*-metolachlor, glyphosate, and mesotrione (Halex GT 2 qt/ac) plus atrazine (Aatrex 1 qt/ac). Pioneer 1197 YHR was planted on 5 April 2021, and a visual weed control assessment was taken 28 DAP. There was no difference in Palmer amaranth or barnyardgrass control when the cover crop was terminated 7 DPP, at planting, and 7, 14, 21, and 28 DAP. Palmer amaranth control ranged from 78% to 90%, while barnyardgrass control ranged from 81% to 91% controlled. The 14 DPP termination timing only provided 50% control of Palmer amaranth and 47% control of barnyardgrass, while the conventional tillage treatment provided the least (37%) control of both Palmer amaranth and barnyardgrass. Control of Palmer amaranth and barnyardgrass was increased to 94–99% for all termination timings following the V4 POST application, and no significant differences were observed from 7–21 days following the V4 application. Corn yields were highest (160–81 bu./ac) for 14 DPP, 7 DPP termination timings, and the conventional tillage treatments. Yields from plots where the cover crop was terminated at planting, 7,14, and 28 DAP ranged from 144 to 128 bu./ac. Cover crops terminated at 21 DAP resulted in the lowest yield of the study, only 125 bu./ac.

Introduction

Cover crops have become increasingly popular in the midSouth, primarily for erosion control as well as an economic benefit to soil health and weed suppression (Butts et al., 2020). With the increased interest in the utilization of cover crops, a common concern is deciding when to terminate the cover crop to achieve optimum weed suppression while maintaining adequate yield. Cover crops have proven beneficial in reducing weed germination (Palhano et al., 2018). Corn producers in Arkansas are interested in cover crop systems but are unsure of optimum times to terminate cover crops to achieve optimum weed suppression while maintaining adequate corn yield. The objective of this study was to evaluate cover crop termination timings for optimum weed control while achieving comparative yield.

Procedures

A trial was conducted to evaluate the optimum time to terminate a cover crop in a corn production scenario at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station near Marianna, Arkansas. The experiment was arranged in a randomized complete block design with plots 12.5 by 30 feet. A cover crop blend consisting of cereal rye, Austrian winter pea, tillage radish, black oats, and crimson clover was planted in November 2020 on a Calloway silt loam soil at 50 lb/ac utilizing a 7.5-in. drill spacing across 38-in. raised beds. Corn was planted on 5 April 2021 utilizing Pioneer 1197 YHR variety planted at 32,000 seeds/ac on 38-in. beds. All herbicide treatments were applied using a compressed air broadcast sprayer with 11002 Tee Jet Air-Mix nozzles on 19-in. spacing utilizing 15 gal/ac carrier volume. Cover crop termination consisted of seven timings: 14 and 7 days prior to planting (DPP); at planting (AP); and 7, 14, 21, and 28 days after planting (DAP). A conventional tillage treatment was added for comparison where plots were kept clean utilizing common burndown herbicides and tillage practices until treatments were applied at planting on 5 April 2021. Glyphosate (Roundup Powermax 2) was applied at 40 oz/ac plus *S*-metolachlor (Dual II Magnum) at 1.3 pt/ac and atrazine (Aatrex) at 1 qt/ac for each cover crop termination timing. A postemergence (POST) application was made at the V4 corn stage across all treatments utilizing a premix of *S*-metolachlor, glyphosate, and mesotrione (Halex GT 2 qt/ac) plus atrazine (Aatrex 1 qt/ac). A visual weed control assessment was taken 4 weeks after planting and two weeks after the V4 POST application. The conventional tillage treatment was used as a comparison against all cover crop termination treatments. All other recommendations for corn production, including fertility,

[1] Program Associate, Professor, and Program Associate, Department of Crop, Soil, and Environmental Sciences, Lonoke.
[2] Distinguished Professor and Elms Farming Chair of Weed Science, Department of Crop, Soil, and Environmental Sciences, Fayetteville.
[3] Program Associates, Crop, Soil, and Environmental Sciences, Monticello.

irrigation and general management practices were conducted according to University of Arkansas System Division of Agriculture Cooperative Extension Service recommendations. Data were analyzed using Fisher's protected least significant difference at $P \leq 0.05$ for significance to separate treatment means.

Results and Discussion

Cover crop termination 7 DPP, AP, as well as 7, 14, 21, and 28 DAP treatments resulted in 78–90% control of Palmar amaranth at 28 days after planting (Fig. 1). Control of Palmer amaranth was significantly reduced (<50%) when cover crops were terminated at 14 DPP, as well as conventional tillage, where control was reduced to 37% (Fig. 1). Common barnyardgrass control was similar with 7 DPP, AP, and 7, 14, 21, and 28 DAP resulting in 81–91% control. Cover crop termination 14 DPP provided only 47% control, while conventional tillage provided 37% (Fig. 1). Two weeks after the blanket POST application, there was no significant difference between treatments in Palmer amaranth control (Fig. 2). However, 14 DAP provided 91% control of Common barnyardgrass while all other treatments provided 95–99% control (Fig. 2). Corn yields were highest (160–181 bu./ac) for 14 DPP, 7 DPP, and conventional tillage treatments (Fig. 3). All other treatments where the cover crop was terminated at planting or later were significantly lower yielding ranging from 125 to 144 bu./ac. Treatments where the cover crop was terminated at 21 DAP resulted in the lowest yield of the study (125 bu./ac). These lower yields could be contributed to cover crop competition with the corn for light, nutrients, and moisture. Termination of the cover crop at planting or later resulted in early stunting (data not shown) that continued throughout the season. Other causes, such as insect damage, cannot be ruled out, although none were apparent in the research plot area.

Practical Applications

Overall, preliminary results indicate terminating a cover crop seven days prior to planting corn produces adequate weed control while achieving optimum corn yield assuming an early April planting date. The study shows that terminating the cover crop 14 DPP and conventional tillage resulted in the highest yields. However, effective POST options for Palmer amaranth control are typically more costly and can be less effective. Therefore, terminating cover crops closer to planting may be beneficial in reducing resistant Palmer amaranth emergence. This study will be repeated in 2022.

Acknowledgments

Special thanks to the University of Arkansas System Division of Agriculture and the Arkansas Corn and Grain Sorghum Promotion Board for providing funding for this research.

Literature Cited

Butts, T.R., L.T. Barber, and J.K. Norsworthy 2020. Distribution and Management of Herbicide-Resistant Palmer Amaranth in Arkansas. University of Arkansas System Division of Agriculture Cooperative Extension Service. FSA 2188. https://www.uaex.uada.edu/publications/PDF/FSA2188.pdf

Palhano, M., J.K. Norsworthy, and T. Barber 2018. Cover crop suppression of Palmer amaranth (*Amaranthus palmeri*) in cotton. Weed Technol. 32(1):60-65. https://dx.doi.org/10.1017/wet.2017.97

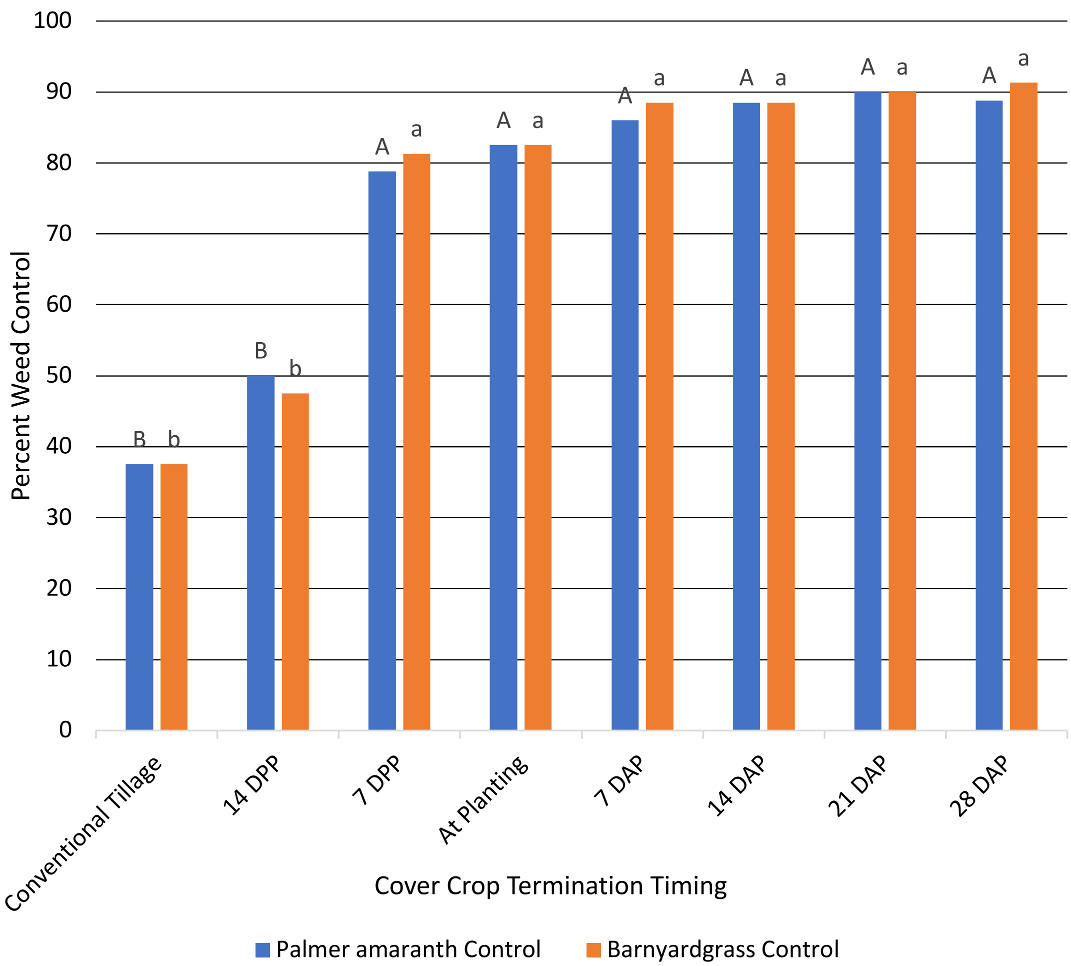

Fig. 1. Visual assessment of Palmer amaranth control 28 days after planting. Treatments with the same lowercase letter are not significantly different for barnyardgrass or upper-case letters for Palmer amaranth. Difference among treatments were determined by the least significant difference (LSD) greater than 20.99% for Palmer amaranth control and 18.6% for barnyardgrass control. DPP = days prior to planting; DAP = days after planting.

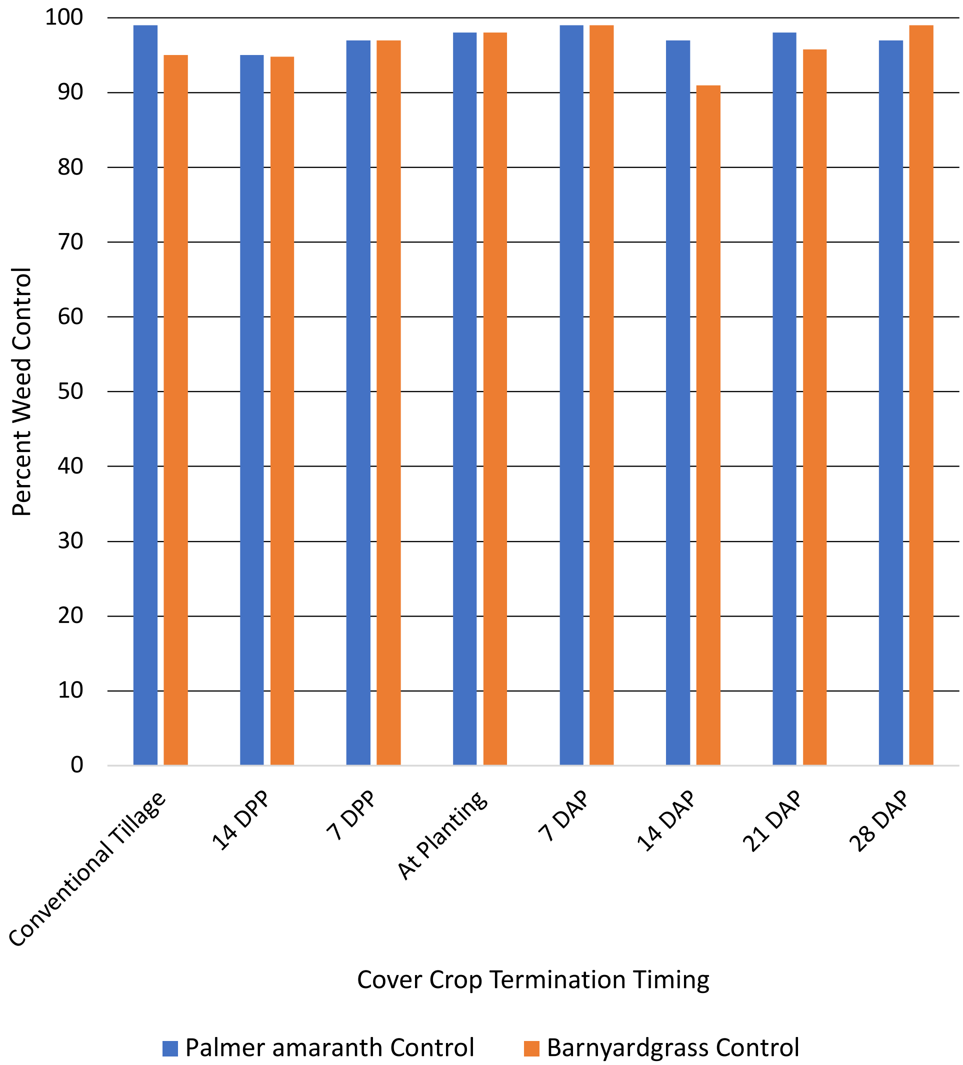

Fig. 2. Visual assessment of Palmar amaranth control 14 days after blanket postemergence application (POST). No significant differences were observed among treatments according to Fisher's protected least significant difference at *P* ≤ 0.05. DPP = days prior to planting; DAP = days after planting.

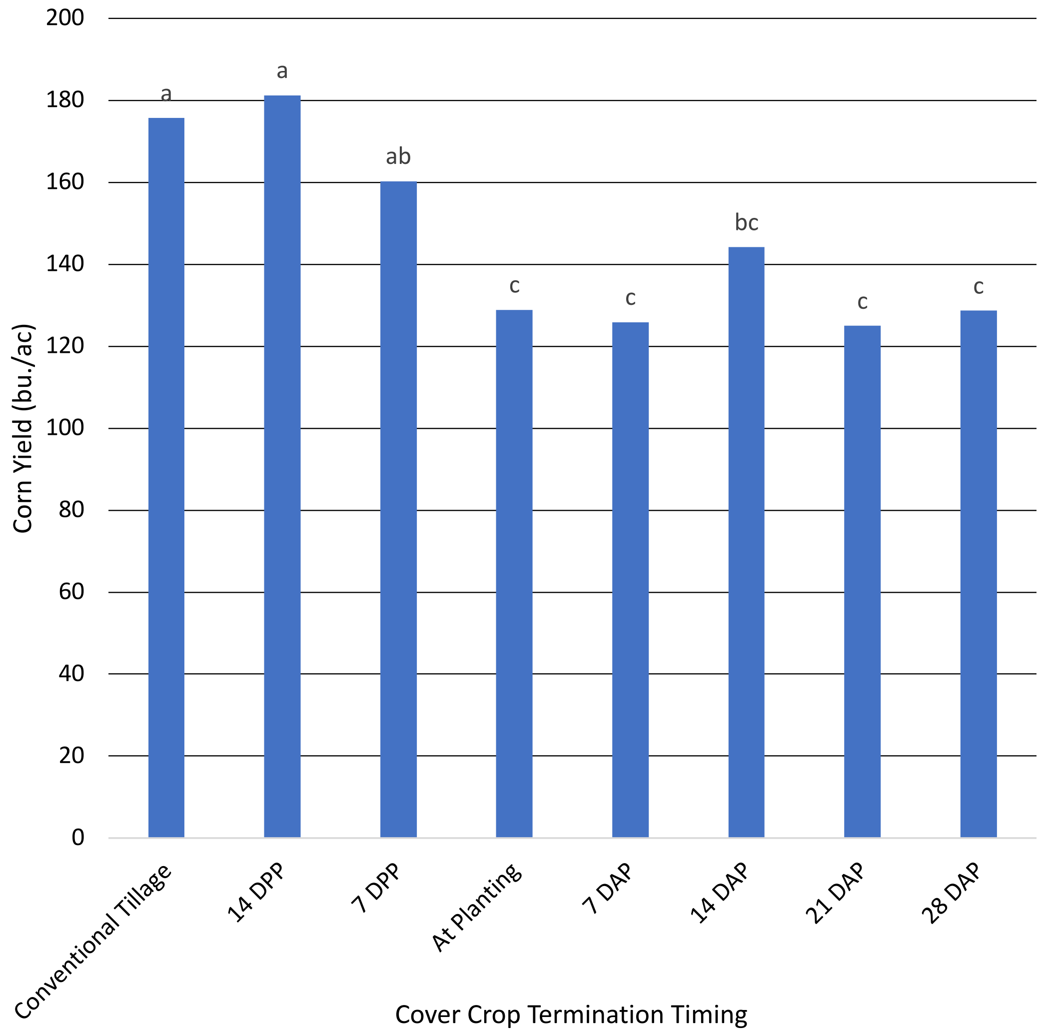

Fig. 3. Assessment of corn yield in bushels per acre (bu./ac). Differences among treatments were determined by the least significant difference (LSD) greater than 21.45 bu./ac. Yields with similar lowercase letters are not significantly different. DPP = days prior to planting; DAP = days after planting.

Net Present Value (NPV) Analysis Comparing Pumping Plant Energy Sources and Soil Moisture Monitoring, Surge Irrigation, and Computerized Hole Selection for Arkansas Corn Production

E.S.Caroline,[1] R.U. Mane,[2] C.G.Henry,[3] and K.B. Watkins[3]

Abstract

This study investigated the Net Present Value (NPV) differences of different energy sources and irrigation pump types used to irrigate corn (*Zea mays*) and four irrigation water management (IWM) options of Computerized Hole Selection, Surge Irrigation, and soil moisture monitors. Four options of IWM tools ranging from manual read sensors to multi-unit low-cost telemetry options were investigated. In general, the NPV follows the energy cost and pump type, in that the lowest-cost energy source, the electric relift, has the highest NPV, followed by the diesel relift, followed by the electric alluvial well, followed by the diesel alluvial well, and lastly the electric deep well. The higher the energy cost, the larger the difference between NPV IWM option and no-IWM. In all cases, the NPV was higher for all IWM options than for the no-IWM option. Thus we can conclude that investment in IWM is preferable to no investment. Essentially, the improved yield and reduced water use from utilizing IWM pays for the capital and annual costs.

Introduction

The Mississippi River Valley alluvial aquifer (MRVAA) was the second most heavily pumped principal aquifer in the United States in 2015, with withdrawals of 12.1 billion gallons (Bgal) per day (Lovelace et al., 2020). Irrigation was the largest user of groundwater from the MRVAA, accounting for 97% of daily withdrawals (11.7 Bgal per day) in 2015 (Lovelace et al., 2020). Groundwater withdrawals from irrigation have resulted in substantial areas of water-level decline in many parts of the MRVAA, as evidenced by cones of depression developing in both Arkansas and Mississippi (Barlow and Clark, 2011). Improving irrigation efficiency is, thus, of paramount importance in the region.

Currently, most irrigators in the mid-southern U.S. do not use scientific tools to schedule irrigations. Soil moisture sensors are a scientific scheduling tool that can improve irrigation timing by in situ measurements of soil moisture in the rooting zone. Sensor-based scheduling can reduce total water applied by up to 50% (Hassanli et al., 2009). The adoption of soil moisture sensors in the Delta region of Mississippi and Arkansas is less than 11%, indicating a tremendous potential for improvement in irrigation application (USDA-NASS, 2013). Computerized hole selection (CHS) improves irrigation application efficiency by considering the shape of the field, length of poly-tubing, and elevation changes along the field crown (Bryant et al., 2017). Surge Irrigation has been reported to reduce water use or increase water use and improve yields (Wood et al., 2017; Spencer et al., 2019; Bryant et al., 2017; Yonts et al., 1996). Combinations of these irrigation management tools have been referred to in the literature as irrigation water management (IWM).

Spencer et al. (2019) compared IWM practices for furrow irrigated corn in Arkansas and Mississippi on paired grower fields. Implementation of IWM practices reduced total water use by 39.5%, increased grain yield by 6.5 bu./ac, and increased irrigation water use efficiency by 51.3%. Similar results were reported by Henry and Krutz (2016) in 14 on-farm comparisons and via side-by-side comparisons at 4 research stations. Their data shows a 3–5% increase in yields (around 8 bu./ac) and a 40% decrease in water use. Spencer et al. (2019) also compared the average net returns of IWM relative to conventional water management in furrow-irrigated corn production for varying pumping lifts and found in all cases that IWM produced significantly greater net returns. However, Spencer et al. (2019) only considered one set of costs for IWM management. Several different IWM tool combinations, each having varying investment costs, may be used. Spencer et al. (2019) also assumed diesel power only and did not consider electric power units in their net returns analysis.

The purpose of this study is to compare the Net Present Value (NPV) of investment in IWM tools for corn production to no investment in IWM tools, building upon the work reported by Spencer et al. (2019). The Spencer study assumed a single cost for four Watermark Sensors™ surge valves and a diesel alluvial well, and varied irrigation costs using depth to water and commodity prices. There is a wide range of capital costs for soil moisture sensors and two commonly available surge valve models. Additionally, McDougall (2015) reported the cost of water (COW) for electric alluvial wells, electric relift (surface water), electric deep wells, diesel alluvial wells, and diesel relift (surface) pumping plants. He measured the cost of water in an integrated method during the season on over 100 Arkansas

[1] Program Specialist, Department of Agricultural Economics and Agribusiness, Fayetteville.
[2] Assistant Professor, Department of Agriculture, University of Arkansas, Pine Bluff.
[3] Associate Professor and Water Management Engineer, and Professor, respectively, Rice Research and Extension Center, Stuttgart.

farms over 3 years and found the COW to be 30% higher than the Nebraska Pumping Plant Criteria. Most economic analyses of irrigation pumping plant costs assume NPPC efficiency; thus, the actual irrigation energy costs are about 30% much higher than assumed in Spencer et al. (2019). This study attempts to vary the IWM equipment costs and the pumping plant energy type and measured costs to further assess how these decisions vary the economic return on IWM investment.

Procedures

A net present value (NPV) approach is used to evaluate the monetary benefits of IWM relative to no IWM in furrow-irrigated corn production for a 40-ac field. The NPV of an investment is equal to the sum of the present values of annual net monetary benefits to the investment over a specific planning horizon less the investment's initial cost and can be expressed as follows:

$$NPV = -IC_0 + \sum_{t=0}^{T} \frac{B_t - C_t}{(1+i)^t}$$

Where $t = 0$ to T years in the planning horizon, IC_0 is the initial cost of investing in IWM, B_t is the benefits in year t of IWM (or no IWM), C_t is the periodic cost in year t that changes from year to year for IWM components, and i is the discount rate. In this study, $T = 20$ years, $i = 4.5\%$, B_t = net returns to furrow-irrigated corn with or without IWM, and C_t = the cost of periodic maintenance, replacement, and labor associated with IWM components. The investment with the largest NPV is the preferred investment.

The average price of IWM equipment in this study was estimated based on a phone survey conducted in 2019 of producers, retailers, and dealers that either used, purchased, or sold the equipment. The specific details of each IWM tool were noted and used in the NPV analysis. These details include the life expectancy of each tool, annual fees per year, and any additional maintenance charges. All IWM equipment cost information is presented for four different investment options in Table 1.

The input costs for corn production are based on Arkansas Field Crop Enterprise Budgets for furrow-irrigated corn from 2017 to 2022 (UADA CES, 2022). All variable input costs for the 2017, 2018, 2019, 2020, 2021, and 2022 crop years were adjusted on an annual basis with the exception of diesel and electricity. Diesel and electric prices used in the analysis were \$3.30/gallon and \$0.10/kWh, respectively, based on prices used in McDougal (2015).

Energy cost was adjusted in the budgets for each type of energy source reported in McDougall (2015), electric surface relifts, diesel surface relifts, electric alluvial wells, diesel alluvial wells, and electric deep wells (Table 2). Relifts are surface pumps that lift surface water from a bayou or storage reservoir and deliver it to the irrigation system. Alluvial wells are considered shallow wells, generally between 80 and 250 ft in depth, and deep wells are classified as wells that are deeper than 250 ft. Few diesel deep wells exist because of the high operational cost. The average price of corn was assumed to be \$5.17/bu. based on market data for 2021. The diesel price used in McDougall (2015) is lower than current market conditions. Thus, an adjustment to the diesel energy cost is warranted. However, electric rates were assumed to be very similar to the 2015 time period of the McDougall study. Thus no adjustments were made to the COW reported by McDougall (2015) in this study.

The NPV analysis assumes no crop rotation since these tools will be used for different corn fields every year over a period of 20 years, and life expectancy and replacement of IWM tools were accounted for in the analysis. There are many different options for IWM and many companies that provide similar products. This study assumed the IWM would implement Computerized Hole Selection, surge irrigation, and soil moisture monitoring using matric potential sensors. Computerized Hole Selection is software that is free to use, but \$10 per field was assumed as a labor cost for developing a punch plan. There are two primary options with surge irrigation, a simple surge valve, a Junior III for square fields only, and a more expensive and adjustable surge valve, referred to as a Star. Retail costs for a 10-in. (P and R Surge Systems, Lubbock, Texas) surge valve were used in the analysis and are the most commonly marketed surge valves in the region. Finally, a granular matric potential sensor was assumed with three data collection and display options. The time to install sensors was assumed to take 15 minutes per set, assuming an hourly rate of \$11.33 or \$2.83 per field per year. Four options were included in the analysis that the authors felt generally represented most options available in the marketplace.

First, Option A assumed a manual reader was used to interpret sensors, and the reader was assumed to be capitalized on 500 acres, and the additional labor cost of (\$18.40) was included for the time to enter the field 6 times during the season to connect and read sensors. This option also assumed CAT 5 wire would be used to relay the wires to the edge of the field. The Junior III, or lowest cost surge valve, was assumed in this scenario to represent the lowest cost IWM option.

Next, Option B assumed a datalogger Watermark 900M (Irrometer, Riverside, Calif.) at a cost of \$419 was used with the 100 ft of CAT 5 wire and stationed at the edge of the field. This option assumed the Star surge valve. No labor for reading was assumed since readings are easy to display. No additional labor was assumed as it is expected that the farmer would be near the field to decide on irrigation. However, some additional trips or time may be required with this option to read the sensors.

The third option, Option C, assumed a single cellular gateway unit that gathered and reported sensor readings on an hourly basis, and the data was accessible on the internet. No additional labor outside of sensor installation (\$2.83) was assumed. The telemetry unit cost was assumed to be \$1,150 and required an annual fee of \$150 per year for data fees. For this option, each field would require a complete telemetry unit and annual data fees.

The last option, Option D, assumed a base and rover soil moisture telemetry unit, where many fields would be within a serviceable distance (assumed 1–5 miles) to a base gateway that communicated with rover units using low band radios. In this option, the base unit cost was assumed to be \$450 with 10 rovers at a cost of \$650 and an annual data cost of \$100 for the gateway. Thus the annual cost of the unit was assumed to be \$510 with an annual fee of \$10 for data fees. For this option, the Star surge valve was also assumed.

Options A–D represent the different options and provide different expected costs of implementing IWM systems. Option A provides the lowest entry option, Option B provides an intermediary option, and Option C represents the cellular telemetry option that is very popular and widely available. Option D represents the lower data fee model that can be obtained in a large-scale deployment of monitoring units.

Finally, the COW for each of the 5 commonly used pumping plants was applied to assess the NPV of each combination. These four IWM options were evaluated in this study relative to the control of no IWM practices.

The amount of water applied to corn for all four IWM practices was 5.2 ac-in./ac while the water applied under no IWM was 8.6 ac-in./ac, reflecting a 39.5% savings in irrigation water for IWM relative to no IWM in furrow-irrigated corn, as reported in Spencer et al. (2019). Average yields for furrow-irrigated corn were assumed to be 222.9 bu./ac and without IWM, 216.4 bu./ac, as reported in Spencer et al. (2019).

Results and Discussion

The total capital cost for each option was combined and is reported in Table 1. The average cost of IWM system investment in this study ranged between $2,792 and $4,581, with an annual telemetry cost of between $0 and $150. The surge irrigation controller and valve were always the most expensive IWM items, followed by the different soil moisture equipment. The cost of energy to pump irrigation water varies considerably between $0.67/ac-in. for an electric relift pump to as high as $4.02 for an electric deep well (Table 2). Diesel deep wells are not considered in the analysis; because of the extremely high cost to operate, they rarely exist. Tables 3 and 4 then compare the different options to themselves and to the control, no IWM.

A higher NPV than another scenario means that the payback for that practice will be faster than a lower NPV. In all cases, the NPV was higher for all IWM options than for the no-IWM option. Thus we can conclude that investment in IWM is preferable to no investment. Essentially the improved yield and reduced water use utilizing IWM pay for the capital and annual costs. The NPV of the IWM options versus the pump and energy types is shown in Table 3. Differences in NPV between each IWM option and the no-IWM option are presented by pump and energy differences in Table 4.

Option A, which is a manual reader and Junior III surge value on a surface electric relift, has the highest NPV. The lowest NPV is Option C with the electric deep well. In general, the NPV follows the energy cost and pump type in that the lowest cost energy source, the electric relift, has the highest NPV, followed by the diesel relift, followed by the electric alluvial well, followed by the diesel alluvial well, and lastly the electric deep well. The higher the energy cost, the larger the difference between the NPV IWM option and no-IWM. Thus, IWM has the most benefit in improving NPV, where pumping plant energy cost is the highest.

Options A, B, and D, which represent the manual read, datalogger, and the lower data fee large-scale deployment options, have very similar NPVs. Option C, which is the cellular single-unit telemetry unit, has the lowest NPV, likely because of the higher capital cost per field and higher telemetry fee; however, it is still higher than the no-IWM scenario, indicating that even with this perceived more expensive option, the additional cost is recovered and is more profitable than not using these IWM tools.

Another interesting trend in Tables 3 and 4, when comparing Option B with Option D, is that as technology allows for lower data fees and capital costs, the NPV between the datalogger and multi-unit sensor and telemetry deployment have similar NPVs, suggesting that a large deployment of lower-cost telemetry units and data fees (Option D) do not result in an appreciable difference in NPV to the lower capital cost datalogger reader Option B.

Practical Applications

The application of IWM practices of CHS, Surge irrigation, and Soil Moisture Monitoring appear to always provide for an improved NPV, irrespective of the technology selected or the energy or pump type. The energy savings and improved yield pay back in excess of the capital and the annual cost of IWM practices.

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. Support was also provided by the University of Arkansas System Division of Agriculture.

Literature Cited

Barlow, J.R.B. and B.R. Clark. 2011. Simulation of water-use conservation scenarios for the Mississippi Delta using an existing regional groundwater flow model: U.S. Geological Survey Scientific Investigations Report 2011–5019.

Bryant C.J., L.J. Krutz, L. Falconer, J.T. Irby, C.G. Henry, H.C. Pringle III, M.E. Henry, D.P. Roach, D.M. Pickelmann, R.L. Atwill, and C.W. Wood. 2017. Irrigation water management practices that reduce water requirements for Mid-South furrow-irrigated soybean. Crop Forage Turfgrass Manage. 3(1). Available at: https://dx.doi.org/10.2134/cftm2017.04.0025

Hassanli, A.M., M.A. Ebrahimizadeh, and S. Beecham. 2009. The effects of irrigation methods with effluent and irrigation scheduling on water use efficiency and corn yields in an arid region. Agric. Water Manage. 96(1):93–99. Available at: https://dx.doi.org/10.1016/j.agwat.2008.07.004

Henry, W.B. and L.J. Krutz. 2016. Water in Agriculture: Improving Corn Production Practices to Minimize Climate Risk and Optimize Profitability. Current Climate Change Reports, 2:49-54. Available at: https://dx.doi.org/10.1007/s40641-016-0035-9

Lovelace, J.K., M.G. Nielsen, A.L. Read, C.J. Murphy, and M.A. Maupin. 2020, Estimated Groundwater Withdrawals from Principal Aquifers in the United States, 2015 (ver. 1.2, October 2020). U.S. Geological Survey Circular 1464, 70 pp. Accessed 7 October 2021. Available at: https://dx.doi.org/10.3133/cir1464

McDougall, W. M. (2015). A Pump Monitoring Approach to Irrigation Pumping Plant Performance Testing. Graduate Theses and Dissertations Retrieved from https://scholarworks.uark.edu/etd/1146

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

UADA CES. 2022. University of Arkansas System Division of Agriculture, Cooperative Extension Service. Arkansas Field Crop Enterprise Budgets. Accessed 18 January 2022. Available at: https://www.uaex.uada.edu/farm-ranch/economics-marketing/farm-planning/budgets/crop-budgets.aspx

USDA-NASS. 2013. United States Department of Agriculture-National Agricultural Statistics Service. Farm and ranch irrigation survey. Accessed 22 Feb. 2018. Available at: https://agcensus.library.cornell.edu/census_parts/2012-2013-farm-and-ranch-irrigation-survey/

Wood, C.W., L.J. Krutz, L. Falconer, H.C. Pringle III, B. Henry, T. Irby, J.M. Orlowski, C.J. Brant, D.L. Boykin, R.L. Atwill and D.M. Pickelmann. 2017. Surge Irrigation Reduces Irrigation Requirements for Soybean on Smectitic Clay-Textured Soils. Crop, Forage and Turfgrass Management. p. 1-6.

Yonts, C.D., D.E. Eisenhauer, and D. Fekersillassie. 1996. Impact of surge irrigation on furrow water advance. Transactions of the ASAE v39n3. 973-979.

Table 1. **Irrigation Water Management (IWM) tool options for field sizes of 40–60 acres.**

Options	Qty.	Total Retail	Installation Cost Labor Cost	Total cost	Life Expectancy	Annual Fee
		($ USD)	($ USD)	($ USD)	(Years)	($ USD)
Option A						
Manual Reader (Manual labor)	1	16.68	18.40	35.08	5	
Sensor (Watermark)	4	37.57	2.83	161.61	5	
CHS	1		10.00	10.00		
Cat 5 Wire (100ft)	1	21.99		21.99		
Surge Valve with Controller (Junior 3) 10-in.	1	2473.00		2473.00	20	
Total				**2701.68**		
Option B						
Datalogger/ Monitor (Watermark)	1	419.00	2.83	421.83		
Sensor (Watermark)	4	37.57	2.83	161.61	5	
Cat 5 Wire (100ft)	1	21.99		21.99		
Surge Valve with Controller(Star)10-in.	1	3256.00		3256.00	20	
CHS	1		10.00	10.00		
Total				**3871.43**		
Option C						
Telemetry Unit (Aqua Track)	1	1150.00	2.83	1152.83	10	150
Sensor (Watermark)	4	37.57	2.83	161.61	5	
CHS	1		10.00	10.00		
Surge Valve with Controller(Star)10-in.	1	3256.00		3256.00	20	
Total				**4580.44**		
Option D						
Telemetry Unit (low cost)	1	510.00		510.00	10	10
Sensor (Watermark)	4	37.57	2.83	161.61	5	
Surge Valve with Controller (Star) 10-in.	1	3256.00		3256.00	20	
CHS	1		10.00	10.00		
Total				**3937.61**		

Table 2. Energy cost of pumping water based on source and equipment.

System Category	Cost of Water (COW)
	($/ac-in.)
Electric Surface Relift	0.67
Diesel Surface Relifts	1.25
Electric Alluvial Wells	1.69
Diesel Alluvial Wells	2.37
Electric Deep Wells	4.02

Table 3. Comparative analysis of Net Present Value (NPV) for different Irrigation Water Management (IWM) options in U.S. dollars.

System Category	No IWM	Option A	Option B	Option C	Option D
Electric Surface Relift	235,431	251,003	249,902	246,499	249,377
Diesel Surface Relifts	232,836	249,434	248,333	244,930	247,808
Electric Alluvial Wells	230,867	248,243	247,142	243,740	246,618
Diesel Alluvial Wells	227,824	246,403	245,302	241,900	244,778
Electric Deep Wells	220,441	241,939	240,838	237,435	240,313

Table 4. The difference between Net Present Value (NPV) of Irrigation Water Management (IWM) options with NPV no IWM in U.S. dollars.

System Category	No IWM	Option A	Option B	Option C	Option D
Electric Surface Relift		15,571	14,470	11,068	13,945
Diesel Surface Relifts		16,597	15,496	12,094	14,971
Electric Alluvial Wells		17,375	16,275	12,872	15,750
Diesel Alluvial Wells		18,578	17,478	14,075	16,953
Electric Deep Wells		21,497	20,397	16,994	19,872

Tillage, No-till, and Intercropping Effects on Furrow Irrigated Corn Yield and Water Use

C.G. Henry[1] *and T. Clark*[1]

Abstract

A study was conducted to determine the effects of a long-term no-till system in corn compared to a conventional tillage system. The study was located at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas. Both treatments were managed the same, except the tillage treatment was field cultivated and bedded before planting, whereas the no-till treatment only had a furrow runner used. Yield was not significantly different between tillage and no-till treatments, with the tillage treatment yielding 153 bu./ac and the no-till treatment yielding 156 bu./ac. The no-till treatment required irrigation before the tillage treatment resulting in an additional irrigation event for the no-till treatment. Consequently, the water use efficiency of the no-till treatment at 5.62 bu./in was significantly less than the tillage treatment at 6.54 bu./in. Intercropping yield was significantly less than the no-till and tillage treatment (140 bu./ac), likely due to weed competition. No-till production systems require less tillage, are not resulting in a yield penalty, and thus can improve farmer profitability compared to tillage production systems.

Introduction

Halvorson et al. (2006) reported that irrigated no-till systems had the potential to replace continuous tillage systems in the central Great Plains in a continuous irrigated corn (*Zea mays* L.) system. They found a 16% average higher yield in continuous tillage systems than in the no-till systems, but the lower yield in no-tillage systems may have been a result of slower early spring development and delayed tasseling. Sainju and Singh (2001) found that corn yields between chisel plow (tillage) and no-till in central Georgia could be maintained by terminating the cover crop 2 weeks earlier in the spring due to nitrogen sequestering by the residue. Habbib et al. (2016) found that after four years of conversion from tillage to a no-till cover crop system, the nitrogen-use efficiency, grain yield, and grain nitrogen content increased in corn.

Few studies have evaluated yield and water use differences in southern corn production from tillage, no-till, and cover crops with mixed results. Anapalli et al. (2018) reported lower yields in no-till corn fields in a humid climate due to lower soil temperatures, percolation, denitrification, and higher water content. Bradon et al. (2020) found the addition of cover crops and minimum tillage to a corn-soybean rotation in the mid-South on paired producer fields had no effect on yield, water use, or irrigation water applied but resulted in an economic loss of $223/ha ($94/ac). A yield improvement was reported by Sanchez et al. (2019) in Lousianna on corn, where the combination of cover crops increased soil carbon and reduced nitrate-N during the fallow season. Thus, research on cover crops, water use, water use efficiency, economic viability, and ecosystem services of no-till and cover crop practices is needed in the mid-South. Research and development are needed for Arkansas corn production in furrow irrigated soils to understand if and how no-till and cover crops could be successfully adopted compared to tillage.

Procedures

This study was conducted at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center near Stuttgart, Arkansas. The soil type is a Dewitt silt loam. The study consisted of 3 treatments with 4 replications each. The treatments were tillage, no-till, and no-till with an intercrop. Each replication plot was 8 beds on 30-in. centers and 1200 ft long. The tillage treatment was field cultivated and bedded on 5 April 2021. The no-till treatment has been continuous no-till since 2017, with a Perkins Furrow Runner (Perkins Sales, Bernie, Mo.) being used at planting to clean the furrow. The intercrop treatment, which is the growing of multiple crops at the same time, attempts to grow clover with the corn crop or after the corn matures. The purpose of the intercrop is to have a faster cover crop established and maximize biomass and cover for weed suppression and erosion protection. The intercrop treatment has been in continuous no-till since 2017 and was planted with crimson clover at a rate of 15 lb/ac with a drop spreader on 7 May after the corn stand was established. On 5 April, a fertilizer application of 140 lb N/ac as preplant N composed of 60 lb N/ac of Environmentally Smart Nitrogen (ESN) and 80 lb N/ac of ammonium sulfate was applied. Additionally, 0-110-115-91-0.27-15-0.29-0.95 (N-P_2O_5-K_2O-SO_4-Zn-Mn-Fe) was applied preplant.

Corn was planted on 6 April at a rate of 35,700 seeds/ac. For the till and no-till treatments, a pre-emergence herbicide

[1] Associate Professor and Water Management Engineer, and Program Technician, respectively, Department of Biological and Agricultural Engineering, Rice Research and Extension Center, Stuttgart.

of Glyphosate (32 oz/ac), Acuron (72 oz/ac), and Atrazine (32 oz/ac) was applied on 6 April. For the intercrop treatment, only Glyphosate (32 oz/ac) was applied so that clover would germinate. On 7 May, at the time of clover planting, Glyphosate (32 oz/ac) was applied to the intercrop treatment to kill emerged weeds. This was the last herbicide application for the intercrop treatment. On 9 May, 85lb/ac of N as urea was applied to the whole study. On 25 May an application of Glyphosate (32 oz/ac), Atrazine (32 oz/ac), and Gambit (Halosulfuron-methyl, methyl 3-chloro-5-(4,6-dimethoxypyrimidin-2-ylcarbamoylsulfamoyl)-1-methylpyrazole-4-(carboxylate) + Prosulfuron: 1-(4-methoxy-6-methyl-triazin-2-yl)-3-[2-(3,3,3-triflupropropyl)-phenylsulfonyl]-urea) (2 oz/ac) was applied to the till and no-till treatments. This application corresponded with V6–V7 and just before canopy closure. Black layer was on 8 August and the grain was harvested on 25 August.

The timing of the furrow irrigation treatments was determined by Irrometer Watermark 200SS soil moisture sensors (Irrometer, Riverside, Calif.) placed at soil depths of 6, 12, 18, and 30 inches. The sensors were placed roughly two-thirds down the field, and data were provided using an Agsense Aquatrac (Valmont, Valley, Neb.) telemetry unit. The data was put into the University of Arkansas System Division of Agriculture's Soil Moisture Sensor Calculator app (UASDA Irrigation Water Management Team, 2021a,b), and irrigation was initiated at 50% allowable depletion. Each treatment was independently irrigated using a set of sensors installed in one replication of a treatment; all replications were irrigated at the same time.

Irrigation totals were measured using a McCrometer portable propeller style flowmeter. Rainfall was measured using a Davis Weatherlink Station located adjacent to the field.

On 5–9 June, 8.52 inches of rainfall occurred, resulting in a prolonged period of saturated conditions of 7–10 days at tasseling, likely causing water stress and reducing the yield potential of the study.

Results and Discussion

The till and no-till treatments did not have any major issues, but there were issues establishing clover in the intercrop treatments. The clover was planted on 7 May, emergence was good, and by 25 May, the second true leaf could be seen. This corresponded to around the time of canopy closure and the application of herbicides on the other treatments. Within 2 weeks, all of the clover had wilted and died. Consequently, the lower yield results of the intercrop treatment are most likely due to the added morning glory pressure from not using residual herbicides at planting and the earlier application of the mid-season herbicide.

The field received 18.15 in. of rain during the growing season between planting and black layer. The no-till treatment received 9.7 ac-in./ac of irrigation, the tillage study received 5.3 ac-in./ac of irrigation, and the intercrop treatment required 2.51 ac-in./ac of irrigation. The yields of the three treatments for 2021, and previous years, can be seen in Table 1. Yield was not significantly different between the till and no-till treatments at 153 bu./ac and 156 bu./ac, respectively. The intercrop treatment did, however, have a significantly lower yield at 140 bu./ac. The no-till treatment received the most irrigation with 3 irrigation events. The tillage treatment received 2 irrigations and the intercrop study received 1. The difference in the number of irrigations between the till and no-till treatments can be attributed to the no-till treatment needing the first irrigation earlier than the tillage treatment. The subsequent time between irrigation events was similar, but a rain event a few days after the no-till treatment was irrigated and before the tillage treatment required water, resulted in the no-till treatment being irrigated 1 extra time. The lower irrigation volume applied to the cover crop treatment may be due to lower yield and better infiltration. Further work is needed to better explain the difference in water use between the treatments.

The intercrop treatment had the highest total water use efficiency (WUE) at 6.77 bu./in, with the tillage treatment being not significantly lower at 6.54 bu./in. The no-till treatment had a significantly lower WUE of 5.62 bu./in due to the extra irrigation.

Practical Applications

Often it is assumed that there will be a loss of yield if no-till practices are used. The results of this study indicate that no-till practices, when done correctly, can yield equally to a tillage system. As the cost savings of a no-till system are often used to offset the profit decrease from the reduced yield, the potential for increased profit through a continuous no-till system is demonstrated.

The issues with getting a stand of clover in the intercrop treatments resulted in a yield penalty, relative to the other treatments, and required a late-season application to control morning glories. Clover germination is slow, and the rapid growth of the corn appears to shade out the clover before it can establish. In previous years, cover crops did not reliably establish in the spring, or the fall was too wet to seed. As an alternative to a winter cover crop, the cover crop treatment would be interseeded with a legume just after the cash crop emergence. This was done in an attempt to establish a cover crop for the following year. The authors have found the best result when a cover crop was seeded immediately after harvest. Fall cover crops seeding and spring intercrop seeding have not resulted in enough above-ground biomass to create a reliable treatment effect. More work is needed to verify a cover crop system yield and profitability, but this study demonstrates that a no-till continuous corn system does not result in a yield penalty.

Acknowledgments

Funding for this work was provided by corn and grain sorghum check-off funds administered by the Arkansas Corn and Grain Sorghum Board. Support was also provided by the University of Arkansas System Division of Agriculture.

Literature Cited

Anapalli, S.S., K.N. Reddy, and S. Jagadamma. 2018. Conservation Tillage Impacts and Adaptions in Irrigated Corn Production in a Humid Climate. *In*: Soil Tillage, Conservation and Management. Agron. J. 110(6):2673-2686.

Badinm T.B., J.M.P. Czarnecki, L.J. Krutz, J.M. Shockley, and B.H.Baker. 2021. Cover crop and minimum tillage effects on yield, irrigation water use and net returns. Agrosyst. Geosci. Environ. 4:e20158. https://dx.doi.org/10.1002/agg2.20158

Halvorson, A. D.A.R Mosier. C.A. Reule, and W.C. Bausch. 2006. Nitrogen and Tillage Effects on Irrigated Continuous Corn Yields. Agron. J. 98(1):63-71. https://dx.doi.org/10.2134/agronj2005.0174

Habbib, H., J. Verzeauz, E. Nivelle, D. Roger, J. Lacoux, M. Catterou, B. Hirel, F. Dubois, and T. Tetu. 2016. Conversion to No-Till Improves Maize Nitrogen Use Efficiency in a Continuous Cover Cropping System. PloS One 11(10):e0164234. https://dx.doi.org/10.1371/journal.pone.0164234

Sainju, U.M. and B.P. Singh. 2001. Tillage, Cover Crop, and No-till Kill-Planting Date Effects on Corn Yield and Soil Nitrogen. Agron. J. 93(4):878-886.

UASDA Irrigation Water Management Team. 2021a. University of Arkansas System Division of Agriculture's Rice Irrigation. Mobile Application Software. https://play.google.com/store/apps/details?id=com.uark.irrigation

UASDA Irrigation Water Management Team. 2021b. University of Arkansas System Division of Agriculture's Rice Irrigation. Mobile Application Software. https://apps.apple.com/us/app/rice-irrigation/id1188474415

Table 1. Corn Yield (bu./ac) by year and Tillage, No-Till, and Intercrop Treatment, University of Arkansas System Division of Agriculture's Rice Research and Extension Center, Stuttgart.

Year	Tillage/Conventional	No-Till	Intercrop
	bu./ac	bu./ac	bu./ac
2021	153 a†	156 a	140 b
2020	181.0 a	195.4 a	182.0 a
2019	217.1 a	223.8 a	195.9 b
2018	165.6 a	157.3 a	147.3 b
2017	158 a	138 ab	124 b

† Letters denote significant difference for the row (α = 0.05).

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

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

Abstract

The University of Arkansas System Division of Agriculture's Irrigation Yield Contest was conducted in 2018, 2019, 2020, and 2021. The contest was designed to promote better use of irrigation water as well as to record data on water use and water use efficiency (WUE) for various crops. Unlike yield contests where winners are decided by yield alone, the irrigation contest results are decided by the highest calculated total 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 was recorded by using 8-in., 10-in., and 12-in. portable mechanical flow meters. Rainfall totals were calculated using Farmlogs^{TM}. The average water use efficiency of 2018–2021 for corn was 8.76 bu./in. The winning WUE was 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. 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 8.9 ac-in./ac of irrigation for the four years.

Introduction

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

The University of Arkansas System Division of Agriculture's (UASDA) Irrigation Yield Contest was designed as a novel way of encouraging and recognizing 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 water use efficiency (WUE) in multiple crop types under irrigated production in Arkansas, and recognizing producers who achieved a high water use efficiency.

Procedures

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

A portable propeller-style mechanical flowmeter was used to record water use. All flow meters were checked for proper installation and sealed using 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 date of emergence to the date of physiological maturity. Emergence was assumed as 7 days after the planting date provided on the entry form. For physiological maturity, the seed companies' published days to maturity is used. Rainfall is adjusted for extreme events.

The harvest operations were observed by a third-party observer, often an Extension agent, Natural Resources Conservation Service employee, or UASDA staff. For the yield estimate, a minimum of 3 acres was harvested from the contest field.

The equation used for calculating WUE for the contest was:

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

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

Results and Discussion

Detailed results are published on the contest website (www.uaex.uada.edu/irrigation) for each year of the contest. Over the

[1] Associate Professor and Water Management Engineer, Program Technician, and Program Associate, respectively, Department of Biological and Agricultural Engineering, Rice Research and Extension Center, Stuttgart.

[2] Undergraduate Student, Federal University of Pelotas, Brazil.

four years that the competition has been conducted, there have been 40 fields entered for corn. The average WUE over the 4 years was 8.76 bu./in. By year, the average WUE was 10.53 bu./in. for 2021 with 7 eligible 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 2020 and 2019, there were more contestants in corn than in 2018 and 2021, which may partially explain the differences in WUE because more variation is expected with a larger number of growers. The winning WUE was higher in 2021 than in the previous three years. The winning WUE for each year was 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 was higher in 2019 and 2020 than in 2018 and 2021.

The contest has one former corn winner, who won the soybean division in 2021, and the rice winner from 2020 came in second in soybeans in 2021. One corn contestant has placed second in 2021, 2020, and 2019.

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

Contestants are asked about their adoption of IWM tools when they enter the contest (Table 2). In total, 64% of the participants across all three categories included responses in their entry form. The IWM tool that was most widely adopted was computerized hole selection. The average use among respondents was 90% across all four years, with 88% in 2018, 72% in 2019, and 100% in 2020 and 2021. For soil moisture sensors, 64% of respondents from all four years said that they used soil moisture sensors on their farm, with 60% in 2018, 67% in 2019, 42% in 2020, and 90% in 2021. Surge valves were the least used IWM tool, with 32% of respondents from all 4 years indicating they used surge irrigation. This included 44% from 2018, 28% from 2019, 16% from 2020, and 30% in 2021. Usage of IWM practices, surge irrigation, computerized hole selection, and soil moisture sensors is increasing over time when comparing the original baseline developed by the survey in 2015 and contest usage in 2018 and 2019. Contestant participants rely heavily on computerized hole selection (97% and 100% in 2020 and 2021, respectively) and soil moisture monitoring (40% in 2019 to 87% in 2021). Thus, adoption and usage of these IWM tools are likely increasing in Arkansas as a result of contest participation.

Practical Applications

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

On average, corn growers in the contest across the four years averaged 8.76 ac-in./ac applied and a total water use of 26.4 in. of total water for corn. The average WUE of the contestants as a group has been improving over time.

Acknowledgments

The material is based on work that is supported, in part, by the USDA Natural Resource Conservation Service, the Arkansas Corn and Grain Sorghum Board, the Arkansas Soybean Promotion Board, RiceTec, Mars Corporation, McCrometer, Seametrics, P and R Surge, Valmont-AgSense, Trellis, Irrometer, Delta Plastics, CropX, and the USDA National Institute of Food and Agriculture (Project No. ARK02591).

Literature Cited

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

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

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

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

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

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

National Wheat Foundation. 2018. National Wheat Yield Contest Rules. Accessed 14 January 2021. Available at:

https://yieldcontest.wheatfoundation.org/Content/RulesPDF/NWYC%20Entry%20Harvest%20Rules.pdf

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

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

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

Table 1. Maximum, average, and minimum values for water and yield data points for corn from the Arkansas Irrigation Yield Contest, 2018–2021.

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

Table 2. Usage of irrigation water management practices by contestants in the Arkansas Irrigation Yield Contest, 2018–2021.

Year	Soil Moisture Sensors	Computerized Hole Selection	Surge Irrigation
2021	87%	97%	35%
2020	42%	100%	16%
2019	40%	43%	28%
2018	50%	73%	44%

Water Use, Water Use Efficiency, and Yield Differences on Corn Yield Between Sensor-Based Irrigation and Calendar Methods

C.G. Henry,[1] J.P. Pimentel,[2] M. Ismanov,[3] P. Francis,[4] L. Espinoza,[3] T. Spurlock,[5] and T. Clark[1]

Abstract

A study was conducted at three locations in Arkansas to compare the difference in water use and corn yield when using soil moisture sensors to initiate irrigation compared to a conventional calendar-based irrigation schedule. No significant differences in corn grain yields were observed among the sites, but a 0%, 25%, and 45% reduction in irrigation water use was observed from the sensor treatments.

Introduction

As groundwater becomes more scarce for irrigation supplies for crops, a better understanding of technology solutions and their impact on water use, yield, and profitability is needed. Spencer et al. (2019) compared Irrigation Water Management (IWM) practices for furrow irrigation in Arkansas and Mississippi on paired grower fields that implemented IWM practices and those that did not. The implementation of the IWM practices reduced total water use by 39.5%, increased grain yield by 6.5 bu./ac, and increased irrigation water use efficiency by 51.3%. Similar results were reported by Henry and Krutz (2016) in 14 on-farm comparisons and via side-by-side comparisons at 4 research stations. Their data shows a 3–5% increase in yields (around 8 bu./ac), and water use was decreased by 40%.

A study was first initiated in 2018 to compare the differences between the traditional method of irrigating corn in Arkansas, the calendar method, and the use of granular matric potential sensors and the mobile app, the Arkansas Soil Sensor Calculator on water use, water use efficiency, and yield. Between 2018–2020, similar tests were conducted at three different sites. This paper reports the results of 2021 and the aggregated results of the 4-year history of the study and serves as a validation study for recommendations for using soil moisture sensors to schedule irrigation using mid-South regional varieties of corn in Arkansas soils.

Procedures

A study to assess the water-saving potential of using soil moisture thresholds to trigger irrigation has been conducted for four years. In 2021, the study was conducted at three University of Arkansas System Division of Agriculture research stations. The Rice Research and Extension Center near Stuttgart, Ark.; the Lon Mann Research Station near Marianna, Ark.; and the Rohwer Research Station in Rohwer, Ark. For 2021, Pioneer hybrid P1197YHR was planted at all 3 locations. The 2 treatments were sensor-based and calendar-based irrigation. The sensor-based irrigation used Irrometer Watermark 200SS sensors placed at 6, 12, 18, and 30 inches, approximately two-thirds down the rows from the crown, and were read using Agsense Aquatrac units for remote reading. The data was put into the University of Arkansas System Division of Agriculture's Soil Moisture Sensor Calculator app (UA Irrigation Water Management Team, 2021a, 2021b), and irrigation was initiated using a 50% allowable depletion. The calendar-based treatment was irrigation once weekly unless sufficient rainfall occurred. This treatment is based on how researchers have observed farmers in the region irrigating corn. Irrigation was delivered using lay-flat polyethylene irrigation pipe and computerized hole selection to determine hole sizes for the planned irrigation capacity.

Stuttgart

The Stuttgart location was at the University of Arkansas System Division of Agriculture's Rice Research and Extension Center. The soil type was a Dewitt Silt Loam. On 5 April, a fertilizer application of 140 lb N/ac that was composed of 60 lb N/ac of Environmentally Smart Nitrogen (ESN) and 80 lb N/ac as ammonium sulfate was applied. Additionally, 110 lb P/ac, 115 lb K/ac, 91 lb S/ac, 0.27 lb Mg/ac, 15 lb Zn/ac, 0.29 lb Mn/ac, and 0.95 lb Fe/ac were applied. The field has been no-till since 2017, which is the last year a cultivator was used. A Perkins furrow runner was used before planting to clean out the furrows. The corn was planted on 6 April at a rate of 35,700 seed/ac. A pre-emergence herbicide of Glyphosate (32 oz/ac), Acuron (*S*-Metolachlor + Atrazine + Mesotrione + Bicyclopyron) (72 oz/ac), and Atrazine (32 oz/ac) was applied on 6 April. On 9 May, 85 lb/ac of N as urea was applied. On 25 May, an application of Glyphosate (32 oz/ac), Atrazine (32 oz/ac), and

[1] Associate Professor and Water Management Engineer, and Program Technician, respectively, Department of Biological and Agricultural Engineering, Rice Research and Extension Center, Stuttgart.
[2] Undergraduate Student, Federal University of Pelotas, Brazil.
[3] Program Associate and Associate Professor and Soil Scientist, respectively, Department of Crop, Soil and Environmental Sciences, Little Rock.
[4] Professor, University of Arkansas-Monticello.
[5] Associate Professor and Extension Plant Pathologist, Department of Entomology and Plant Pathology, Little Rock.

Gambit (Halosulfuron-methyl, methyl 3-chloro-5-(4,6-dimethoxypyrimidin-2-ylcarbamoylsulfamoyl)-1-methylpyrazole-4-carboxylate) + Prosulfuron: 1-(4-methoxy-6-methyl-triazin-2-yl)-3-[2-(3,3,3-triflupropropyl)-phenylsulfonyl]-urea) (2 oz/ac) was applied. This application corresponded with V6–V7 and just before canopy closure. Black layer formation was noted on 8 August, and the crop was harvested starting on 25 August.

Rohwer

The Rohwer location was at the University of Arkansas System Division of Agriculture's Rohwer Research Station. The soil type was Sharkey Clay. The corn was planted on 6 April. A foliar fungicide (Trivapro, Benzovindiflupyr+Azoxystrobin +Propiconazole, 13.7 oz/acre) was applied at early grain fill by air, R5.5, using 5 gallons of water volume per acre. The first irrigation event for both treatments occurred on 2 June 2021. Unprecedented rainfall occurred between 7–9 June 2021 and resulted in a record rainfall total of 19.22 in. Plots were under water for approximately three days, but there was minimal damage to the corn plants that were at V9–10 growth stage. Saturated soil conditions existed at the 30-in. depth until late dent growth based on soil moisture readings and were verified by soil core samples.

Marianna

The Marianna location was at the Lon Mann Cotton Research Station in Marianna, Arkansas, on a 38-in. row spacing furrow-irrigated field on a soil mapped as a Memphis silt loam soil. Plots were 6 rows wide and 30 ft long with five replications, and the middle four rows were harvested for yield.

Results and Discussions

Yield and irrigation water use for all stations can be found in Table 1. Data from previous years is also included. The discussion is separated by research station location. Only one site year resulted in a yield penalty for sensor-based irrigation (Stuttgart in 2018). Two site years (Stuttgart and Marianna in 2020) resulted in significantly higher yields from sensor-based irrigation than with the calendar method. In Stuttgart and Marianna, water use is always less with sensor-based irrigation than the calendar method. Stuttgart and Marianna, on average, used 52% and 34% less water, respectfully, using sensor-based scheduling than with the calendar method. At Rohwer, no significant difference in yield or a noticeable difference in water use has been observed during the course of this study.

Stuttgart

Between 5–9 June, 8.52 in. of rainfall occurred, resulting in a prolonged period of saturated conditions of about 7–10 days at tasseling, likely causing water stress and reducing the yield potential of the study.

The sensor treatment received a total of 6.7 ac-in./ac of irrigation over 3 events, and the calendar treatment received 12.1 ac-in./ac of irrigation over 5 events. Combined with the 18.15 in. of rainfall, the total water received was 24.85 ac-in./ac for the sensor treatment and 30.26 ac-in./ac for the calendar treatment, or 45% less irrigation water. The yield of the sensor treatment and calendar treatment were not significantly different at 145 bu./ac and 152 bu./ac, respectively. By dividing yield by total water, water use efficiency (WUE) can be calculated. The sensor study achieved a WUE of 5.84 bu./in., which is significantly higher than the calendar study's WUE of 5.03.

Rohwer

The timing of irrigation was nearly identical between methods. Five irrigations were applied on 2 June, 24 June, 1 July, 8 July, and 16 July 2021. Total irrigated water applied was 7.81 in. for both scheduling methods, and grain yield ranged from 179.1 to 211.7 bu./ac across all treatment combinations, with the average yield of the sensor-based irrigation resulting in 197 bu./ac and the calendar method, 198 bu./ac. No significant difference in grain yield was found between the treatments. This trend of no yield and water use differences on the clay soil has been consistently the same since 2019. Grain yields were surprisingly higher than expected, given the condition of the field in early June, but the field drained well, and the data revealed that corn could recover from brief floods that occur during late vegetative growth. The results also showed that the timing of irrigation between a 7-day calendar method and a soil moisture sensor/managed allowable deficit method was very similar on a heavy clay soil.

Overall, foliar diseases occurred at low incidence. Southern rust (*Puccinia polysora*) levels were evaluated approximately two weeks after fungicide was applied. While the fungicide application provided some control of southern rust, disease was not significantly different by irrigation treatment.

Marianna

The corn in Marianna emerged after 10 days and 211 growing degree days. Plant height was not significantly different between the sensor and calendar-based irrigation treatments. The calendar-based irrigation treatment was irrigated 5 times using 22.6 ac-in./ac, and the sensor-based irrigation treatment received 4 irrigations for a total of 17.0 ac-in./ac. Yield was not significantly different between the 2 treatments, with the calendar-based treatment yielding 195.0 bu./ac, and the sensor-based treatment yielded 194.1 bu./ac with 25% less water.

Practical Applications

The use of soil moisture sensors can take the guesswork out of determining the amount of water available in the soil profile without needing to take soil cores. At 2 of the 3 sites, this resulted in a reduction in irrigation water applied. At the Stuttgart location, 52% less water was applied, and at the Marianna location, 34% less water was applied. At the Rohwer location, which has a Sharkey clay soil, no irrigation water was saved, which was consistent with the results from previous years. One site year had a significant yield penalty, but two site years had significantly higher yields from the sensor-based irrigation treatments. In Stuttgart and Marianna, water use from sensor-based irrigation was considerably less than the calendar-based method suggesting improved profitability that can be claimed from energy savings. An economic analysis of the data would be warranted to establish if overall profitability could be improved using sensor-based irrigation.

Acknowledgments

Funding for this work was provided by corn and grain sorghum check-off funds administered by the Arkansas Corn and Grain Sorghum Board. Support was also provided by the University of Arkansas System Division of Agriculture.

Literature Cited

Henry, W.B. and L.J. Krutz. 2016. Water in Agriculture: Improving Corn Production Practices to Minimize Climate Risk and Optimize Profitability. Current Climate Change Reports. 2:49-54. https://dx.doi.org/10.1007/s40641-016-0035-9

Pickelmann, D.M., C.G Henry, V. Kandpal, and G. Simpson. 2018. Grain Yield Response of Furrow-Irrigated Clearfield Hybrid RT 7311 to Different Nitrogen Sources. *In*: Norman, R.J. and K.A.K Moldenhauer (eds.). B.R. Wells Arkansas Rice Research Studies 2018. Arkansas Agricultural Experiment Station Research Series 659:343-351. Fayetteville.

Spencer G.G., L.J. Krutx, L.L Falconer, W.B. Henry, C.G. Henry, E.J. Larson, H.C. Pringle III, C.J. Bruant, and R.L. Atwill. 2019. Irrigation Water Management Technologies for Furrow-Irrigated Corn that Decrease Water Use and Improve Yield and On-Farm Profitability. Crop, Forage and Turfgrass Management. 5 (1):1-8. https://dx.doi.org/10.2134/cftm2018.12.0100

UA Irrigation Water Management Team. 2021a. Rice Irrigation. Mobile Application Software. https://play.google.com/store/apps/details?id=com.uark.irrigation

UA Irrigation Water Management Team. 2021b. Rice Irrigation. Mobile Application Software. https://apps.apple.com/us/app/rice-irrigation/id1188474415

Table 1. Yield and irrigation water use for sensor-based and calendar-based irrigation. Listed by year and location.

Year	Location	Sensor-based Scheduling	Calendar	Sensor-based Scheduling	Calendar
		bu./ac	bu./ac	ac-in./ac	ac-in./ac
2021	Stuttgart	145 a†	152 a	6.7	12.1
2021	Marianna	194.1 a	195.0 a	17.0	22.6
2021	Rohwer	197.9 a	194.4 a	7.81	7.81
2020	Stuttgart	179.3 a	158.8 b	9	21
2020	Marianna	242.3 a	229.9 b	9	17
2020	Rohwer	251.3 a	246.5 a	13	13
2019	Marianna	178 a	163 a	‡	‡
2019	Stuttgart	237 a	225 a	‡	‡
2018	Stuttgart	167 a	187 b	11.8	24.3

† Denotes significant difference for the row (alpha = 0.05).

‡ Irrigation data not available.

An Algorithm to Assess Mid-Season Nitrogen Fertilizer Needs from Drone Imagery

A.M. Poncet,[1] T. Bui,[1,2] O.W. France,[1] L.C. Purcell,[1] T.L. Roberts,[1] and J.P. Kelley[3]

Abstract

Three-split N application strategies can help maintain corn yields with smaller total nitrogen (N) fertilizer amounts when applied rates match the crop requirements throughout the growing season. The need for a third application depends on the amount of N provided during the first two applications and how efficiently the applied fertilizer was utilized by the crop. However, current recommendations do not account for early-season N losses and mid-season crop N status, making it difficult to execute optimized N management strategies. Recent research demonstrated that red, green, and blue (RGB) drone imagery can be used to assess mid-season corn N status and fine-tune the current extension guidelines, but adoption of drone imagery is limited because of the need for multi-step image processing. Decision-support system development is needed to make existing research results available to Arkansas corn producers. The objective of this study was to automate drone image processing to assess mid-season corn N status and determine if additional N should be applied to prevent yield loss from N deficiencies. The images used to complete the study objective were collected at the University of Arkansas System Division of Agriculture's Pine Tree Research Station during the 2021 growing season. An algorithm was developed to automate image processing and generate a pre-tassel N fertilizer recommendation from RGB drone images collected between V8 and VT stages. The created algorithm outputs canopy greenness measured using Dark Green Color Index (DGCI), relative grain yield, and N fertilizer recommendation (Yes/No) maps from the collected drone raw images. The next steps toward a functional decision support system are the integration of the created software into a user interface, on-farm validation, and deployment. The created tool will help Arkansas corn producers optimize N input management, which will ultimately increase farm profitability.

Introduction

Corn receives more nitrogen (N) per unit area than any other crop cultivated in Arkansas. Nitrogen amounts are prescribed according to soil texture, crop rotation, crop nutrient requirements, and yield goal, and delivered in two or three-split applications (Espinoza and Ross, 2008). Three-split strategies can help minimize yield loss from N deficiency with smaller total N fertilizer amounts when unfavorable conditions, such as excess rainfall, increase early-season N loss (Slaton et al., 2013). However, current recommendations do not account for mid-season crop N status because of the difficulty in identifying N stress before permanent yield loss has occurred. This may lead to less-than-optimum N fertilization strategies.

Until recently, corn leaf analysis was the only reliable method available to diagnose N deficiencies when symptoms of mild to moderate stress could not be identified using visual scouting. However, the cost of ground-truthing and sample analysis incurred to build insights at the production scale create an economic barrier for most producers who continue to rely solely on visual scouting. Fortunately, the rapid pace of technological development provides new opportunities for agricultural research and for stakeholders gaining interest in using drone remote sensing to inform farm management practices (Bai and Purcell, 2019; Hoyos-Villegas et al., 2014).

In the past few years, strong correlations were identified between corn yield, leaf N concentration, and canopy greenness measured from drone imagery (Dos Santos et al., 2020). More specifically, research demonstrated that if leaf N concentration measured between V8 and VT stages is less than 3%, then it is possible to refine mid-season N fertilizer rate recommendations using red, green, and blue (RGB) imagery collected with relatively inexpensive Unmanned Aerial Systems (UAS, or drones). Canopy greenness was quantified using the Dark Green Color Index (DGCI; Karcher and Richardson, 2003), and calibration curves were established to relate pre-tassel DGCI values to mid-season crop N status (Purcell et al., 2013; 2015). These curves can be used to determine if additional N fertilizer is needed to maintain 95% corn yield potential, but the findings are not yet accessible to growers as multi-step image processing is needed before the created equations can be used.

Because drone image pixel values depend on lighting conditions at the time of flight, the calculated DGCI values can only provide relevant information about mid-season corn N status if compared to a known reference (Bai and Purcell, 2019; Rorie et al., 2010). Calibration curve development has accounted for this effect of lighting on image quality, and producers planning to use the created equations will need to establish at least one high-N reference strip in each field. This can be done by applying enough N fertilizer at sidedress to ensure sufficiency

[1] Assistant Professor, Program Technician, Program Associate, Distinguished Professor and Altheimer Chair for Soybean Research, and Associate Professor, respectively, Department of Crop, Soil, and Environmental Sciences, Fayetteville.
[2] Graduate Student, Department of Computer Science and Computer Engineering, Fayetteville.
[3] Professor and Extension Wheat and Feed Grains Agronomist, Cooperative Extension Service, Little Rock.

independently from weather conditions. The high-N reference should be visible in most images so that mid-season corn N status can be assessed by comparing in-field DGCI values to the neighboring high-N reference DGCI values. Then, the collected imagery can be processed as follows: identification of high-N reference within the collected imagery, calculation of DGCI values from the raw image pixel values, computation of relative grain yield (RGY), and determination of mid-season crop N status and pre-tassel N fertilizer needs. The objective of this study was to automate drone image processing to assess mid-season corn N status and determine if additional N should be applied to prevent yield loss from N deficiencies. The created software is needed to develop a decision-support system that will allow Arkansas corn producers to optimize their N management practices with drones.

Procedures

An algorithm was created based on remote sensing data collected in two production fields at the University of Arkansas System Division of Agriculture's Pine Tree Research Station near Colt, Ark. Both fields were managed using the Station Director's preferred management strategy, except for N fertilization. In each field, the extension recommendation was 220 lb N/ac (Espinoza and Ross, 2008), and only 110 lb N/ac (or half of the recommended amount) was applied to create visible symptoms of N deficiency. The total N fertilizer amount was delivered in two split applications with 80 lb N/ac applied at planting and 30 lb N/ac applied at sidedress. In the middle of the field, an additional 130 lb N/ac was applied at sidedress to create a high-N reference strip. The total N fertilizer amount applied in the high-N reference strip was 10% higher than the total recommended amount to ensure N sufficiency independently from weather conditions. The high-N reference strip was 150 ft wide and created parallel to the maximum direction of elongation of each field. Red, green, and blue drone imagery was captured once a week in both fields from V6 to VT stages using a DJI Phantom 4 Pro V2.0 (DJI, Nanshan, Shenzen, China) unmanned aerial system. Flight altitude was 250 ft above ground level. The raw images that showed the greatest differences in canopy greenness between the N deficient area and the high-N reference strip were used to facilitate algorithm development.

The first step of data processing was to locate the high-N reference strip in the collected images. This was performed semi-automatically using a built-in python (Python Software Foundation, 2022) function that requires the user to choose an image on their device and click on the top left and bottom right corners of the region they want to select within that image. The region of interest is then automatically cropped out of the image and saved as a new image on the user's device. A reset option was also added to allow the user to select a different region of interest if needed. The second step of data processing was to calculate DGCI values from the raw RGB values in the original and cropped images using Eq. (1):

$$DGCI = \frac{\frac{H-60}{60} + \left(1-S\right) + \left(1-b\right)}{3} \qquad \text{Eq. (1)}$$

where DGCI is the computed DGCI value, H, S, and B are the hue, saturation, and brightness values calculated using Eqs. (2) to (6):

$$\text{If } \max(R,G,B) = R: H = 60 \cdot \frac{G-B}{\max(R,G,B) - \min(R,G,B)} \qquad \text{Eq. (2)}$$

$$\text{If } \max(R,G,B) = G: H = 60 \cdot \left(2 + \frac{B-R}{\max(R,G,B) - \min(R,G,B)}\right) \qquad \text{Eq. (3)}$$

$$\text{If } \max(R,G,B) = B: H = 60 \cdot \left(4 + \frac{R-G}{\max(R,G,B) - \min(R,G,B)}\right) \qquad \text{Eq. (4)}$$

$$S = \frac{\max(R,G,B) - \min(R,G,B)}{\max(R,G,B)} \qquad \text{Eq. (5)}$$

$$B = \max(R,G,B) \qquad \text{Eq. (6)}$$

where R, G, and B are the raw red, green, and blue digital numbers ranging from 0 to 255. The RGY was then computed using Eq. (7):

$$RGY = \frac{e^{0.47+19.6 \cdot DGCI - 18.2 \cdot DGCI_{ref}}}{1 + e^{0.47+19.6 \cdot DGCI + 18.2 \cdot DGCI_{ref}}} \qquad \text{Eq. (7)}$$

where RGY is the computed relative grain yield value, DGCI is the DGCI value computed using Eq. (1) for the original image, and $DGCI_{ref}$ is the median high-N DGCI value computed for the cropped image. The computed RGY value represents the predicted value for the N-deficient area compared to the high N reference strip. If RGY was smaller than a user-defined threshold (by default, 90%), the crop was considered N deficient, and the algorithm determined that pre-tassel N fertilizer was required to maintain yield potential. An option was also added to remove all pixel values in the original image where max (R,G,B) ≠ G. This effectively removed most pixels that did not represent vegetation or its shadow. All computations were performed in Python, and the process was automated by creating a rudimentary software package executable by command line.

Results and Discussion

The created software converts each image provided by the user into three images that will provide valuable N management information to Arkansas corn producers when implemented into a decision-support system. The created images are DGCI, RGY, and pre-tassel N fertilizer recommendations (Yes/No). The DGCI images show differences in canopy greenness within the original images. The RGY images quantify the anticipated yield loss from N deficiency resulting from differences in DGCI values. The pre-tassel N fertilizer recommendation (Yes/No) images determine if additional N is needed to minimize yield loss from N deficiency. For demonstration purposes, one image was processed using the created algorithm, and results are provided in Figs. 1–5. Figure 1 shows the drone raw image used to demonstrate the algorithm functionalities and output. As expected, the high-N reference strip in the middle right portion of the image is darker than the rest of the field (higher canopy greenness values). Soil is also visible between corn rows when the crop canopy is less dense. Figure 2 illustrates the process used to delineate the high-N reference strip in the drone image. Figure 3 shows the computed DGCI values for the raw drone image. Without the vegetation filtering option, the soil pixels are represented by excessively high DGCI values in comparison to the rest of the image, which considerably affects the scale of the legend. With the vegetation filtering option enabled, the soil pixels were removed from the DGCI image (defined as missing values, shown in white), which showed greater contrast in canopy greenness between the high-N reference and the rest of the field. Figure 4 shows the computed RGY values for the drone raw image. As a result of higher DGCI values, the soil pixels are represented with a high RGY value when the vegetation filtering option is not enabled. However, the difference in contrasts between the high-N reference and the rest of the image in the two RGY images is not as great as for the DGCI image. This is because RGY is computed by comparing DGCI values in the field to the median DGCI value in the high-N reference image previously delineated. The DGCI values for the soil pixels were found to be greater than the median DGCI values in the high-N reference image. This means that the computed RGY values for the soil pixels were, in fact, greater than 100%. However, all RGY values greater than 100% were truncated at 100%, and the legend was scaled to the 0% to 100% range. Therefore, the soil pixel did not affect the information provided in the RGY images as much as it did for the DGCI values. With the vegetation filtering option, the soil pixels were also removed from the RGY image and shown using white. Figure 5 shows the computed pre-tassel N fertilizer recommendation, with and without the vegetation filtering, for two different yield goals. As expected, pre-tassel N was needed to reach the user-defined yield goal in the field but not in the high-N reference strip. Only slight differences were found between the two user-defined thresholds. Greater differences would be expected in production fields managed using current extension guidelines.

Practical Applications

The goal of this three-year project is to develop a decision-support system that will help Arkansas corn producers fine-tune N fertilizer application amounts and timing with drones. Automation of drone image processing was the first step. Next, the created software will be integrated into a user interface, validated on-farm, and deployed. Integration of the created software into a user interface will make these findings directly accessible to stakeholders. On-farm validation is necessary to make sure the created decision-support system helps Arkansas corn producers and stakeholders minimize yield loss from N deficiency with smaller total N fertilizer amounts. During the deployment phase, education material will be created and shared with stakeholders to explain how the created tool can help Arkansas corn producers optimize their N management strategies. In-person workshops and training will also be provided to demonstrate tool use, discuss the on-farm validation results, and communicate the need to prepare for tool use by implementing a high-N reference strip in each field at sidedress. In the meantime, additional research is being conducted to overcome some of the limitations of the current version of the created algorithm. More specifically, research is being conducted to determine how much pre-tassel N fertilizer should be applied to maintain the user-defined yield goal when N deficiencies are identified in the field. Research is also being conducted to recalibrate the model for use with stitched drone imagery and satellite imagery as an alternative to drone raw images. Once complete, these additional functionalities will be integrated into the proposed tool and deployed as version 2. On-farm validation will also be performed to validate the new functionalities. Both versions of the proposed tool will help Arkansas corn producers fine-tune current N management guidelines using remote sensing.

Acknowledgments

Project funding was provided by the Arkansas Corn and Grain Sorghum Checkoff Program administered by the Arkansas Corn and Grain Sorghum 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.

Literature Cited

Bai, H., and L.C. Purcell. 2019. Evaluation of soybean greenness from ground and aerial platforms and the association with leaf nitrogen concentration in response to drought. Crop Sci., 59(6):2763-2773.

Dos Santos, C.L., T.L. Roberts, L.C. Purcell. 2020. Canopy greenness as a midseason nitrogen management tool in corn production. Agronomy J. 112(6):5279-5287.

Espinoza, L. and J. Ross. 2008. Arkansas Corn Production Handbook. Chapter 4: Fertilization and Liming. University of Arkansas System Division of Agriculture Cooperative Extension Service, the United States Department of Agriculture, and County Government Cooperating.

Hoyos-Villegas, V., J.H. Houx, S.K. Singh, and F.B. Fritschi. 2014. Ground-based digital imaging as a tool to assess soybean growth and yield. Crop Sci. 54:1756-1768.

Karcher, D.E. and M.D. Richardson. 2003. Quantifying turfgrass color using digital image analysis. Crop Sci. 43(3): 943-951.

Purcell, L.C., R.L. Rorie, and D.E. Karcher. 2013. System and method of determining nitrogen levels from a digital image. U.S. Patent 8,391,565. Issued 5 March 2013.

Purcell, L.C., U.G. Siddons, D.E. Karcher, and R.L. Rorie. 2015. System and method of in-season nitrogen measurement and fertilization of non-leguminous crops from digital image analysis. U.S. Patent 9,117,140. Issued 25 August 2015.

Python Software Foundation, 2022. Python Language Reference, version 2.7. Available at http://www.python.org
Rorie R.L., L.C. Purcell, M. Mozaffari, D.E. Karcher, C.E. King, M.C. Marsh, and D.E. Longer. 2010. Association of "greenness" in corn with yield and leaf nitrogen concentration. Agron. J. 103:529-535.
Slaton, N.A., T.L. Roberts, R.E. Delong, C.G. Massey, J. Shafer, S. Clark, and B. Griffin. 2013b. Corn yield response to nitrogen source, time of application, and/or placement. Arkansas Aes. Res. Ser 616: 52–56.

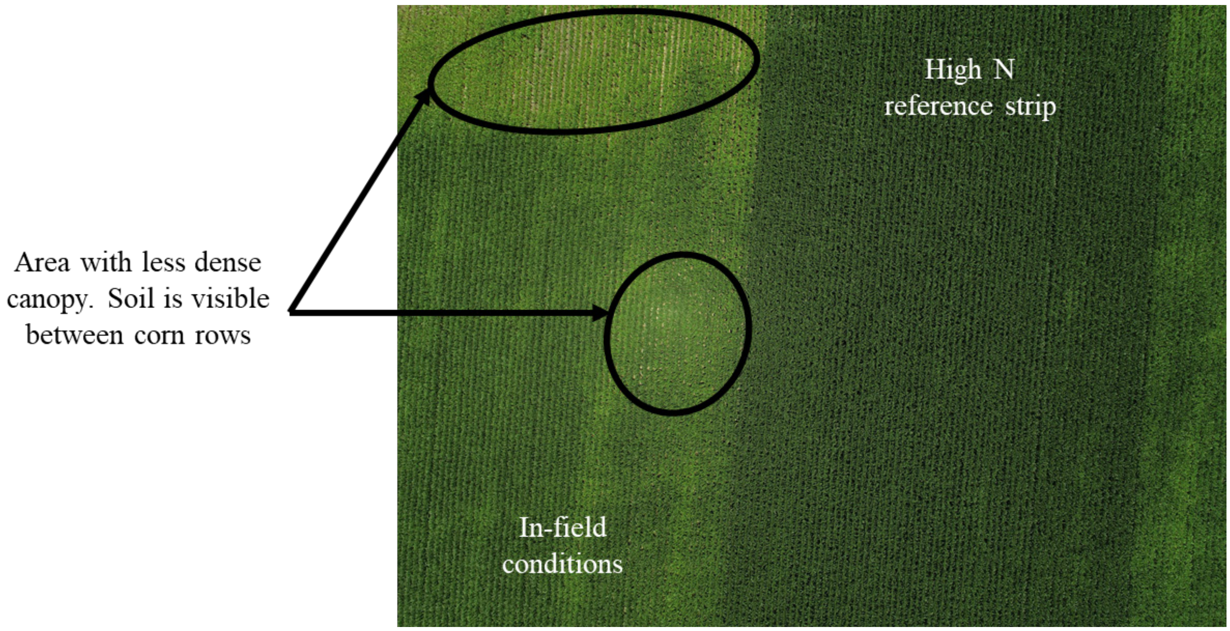

Fig. 1. Red, green, and blue drone raw image used to assess mid-season corn N status using the created algorithm.

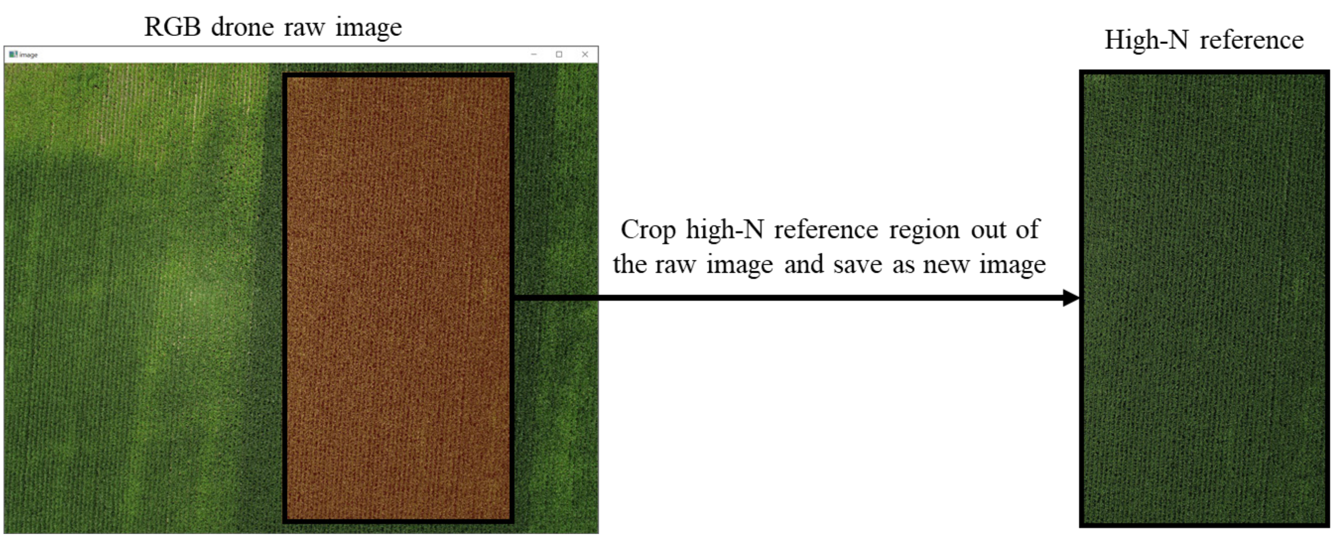

Fig. 2. Semi-automatic delineation of high-N reference strip in the drone raw image.

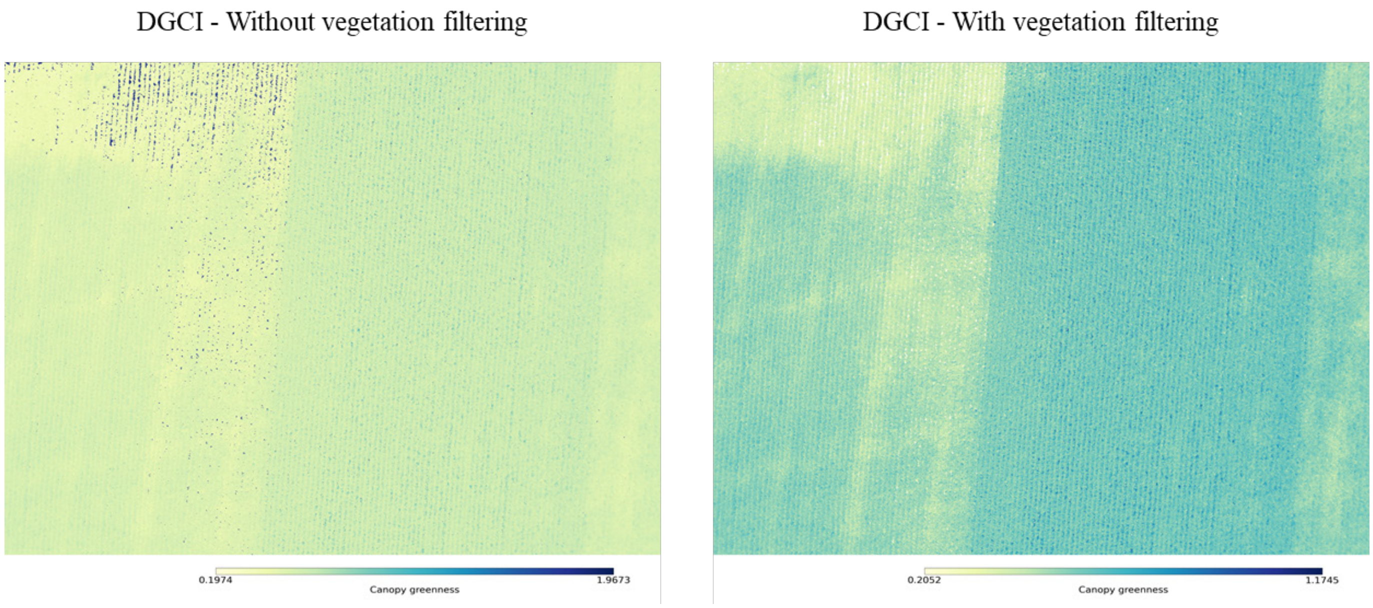

Fig. 3. Calculated Dark Green Color Index (DCGI) image, with and without vegetation filtering.

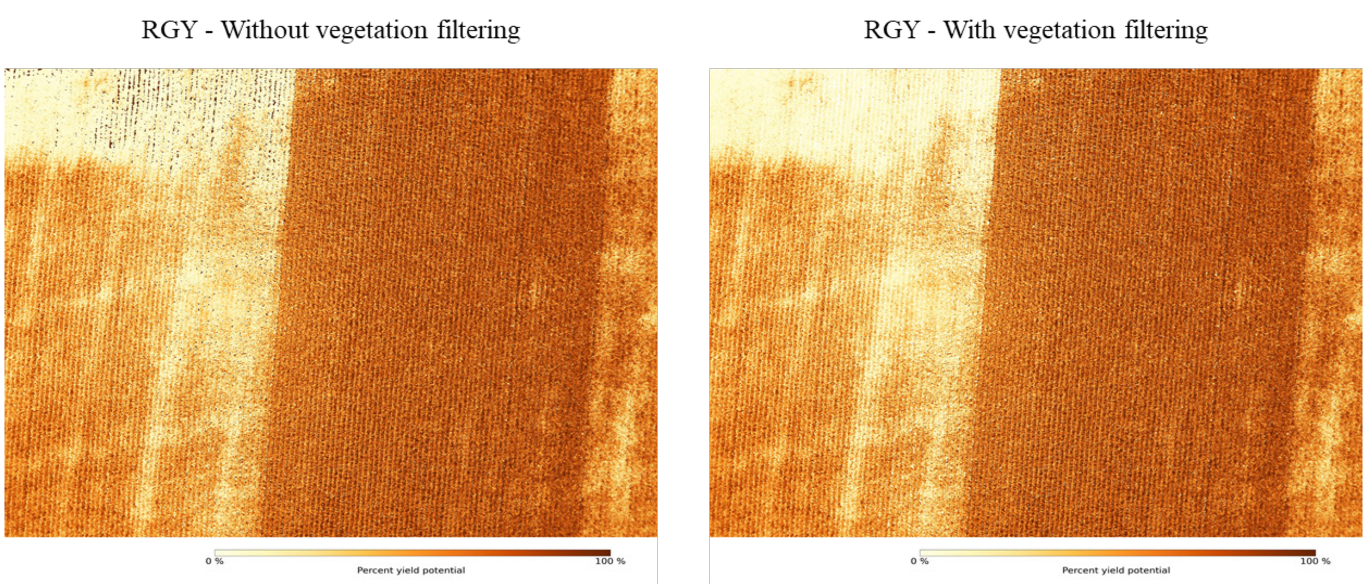

Fig. 4. Calculated relative grain yield (RGY), with and without vegetation filtering.

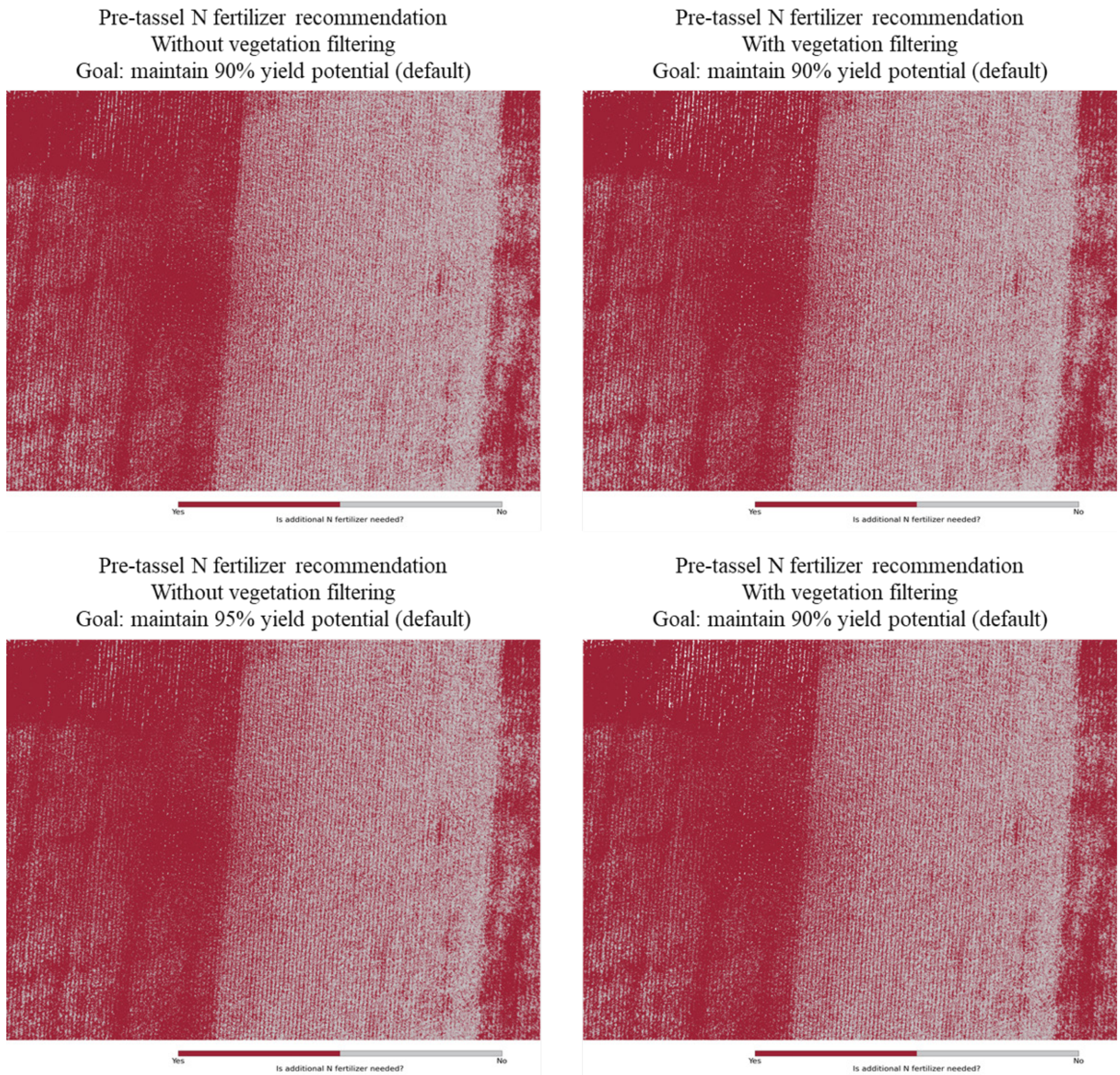

Fig. 5. Pre-tassel N fertilizer recommendation with a 90% (default) and 95% yield goal, with and without vegetation filtering.

Corn Response to In-season Nitrogen Fertilizer Applications

T.L. Roberts,[1] L.C. Purcell,[1] G.L. Drescher,[1] K.A. Hoegenauer,[1] C.C. Ortel,[1] and A.D. Smartt[1]

Abstract

Corn grain yield is closely linked to N fertilization practices, but so is producer profitability. Research to verify the capabilities of aerial imagery and dark green color index (DGCI) to successfully identify corn tissue N concentration is ongoing. The ability of DGCI via remote imagery to predict corn response to N fertilization has been further validated in the three site years included in this trial. There is a strong relationship between the N rate and corn DGCI value, with the DGCI properly predicting the sufficient tissue N concentration at the V10 and V13 growth stages. Although the data set is limited, a N rate calibration curve based on the tissue N concentration across corn growth stages (V10–VT) to predict in-season N fertilizer rates to maximize corn grain yield is being developed. The successful development of these calibration curves will allow producers to apply site-specific, in-season N fertilizer rates to ensure that their corn grain yields are being maximized. At the V10 growth stage, significant increases in corn grain yield were seen when tissue N concentrations were less than 3.5%N. However, the yield gains from in-season N applications at V10 ranged from 14–100 bu./ac. Similarly, corn grain yield responses to in-season N applications were observed when tissue N concentrations were less than 3.0% N at both the V13 and VT growth stages. Increased N application rates were required to maximize corn grain yield at lower tissue N concentrations at each growth stage and ranged from 45–150 lb N/ac. Additional data will help to refine these in-season N rate predictions based on tissue N concentrations.

Introduction

Corn continues to be an important 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. One of the highest input costs for corn production is fertilization, and nitrogen (N) specifically can account for up to 25% of the total input costs. Previous work has identified that the proper rate and timing of N fertilizer application to corn in Arkansas can lead to high N uptake efficiencies (Roberts et al., 2016). In irrigated corn production systems, N uptake values ranged from 50–92%, depending on the rate and timing of application. In-season and later application timings tended to result in greater N uptake values.

One advantage Arkansas production systems enjoy is the access to aerial application equipment that allows producers to apply fertilizers and pesticides to corn much later in the season than what could be accomplished with ground equipment alone. Pre-tassel or late-season N applications to corn have become a frequent practice in Arkansas, but previous research has suggested that a wide range of responses to these applications can occur.

To better predict the needs for in-season 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. Other work by dos Santos et al. (2020) identified a relationship between corn canopy color measured using a dark green color index, or DGCI, and leaf N concentration and relative grain yield. The results of this work will allow the implementation of aerial imagery collected from various sources to aid producers in determining corn crop N needs rather than the traditional destructive plant sampling and analysis methods.

With the development of leaf N sufficiency ranges for corn production comes the need for calibration data that determine the N rates required to maximize or recover yield when the leaf tissue concentrations are below optimal. Proper N management in irrigated corn production systems can be complicated by untimely spring rains and prolonged saturated soils that promote denitrification and loss of plant-available N from the soil system. The ability to apply N in-season all the way until maturity provides producers with the opportunity to monitor their corn crop's N status and ensure the N is not limiting their corn grain yield. However, the identification of corn N sufficiency status (sufficient vs. deficient) does little to solve the problem if the correct rate to correct the deficiency is not defined. The research presented here is an attempt to identify the N application rates required at various points in the growing season to maximize corn grain yield when the leaf tissue N concentrations are below 3.0%.

Procedures

The results presented here are a part of a multi-year trial established at the University of Arkansas System Division of Agriculture's Milo J. Shult Agricultural Research and Extension Center (SAREC) and the Pinetree Research Station (PTRS) during the 2020 and 2021 cropping seasons. The study areas varied for each location and year combination but always followed

[1] Associate Professor, Distinguished Professor, Postdoctoral Research Associate, Graduate Assistant, Graduate Assistant, and Program Associate, respectively, Department of Crop, Soil, and Environmental Sciences, Fayetteville.

soybean (*Glycine max* L.) in rotation. Preplant soil samples were taken and analyzed at the Agricultural Diagnostic Laboratory (Fayetteville, Ark.) for soil pH and routine soil analysis. All nutrients (P, K, and Zn) other than N were applied preplant onto flat ground prior to pulling beds. The N rate structure for this trial consisted of preplant N rates of 0, 10, 100, and 150 lb N/ac and in-season N rates that ranged between 0 and 180 lb N/ac applied at either V10, V13, or VT stage.

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

At each of the predetermined growth stages (V10, V13, or VT), five of the uppermost collared leaves or the earleaf were sampled from each plot that received an in-season N application at that growth stage. Additionally, within 2–3 days of the N fertilizer application and leaf sampling, aerial images were collected with a Phantom 4 Pro (DJI, Shenzen, China) using the camera that comes as standard equipment on the UAS (25.4-mm 20-megapixel CMOS sensor). Images were collected at 100 ft above ground level and with 80% front and side overlap between the pictures. An orthomosaic of the individual images was built using MetaShape Professional (Agisoft LLC, St. Petersburg, Russia). The DGCI values of individual plots were determined from orthomosaic images using Field Analyzer software (http://www.turfanalyzer.com/field-analyzer). Leaf samples were oven-dried at 70 °C until reaching a constant weight, ground to pass through a 20-mesh screen, and analyzed for total N using combustion (Campbell, 1992). The inside two rows of each plot were harvested and adjusted to 15.5% moisture to determine grain yield.

The experiment was arranged in a randomized complete block design (RCBD) with three blocks. At each location, the leaf N concentrations for a specific growth stage were grouped into categories ranging from 2.0 to >3.5% N in 0.5% N increments. The corn grain yield for each N concentration increment within a growth stage was analyzed using a simple one-way analysis of variance (ANOVA) to compare the in-season N treatments. A Fisher's protected LSD ($\alpha = 0.05$) was used to separate yield means among in-season N rates for a specific growth stage when appropriate. The statistical analysis was completed using JMP Pro 15.2.

Results and Discussion

Corn grain yield can be impacted by several factors, but research has consistently shown that N fertilizer influences the yield and profitability of irrigated corn production systems. Aerial imagery has the potential to revolutionize crop management as it pertains to nutrient management, especially N. The relationship between DGCI and leaf N concentration in corn is well established and is further supported by the results from this trial. As shown in Fig. 1, the relationship between DGCI and N application rate is strongly correlated with the DGCI maximizing N rate occurring near 73 lb N/ac. At the V10 growth stage, the N rate of 73 lb N/ac produces a leaf N concentration of >3.0%, which is considered sufficient to produce maximal corn grain yield. Figure 2 provides a more in-depth look at the relationship between DGCI and applied N rate with images captured at the V13 growth stage, which also include plots that were fertilized at the V10 growth stage. For images taken at the V13 growth stage, the join point predicts that a N rate of 89 lb N/ac will maximize leaf DGCI values and subsequently suggests that plots having a DGCI of >0.57 would also have N concentration values >3.0%. Based on the leaf N samples collected in the trial, a N rate of ~100 lb N/ac would have been sufficient to result in a leaf N concentration of at least 3.0%. Therefore, the aerial images and DGCI are in close agreement with the corn tissue N concentrations that were directly measured, further supporting the use of DGCI and aerial imagery as a tool to predict in-season N needs in Arkansas corn production.

The ability to differentiate between sufficient and deficient corn fields is a vast improvement over previous approaches that relied on anecdotal information or "gut feelings." Without calibrated N rates to recover lost corn yield in deficient fields based on the tissue N concentration of the corn crop, the job is merely half done. Successful calibration relies on a wide range of tissue N concentrations (<2.0 to >3.5% N) so that the relationship between the N rate needed and the tissue N concentration can be fully developed. Based on the three site-years of data included in this dataset, we are laying the foundation of a N rate prediction curve based on tissue N concentration at distinct growth stages during the corn growing season.

Corn response to in-season N was categorically delineated into 0.5% increments of tissue N concentration from 2.0 to >3.5% N. Traditionally, tissue N concentrations decrease as the above-ground biomass increases due to the dilution of N within the increasing corn biomass. With the current dataset for all growth stages, the majority of observations were >2.5%, and many were >3.0% N. At the V10 growth stage, there was a significant yield response to in-season N application when tissue N concentrations were <3.5% N (Table 1). When the tissue N concentration at V10 was between 3.0–3.5, 2.5–3.0, and 2.0–2.5% N, the corn plant required 60, 120, and 120 lb N/ac to maximize corn grain yield, respectively. The corn grain yield increase from in-season N applications at the V10 growth stage ranged from 14 to 100 bu./ac, with the largest yield increases occurring when tissue concentrations were lowest (2.0–2.5% N) but also required the highest N application rates to achieve those yield gains (120 lb N/ac). The V13 growth stage exhibited a similar trend but was less responsive at the higher tissue N concentrations (>3.0% N). The yield increase in the two lowest tissue N categories were 80 and 25 bu./ac and required 120 and 60 lb N/ac, respectively. Significant corn grain yield increases were also seen in the two lowest tissue N categories at the VT stage and resulted in yield increases of 100 and 15 bu./ac, which required 150 and 45 lb N/ac, respectively. These data indicate that a successful in-season N rate prediction curve can be developed based on the relationship between corn grain yield response and tissue N concentration at the time of application.

Practical Applications

In times of record-high fertilizer prices, it is imperative that Arkansas corn producers have ample data to make their N management decisions to maximize yield and profitability. Our data further support the use of aerial imagery and DGCI data to determine corn tissue N concentration remotely and nondestructively, which can not only differentiate between deficient and sufficient corn fields but will soon be able to indicate what rate of N will be needed to rescue or maximize corn grain yield. Although there is limited data on hand, within the next few years, there should be sufficient data to provide corn producers with a site-specific in-season N fertilizer rate based on either aerial imagery or leaf tissue N concentration.

Acknowledgments

This research was funded by the Arkansas Corn and Grain Sorghum Research and Promotion Board and the University of Arkansas System Division of Agriculture.

Literature Cited

Campbell, C.R. 1992. Determination of Total Nitrogen in Plant Tissue by Combustion. *In*: C.O. Plank (ed.), Plant Analysis Reference Procedures for the Southern U.S. Southern Cooperative Series Bulletin 368: 20-22. Athens: University of Georgia.

dos Santos, C.L., T.L. Roberts, and L.C. Purcell. 2020. Canopy Greenness as a Midseason Nitrogen Management Tool in Corn Production. Agron. J. 112:5279-5287.

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

Roberts, T.L., N.A. Slaton, J.P. Kelley, C.E. Greub, and A.M. Fulford. 2016. Fertilizer Nitrogen Recovery Efficiency of Furrow-Irrigated Corn. Agron. J. 108:2123-2128.

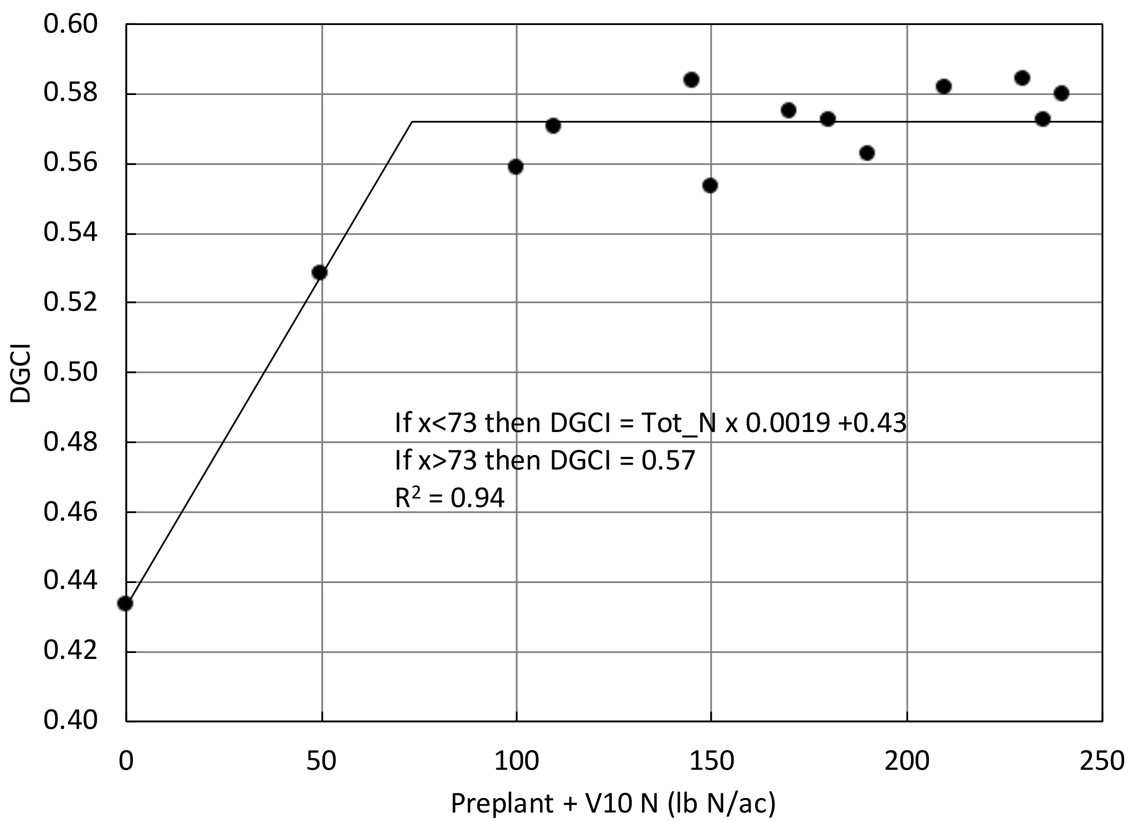

Fig. 1. Dark green color index (DGCI) regressed against applied nitrogen rate at the V10 growth stage.

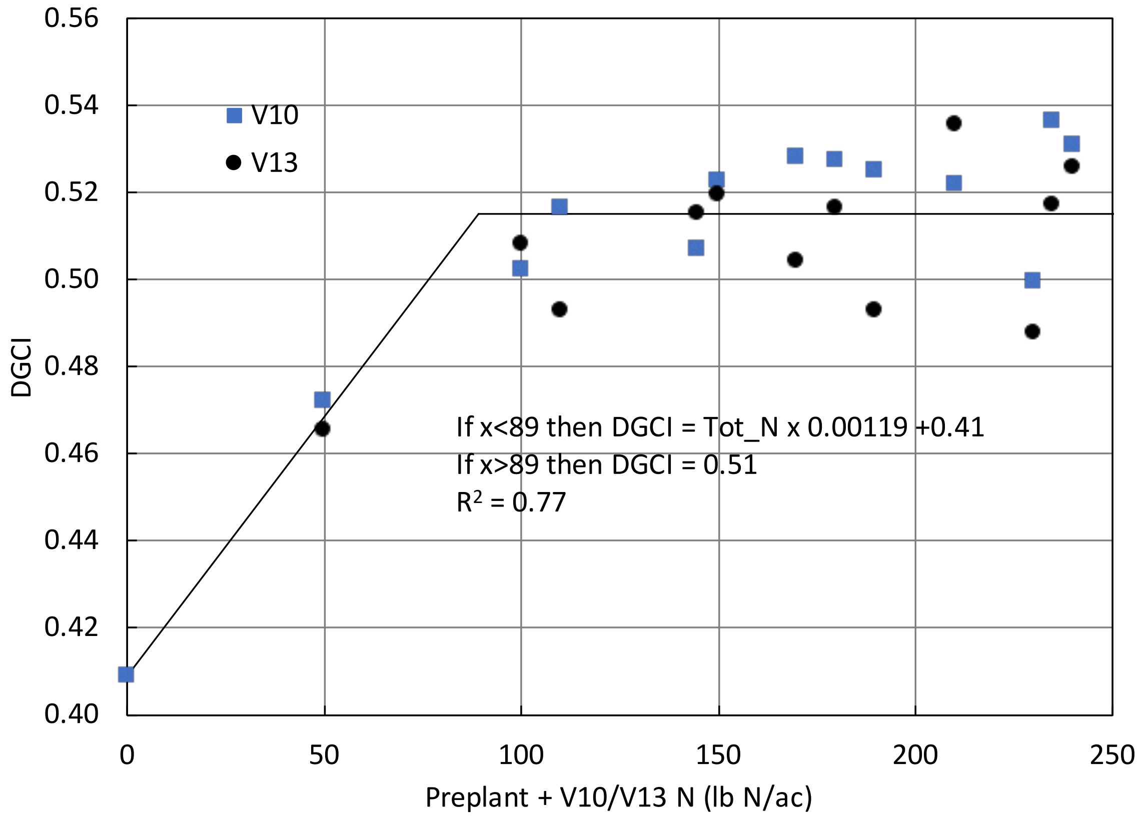

Fig. 2. Dark green color index (DGCI) regressed against applied nitrogen (N) rate at the V13 growth stage including plots that received an in-season N application at the V10 stage.

Table 1. Corn Response to in-season nitrogen (N) applications based on leaf tissue N concentrations at various growth stages.

Corn Leaf Tissue N	Yield Increase From In-season N at Specified Growth Stage	Application Rate Needed to Maximize Yield
(%)	------------------bu./ac----------------	---------------lb N/ac-------------
	V10 Growth Stage	
2.0–2.5	100	120
2.5–3.0	45	120
3.0–3.5	14	60
>3.5	0	-
	V13 Growth Stage	
2.0–2.5	80	120
2.5–3.0	25	60
3.0–3.5	0	-
>3.5	0	-
	VT Growth Stage	
2.0–2.5	100	150
2.5–3.0	15	45
3.0–3.5	0	-
>3.5	0	-

Effect of Cover Crop Termination Timing on Corn Population and Yield

V.S. Green,[1] E.A. Brown,[1] J.H. Massey,[2] and D.A. Dittlinger[1]

Abstract

Winter cover crops may be used to address soil degradation issues. However, impacts of cover crop biomass on the succeeding cash crop growth are not fully understood on soils common to the Arkansas Delta. From 2018 to 2021, a study was conducted on commercial row crop farms to determine the effects of cover crop termination timing (i.e., biomass production) on corn (*Zea mays*) growth and yield in the Arkansas Delta. The relationships between cover crop termination timing and corn plant population, cover crop carbon to nitrogen (C:N) ratios and corn yield were investigated. No differences in corn yields or corn plant population were observed among cover crop termination timing treatments. Cover crop C:N ratios were different among treatments but did not impact corn yields. These results suggest that for silt loam and loam soils in the Arkansas Delta, delaying cover crop termination in order to allow the cover crop to produce more biomass is not likely to negatively affect corn crop yields. Moreover, biomass from cover crop residues may increase soil health benefits over time.

Introduction

Many current crop production systems are associated with soil degradation, including a decline in soil quality, increased compaction, increased soil erosion, reduced soil microbial activity, and reduced water infiltration, as well as reductions in other agronomic and ecosystem services (Lal, 2015). Alternative farming methods that promote sustainability are necessary. Several studies suggest utilizing conservation agriculture methods, such as cover cropping and no-tillage systems, to rebuild soils (Mitchell et al., 2017; Nunes et al., 2018).

The biomass of cover crops directly affects agroecosystems. The amount of cover crop biomass is proportional to cover crop termination timing since a longer growth period allows for more plant growth (Mirsky et al., 2017; Alonso-Ayuso et al., 2014; Balkcom et al., 2015; Acharya et al., 2017). However, many farmers are concerned that too much cover crop biomass may limit crop growth. Therefore, understanding the effects of termination timing on agronomic factors, such as cash crop growth and development, are important. While cover crops are increasingly more accepted as a means to address soil degradation, the effects of cover crops on cash crop growth and development, especially for corn, are still debated by farmers.

The carbon-to-nitrogen ratio (C:N) is an important factor in row crop production systems because high biomass, grass cover crops, such as the winter wheat (*Triticum aestivum*), black oats (*Avena strigosa*), and winter rye (*Secale cereal*) used throughout sites in this study, generally have a high C:N (C:N > 25:1). These high C:N cover crops have been shown to cause N immobilization in the soil, reducing the amount of N accessible by the subsequent cash crop (Dabney et al., 2001; Schomberg et al., 2007). In non-leguminous cash crops that do not fix their own N, such as corn, the lack of available N early in the growing season could be detrimental to cash crop yield potential.

Additional relationships between C:N and corn production have been reported. A study in Pennsylvania on a silt loam soil demonstrated that C:N ratios within a cover crop mixture were positively correlated with N retention but negatively correlated with inorganic N supply and corn yield (Finney et al., 2016). However, diverse cover crop mixes that contain legumes lower the C:N and can supply N to a corn crop early in the season. A study in Arkansas demonstrated reduced N fertilizer requirement in soils with a long history (5+ years) of diverse winter cover crop use. The researchers showed that applying just 75% of the recommended N fertilizer (220 lb/ac standard recommendation) was sufficient for optimum corn yield in 6 of 7 site years (Burns et al., 2022).

The objective of this study was to determine the relationship of cover crop termination timing to the levels of cover crop biomass production and their effect on cover crop C:N and corn growth and development in the Arkansas Delta. We hypothesized that delayed cover crop termination timing would not negatively impact corn crop production, including plant populations and yield, but would provide an increase in cover crop biomass.

Procedures

Cover crop termination timing studies were established in the fall of 2018 at a farm near Walcott, in 2019 on row crop farms near Walcott, Cotton Plant, and Oil Trough, Ark., and in 2020 near Walcott (Table 1). The Walcott and Oil Trough sites were on silt loam soils (Calloway silt loam [fine-silty, mixed, active, thermic Aquic Fraglossudalfs] and Egam silt loam [fine, mixed, active, thermic Cumulic Hapludolls], respectively), while the Cotton Plant site was on a loam soil (Teksob loam [fine-loamy, mixed, active, thermic Typic Hapludalfs]).

The experimental design was a randomized complete block where the treatment was cover crop termination timing. There

---

[1] Professor, Assistant Professor, and Graduate Student, respectively, College of Agriculture, Arkansas State University, Jonesboro.
[2] USDA-ARS, Delta Water Management Research Unit, Jonesboro.

were 4 levels of cover crop termination times at Walcott and Cotton Plant and 3 levels at Oil Trough. All levels of cover crop termination timing were based on the relative growth stage of the grass cover crop within each mix. Termination timings were designated as Early (tillering stage), Mid (stem extension stage), and Late (head in boot or headed), with the addition of a Control (no cover crop), except in the case at the Oil Trough site where delays in study establishment did not allow for a control treatment (Table 1). Cover crop termination timing treatments at each site were replicated 3 times for a total of 12 plots at each site.

Plot dimensions varied by site based on the farm equipment and field layout but generally ranged between 0.6 and 1.2 acres in size. The research sites have been in no-tillage management for many years prior to the initiation of the study and remained in no-tillage during this study. The crop rotation for each of the sites was corn (*Zea mays*)-soybean (*Glycine max*), with cover crops grown over the winter.

Cover crop species selections were made by the cooperating farmers (Table 1). Cover crops were no-till planted after fall harvest and received no synthetic fertilizer. The cover crops were terminated by treatment with Roundup Powermax (N-(Phosphonomethyl)glycine, Bayer AG, Leverkusen, Germany) herbicide applied using a 10-ft ATV-mounted spray boom using flat fan nozzles. Cover crop residues remained on the soil surface, and subsequent corn crops were fertilized according to standard practices of each farmer.

Corn was planted on a row spacing of 38 in. at Cotton Plant (on raised beds) and 30-in. row spacing at Oil Trough (planted flat) and Walcott (on raised beds) (Table 2). Fertilization, irrigation, and weed and pest management of the corn crop were performed by the cooperating farmer according to University of Arkansas System Division of Agriculture Cooperative Extension Services recommendations, with all plots within a farm site treated the same.

Cover crop aboveground biomass was sampled from each treatment at the time of cover crop termination. Cover crop biomass samples were obtained by cutting all living plants at the base, just above the soil surface, from 4, 2.7 ft^2 quadrats within each plot. Samples were then oven-dried for 48 hours at 150 °F before total dry mass per acre (lb/ac) was determined. After dry mass was determined, samples were ground using a Wiley Mill (Thomas Model 4 Wiley, Thomas Scientific, Swedesboro, N.J.) and sent to a commercial lab for C:N analysis (2020 samples) using a dry combustion method with a LECO CN (Leco, CNS 2000, St. Joseph, Mich.) analyzer (Kopp and McKee, 1979).

Cover crop biomass samples for the mid-termination treatment at the Oil Trough site were compromised and therefore not included in cover crop biomass analysis. Corn plant populations were determined by sampling three locations within each plot at every site. Corn population was determined during early growth stages (V1 to V3) using a chain of known length to measure a distance within a single corn row. Healthy corn plants within the same row were counted and then multiplied by a conversion factor to determine plant population. Corn yields were determined by using the farmer's full-size combine and yield monitor equipment when available. When yield monitor equipment was not available, harvest yield masses were measured with a weigh wagon (GW200C, Par-Kan Company, Silver Lake, Ind.) adjusted for moisture at 15.5% using a portable mini GAC plus (mini GAC plus, Dickey-john Corporation, Auburn, Ill.) grain moisture analyzer. Yield measurements from corn were taken from the middle 8 rows of each plot at all sites. At least two full-width header passes were harvested on both the upper and lower ends of the plots at all sites to remove edge effects.

A one-way analysis of variance (ANOVA) was used to test for differences in treatment effects on corn plant population, cover crop C:N, and corn grain yield at four levels of cover crop termination timing using PROC GLIMMIX in SAS v. 9.4 (SAS Institute, Inc., Cary, N.C.). Data by site were analyzed separately due to differences in soil and crop management, weather patterns, and cover crop mixtures. If significant differences were found with the model, Tukey's mean separation test at $\alpha = 0.05$ was used to determine differences among treatment means.

Results and Discussion

Termination of the cover crop mixes was successful at all sites. Cover crop biomass at all sites was significantly influenced by termination timing (Table 3), with late termination timing having greater cover crop biomass than earlier termination timings. Maximum and minimum cover crop biomass across all sites and timings were 2393 and 167 lb/ac, respectively. The results on cover crop biomass in the present study are consistent with results reported by Mirsky et al. (2017) and Acharya et al. (2017) that cover crop biomass is relative to cover crop termination timing. In this study, only above-ground cover crop biomass was sampled, but it was expected that below-ground root biomass increased proportionally with shoot biomass (Qi et al., 2019). Increases in cover crop biomass above- and below-ground do have the potential to improve soil physical and hydraulic properties related to soil health. However, soil health improvements are generally more evident when cover crop biomass levels reach >4500 lb/ac (Keene et al., 2017; Hubbard et al., 2013). The lower cover crop biomass (<2400 lb/ac) produced in this study was attributed to wet fall and early winter seasons, which subjected cover crop seedlings to anaerobic soil conditions and cold temperatures. However, this level of cover crop biomass is common in Arkansas when going into a corn crop in corn-soybean rotations, where soybean is harvested late in the fall and corn is planted early in the spring and, therefore, would be a common scenario for Arkansas corn farmers growing cover crops between a soybean and corn crop.

Corn plant populations did not significantly differ among treatments at any of the sites in which corn was grown and ranged from 27665 to 33625 plants/ac, with lower corn populations at the Cotton Plant site, where the planting rate was lower than at the other sites (Table 4). Cover crop C:N was significantly influenced by cover crop termination timing at all sites as expected (Fig. 1). These results were expected due to the positive relationship between cover crop biomass production and cover crop C:N in non-legume cover crops (Mirsky et al., 2017; Alonso-Ayuso et al., 2014; Balkcom et al., 2015; Acharya et al., 2017). However, we saw no evidence that cover crop termination timing (and therefore C:N) reduced available inorganic N to the point that had any negative effects on corn yield.

Corn yields were not significantly different among cover crop termination treatments within each farm site-year (Table 5). Corn yield across all sites ranged from 150 bu./ac at Cotton Plant to 233 bu./ac at Walcott.

Practical Applications

In the present study, we did not observe significant effects in corn yields due to cover crop termination timing. These results are important to corn producers because profits could potentially increase from cover crop use if they reduce other input costs such as nitrogen fertilizer (Burns et al., 2022). Delaying cover crop termination increased cover crop biomass in this study, resulting in more organic material in the soil compared to early-terminated cover crops. Our results suggest that growers can increase decomposable plant material, and potentially soil organic matter, without risking reductions in corn yields by terminating their cover crops at or near corn planting.

In addition to environmental factors, there is evidence of a correlation between yield and the number of years that cover crops have been implemented into a system. Decker et al. (1994) showed that increases in cash crop yields were not apparent in the first year of use but did increase over a three-year study period. Even with results generally showing no statistically significant increases in crop yields due to later cover crop termination timing or even from cover crop vs. no cover crop, as was observed in the present study, other environmental services provided by cover crops, such as protection from erosion during winter and spring, could be expected to increase over time.

Acknowledgments

Support for this project was provided by Arkansas corn producers through check-off funds administered by the Arkansas Corn and Grain Sorghum Promotion Board with additional support from the University of Arkansas System Division of Agriculture. This material is based upon work that was supported, at least in part, by the Arkansas Natural Resources Conservation Service, Conservation Innovations Grant, United States Department of Agriculture, under award number 68-7103-18-004.

Literature Cited

Acharya, J., M.G. Bakker, T.B. Moorman, T.C. Kaspar, A.W. Lenssen, and A.E. Robertson, 2017. Time interval between cover crop termination and planting influences corn seedling disease, plant growth, and yield. Plant Dis. 101:591–600.

Alonso-Ayuso, M., J.L. Gabriel, and M. Quemada, 2014. The kill date as a management tool for cover cropping success. PLOS ONE 9:e109587.

Balkcom, K.S., L.M. Duzy, T.S. Kornecki, and A.J. Price. 2015. Timing of cover crop termination: management considerations for the southeast. Crop, Forest, & Turfgrass Mgt. 1:1–7.

Burns, B.W., V.S. Green, A.A. Hashem, J.H. Massey, A.M. Shew, M.A.A. Adviento-Borbe, and M. Milad, 2022. Determining nitrogen deficiencies for maize using various remote sensing indices. Precision Agriculture https://dx.doi.org/10.1007/s11119-021-09861-4

Dabney, S.M., J.A. Delgado, and D.W. Reeves, 2001. Using winter cover crops to improve soil and water quality. Comm. Soil Sci. Plant Anal. 32:1221–1250.

Decker, A.M., A.J. Clark, J.J. Meisinger, F.R., Mulford, and M.S. McIntosh, 1994. Legume cover crop contributions to no-tillage corn production. Agron. J. 86:126.

Finney, D.M., C.M. White, and J.P. Kaye, 2016. Biomass production and carbon/nitrogen ratio influence ecosystem services from cover crop mixtures. Agron. J. 108:39.

Hubbard, R.K., T.C. Strickland, and S. Phatak, 2013. Effects of cover crop systems on soil physical properties and carbon/nitrogen relationships in the coastal plain of southeastern USA. Soil Tillage Res. 126:276–283.

Keene, C.L., W.S. Curran, J.M. Wallace, M.R. Ryan, S.B. Mirsky, M.J. VanGessel, and M.E. Barbercheck, 2017. Cover crop termination timing is critical in organic rotational no-till systems. Agron. J. 109:272–282.

Kopp, J.F., and G.D. McKee, 1979. Methods for chemical analysis of water and wastes (3rd ed.). Environmental Monitoring and Support Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio.

Lal, R., 2015. Restoring soil quality to mitigate soil degradation. Sustainability 7:5875-5895.

Mirsky, S.B., V.J. Ackroyd, S. Cordeau, W.S. Curran, M. Hashemi, S.C. Reberg-Horton, M.R. Ryan and J.T. Spargo, 2017. Hairy vetch biomass across the eastern United States: Effects of latitude, seeding rate and date, and termination timing. Agron. J. 109:1510.

Mitchell, J.P., A. Shrestha, K. Mathesius, K.M. Scow, R.J. Southard, R.L. Haney, R. Schmidt, D.S. Munk, and W.R. Horwath, 2017. Cover cropping and no-tillage improve soil health in an arid irrigated cropping system in California's San Joaquin Valley, USA. Soil Tillage Res. 165:325–335.

Nunes, M.R., H.M. van Es, R. Schindelbeck, A.J. Ristow, and M. Ryan, 2018. No tillage and cropping system diversification improve soil health and crop yield. Geoderma 328:30–43.

Qi, Y., W. Wei, C. Chen, and L. Chen, 2019. Plant root-shoot biomass allocation over diverse biomes: A global synthesis. Global Ecol. Cons. 18:e00606.

Schomberg, H.H., N.L. Martini, J.C. Diaz-Perez, S.C. Phatak, K.S. Balkcom, and H.L. Bhardwaj, 2007. Potential for using sunn hemp as a source of biomass and nitrogen for the Piedmont and Coastal Plain regions of the southeastern USA. Agron. J. 99:1448–1457.

Table 1. Cover crop details for all sites and years.

Site	Year	Cover crop mixture†	Termination timing	Termination date	Growth stage‡
Walcott	2019	winter wheat, crimson clover, purple-top turnip	Early	21 March	tillering
			Mid	9 April	early stem extension
			Late	7 May	full-head
Cotton Plant	2020	black oat, radish	Early	25 March	early-tillering
			Mid	1 May	stem extension
			Late	18 May	full-head
Oil Trough	2020	black oat, barley, Austrian winter pea, crimson clover, radish	Early	29 Feb	late-tillering
			Mid	2 April	late-stem extension
			Late	10 April	full-head
Walcott	2020	winter wheat, crimson clover	Early	7 March	tillering
			Mid	4 April	stem extension
			Late	29 April	mid-boot
Walcott	2021	winter wheat, crimson clover	Early	1 April	early stem extension
			Mid	13 April	mid-boot
			Late	7 May	anthesis

† Cover crops were: Austrian winter pea (*Pisum sativum* L.), winter barley (*Hordeum vulgare* L.), black oats (*Avena sativa* L.), winter rye (*Secale cereale* L.), crimson clover (*Trifolium incarnatum* L.), radish (*Raphanus sativus* L.), purple-top turnip (*Brassica rapa* L.), winter wheat (*Triticum aestivum* L.).
‡ Cover crop growth stages were based on the grass species grown within the mix.

Table 2. Corn crop details for all sites and years.

Site	Year	Cash crop	Variety	Seeding rate (seeds/ac)	Planting date	Row spacing (in.)	Harvest date
Walcott	2019	Corn	Dekalb 67-44	34400	24 April	30	17 Sept
Cotton Plant	2020	Corn	High Fidelity Genetics 1161	29500	18 May	38	21 Oct
Oil Trough	2020	Corn	Pioneer 1870YHR	32400	9 April	30	16 Sept
Walcott	2020	Corn	Dekalb 67-44	34400	1 May	30	01 Oct
Walcott	2021	Corn	Dekalb 67-44	34400	7 May	30	16 Sept

Table 3. Cover crop biomass for all sites and years.

Site	**Year**	***P*-value**	**Treatment**	**Biomass**
				(lb/ac)
Walcott	2019	0.0040	Control	–
			Early	520 a[†]
			Mid	1092 a
			Late	2393 b
Cotton Plant	2020	0.0319	Control	–
			Early	244 a
			Mid	504 a
			Late	1662 b
Oil Trough	2020	0.0324	Control	–
			Early	612 a
			Mid	–
			Late	2335 b
Walcott	2020	0.0096	Control	–
			Early	281 a
			Mid	799 a
			Late	1641 b
Walcott	2021	0.0035	Control	–
			Early	167 a
			Mid	616 a
			Late	2206 b

[†] Values with different letters within a site are significantly different by Tukey's honestly significant difference mean comparison ($P < 0.05$). Dash indicates control treatments that were not able to be measured or sample data that was compromised and were therefore not included in statistical analysis.

Table 4. Corn crop plant populations for all site and years.

Site	Year	*P*-value	Treatment	Plant Population
				plants/ac
Walcott	2019	0.7015	Control	30477 ns†
			Early	31039
			Mid	30814
			Late	31939
Cotton Plant	2020	0.4769	Control	27665 ns
			Early	30238
			Mid	28340
			Late	28340
Oil Trough	2020	0.4913	Control	–
			Early	30927 ns
			Mid	29352
			Late	30589
Walcott	2020	0.1353	Control	32501 ns
			Early	33626
			Mid	31604
			Late	33513
Walcott	2019	0.6994	Control	32333 ns
			Early	32222
			Mid	31222
			Late	30889

† ns = not significant at the α = 0.05 level within a site-year. Dash indicates nonexistent treatments at the corresponding site.

Table 5. Corn grain yield for all sites and years.

Site	Year	*P*-value	Treatment	Yield[†]
				bu./ac
Walcott	2019	0.1309	Control	233
			Early	213
			Mid	223
			Late	220
Cotton Plant	2020	0.3236	Control	195
			Early	188
			Mid	175
			Late	150
Oil Trough	2020	0.7718	Control	–
			Early	158
			Mid	179
			Late	174
Walcott	2020	0.3059	Control	203
			Early	208
			Mid	170
			Late	170
Walcott	2021	0.2650	Control	207
			Early	208
			Mid	216
			Late	226

[†] Differences in yield within a site were not statistically different at the $\alpha = 0.05$ level due to high field variability within the large plot farm research.

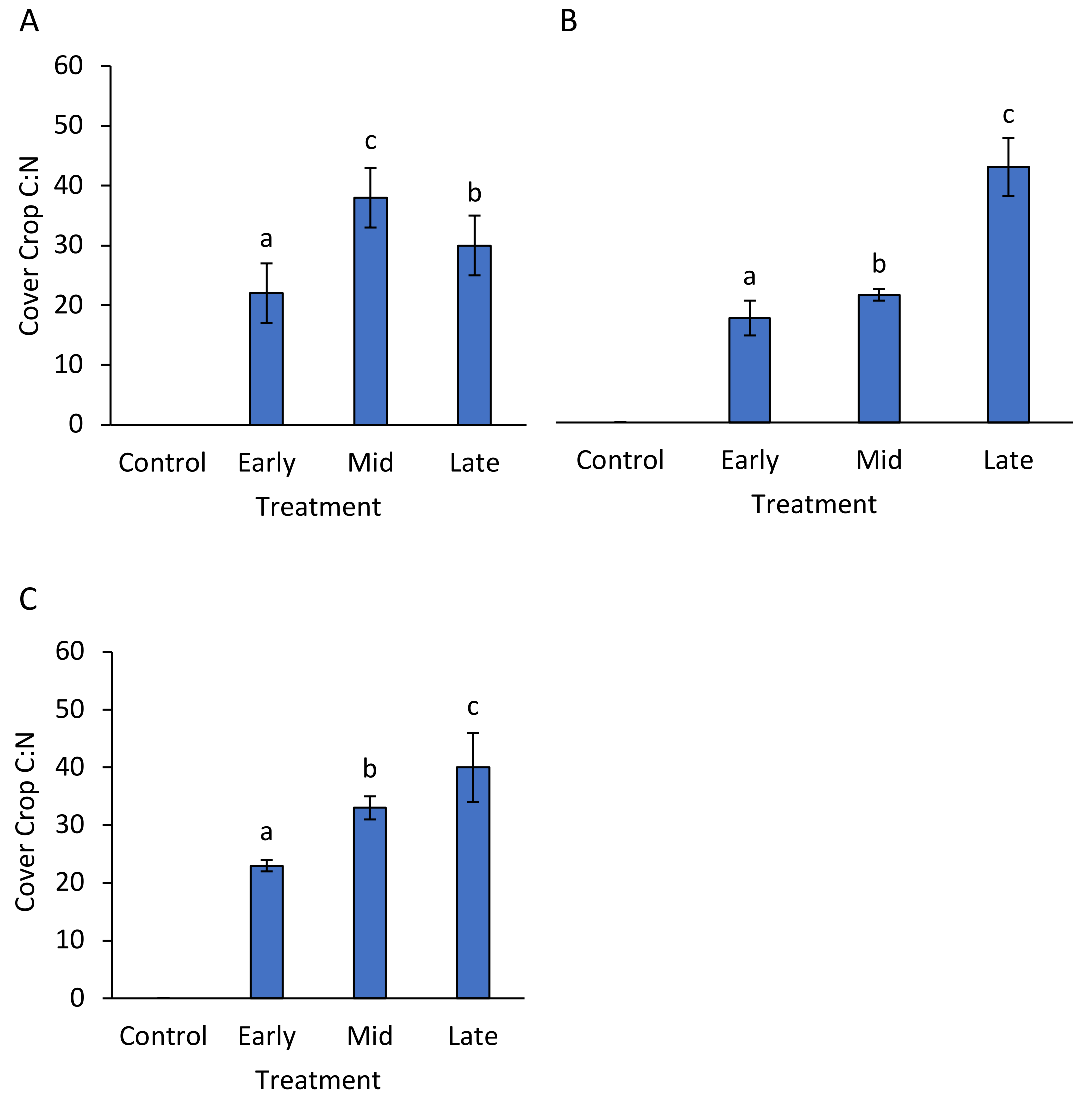

Fig. 1. Cover crop carbon to nitrogen ratio (C:N) for the termination timing treatments, 2020. Walcott (A), Cotton Plant (B), Oil Trough (C). Values with different letters within a site are significantly different by Tukey's honestly significant difference mean comparison ($\alpha = 0.05$). Error bars represent the standard deviation of the treatment means.

Impact of Plant Population on Corn Yield

J.P. Kelley,[1] T.D. Keene,[1] S. Hayes,[2] and C. Treat[3]

Abstract

Identifying the optimum corn (*Zea mays* L.) plant population is critical for growing high-yielding corn. Field trials evaluating the impact of corn plant population, plant population × nitrogen rate, and plant population × row spacing on yield and late-season lodging potential were conducted in 2020 and 2021 at either the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS) near Marianna, Arkansas, or the Southeast Research and Extension Center (SEREC) near Rohwer, Arkansas. In 2021, in a plant population trial at the LMCRS near Marianna, corn yield responded positively to increasing plant population from 20,500 plants/ac to 36,000 to 37,500 plants/ac, depending on the hybrid. Increasing plant populations greater than 40,000 reduced yields regardless of the hybrid. In a separate plant population × nitrogen rate study at Marianna in 2020, corn hybrids DKC 67-44 and Master Farmer MB-T159 both responded to increasing plant populations. The hybrid DKC 67-44's yields were increased from 187.3 bu./ac to 233.7 bu./ac as plant populations increased from 20,520 to 40,140 plants/ac when averaged over nitrogen rates. Master Farmer MB-T159 showed less plant population response, and yields ranged from 172.4 bu./ac at 18,650 plants/ac to 208.4 bu./ac at 28,140 plants/ac when averaged across nitrogen rates. Averaged across plant populations, nitrogen rates of 180 and 220 lb N/ac produced similar yields, while the 260 lb N/ac produced the highest yields for both DKC 67-44 and Master Farmer MB-T159 hybrids. In a plant population × row spacing trial at the SEREC, near Rohwer, row spacings of 38-in. produced 5.6 bu./ac more than 19-in. row spacing when averaged across plant populations that ranged from 18,000 to 45,000 plants/ac, indicating that narrow row spacing does not necessarily increase corn yields and may not provide the necessary yield increase needed to justify the added expense to convert to a narrow row corn system.

Introduction

The average Arkansas corn yield has steadily been increasing by approximately 2.75 bu./ac per year since 1990 and averaged 184 bu./ac in 2021 (USDA-NASS, 2022). There are likely several reasons why yields are increasing, but irrigation plays a large role in increasing yields. Approximately 90% of the corn grown in Arkansas is irrigated (USDA-FSA, 2021), which helps provide consistent yields over the years with varying growing season rainfall and also encourages producers to use more intensive management practices that can lead to higher yields, such as increasing nitrogen rates and increasing plant populations. Corn plant populations have been gradually increasing as new hybrids are developed that provide greater yields at higher populations. The United States' average corn plant population has been increasing by an average of nearly 400 plants/ac per year (USDA-NASS, 2017). Increasing plant populations have been given partial credit for the overall increase in corn yields. The downside to increasing populations is that seed cost is now generally the second highest input cost for corn, behind fertilizer costs in many fields (Watkins, 2022). There is a general lack of unbiased data to support increasing corn plant populations; however, it is generally expected that high populations give higher yields. More local information on plant population responses for full-season corn hybrids that are commonly grown in Arkansas is needed to verify that current plant population recommendations of 32,000 to 34,000 plants/ac for irrigated fields are appropriate. In particular, more information is needed to verify yield responses at various yield levels as well as if increasing plant populations increase the risk of late-season plant lodging. As yields continue to increase, questions arise about whether additional nitrogen is needed to support higher plant populations. Narrow row spacing is often considered a way to increase corn yields in the Midwest. Licht et al., 2019 found that in Iowa, narrowing row spacing from 30-in. to 20-in. increased corn yields in 11 of 22 trials with a corn yield increase of 5–19 bu./ac. Mississippi research (Williams et al., 2021) showed a 5% corn yield increase when narrowing corn row spacing from 38-in. to 19-in. spacing. Since planting corn on raised beds for furrow irrigation is the predominant production practice in Arkansas, a substantial corn yield increase would need to be seen to justify the expense and effort of adopting narrow row corn production.

The present studies were designed to provide more information on the impact of plant populations, nitrogen rates, and row spacing and how all three interact as Arkansas corn yields continue to increase and producers are looking for methods to further increase yields.

[1] Professor and Program Technician, Department of Crop, Soil, and Environmental Sciences, Little Rock.
[2] Former Program Associate, Rohwer Research Station, Rohwer.
[3] Program Assistant, Lon Mann Cotton Research Station, Marianna.

Procedures

Field trials evaluating the impact of corn plant population, plant population × nitrogen rate, and plant population × row spacing on yield and late-season plant lodging were conducted in 2020 or and 2021 at either the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station (LMCRS) near Marianna, Arkansas, or the Southeast Research and Extension Center (SEREC) near Rohwer, Arkansas. 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 followed current CES recommendations. Plant stands were measured soon after emergence to determine final plant populations. Late-season plant lodging was visually estimated prior to harvest when lodging occurred.

Plant Population Trial at the Lon Mann Cotton Research Station

A large plot trial was planted at the LMCRS, near Marianna, on a Calloway silt loam soil on 20 April 2021 with a John Deere vacuum planter. Plot size was 4 rows wide × 500 ft. long with a single replication. Pioneer 1847VYHR, 118-day relative maturity hybrid and DKC 65-99, 115-day relative maturity hybrid were evaluated at populations ranging from 18,000 plants/ac to 50,000 plants/ac. Row spacing was 38-in. wide and plots were planted on raised beds for furrow irrigation. Pre-plant fertilizer was applied at recommended levels and nitrogen was split applied (preplant and V5) with a total nitrogen of 220 lb/ac. Prior to harvest, 10 representative ears were collected from each plot to determine seeds/ear. The two center rows of each plot were combine-harvested at maturity and grain yields were adjusted to 15.5% moisture.

Plant Population × Nitrogen Rate at the Lon Mann Cotton Research Station

A small plot trial evaluating the impact of corn plant population and nitrogen rate was planted on 4 May 2020 at the LMCRS, near Marianna, on a Calloway silt loam soil with a John Deere vacuum planter. Plot size was 4 rows wide × 30 ft. long and each treatment was replicated 4 times. Treatments included two hybrids, DKC 67-44, 117-day relative maturity, and Master Farmer T-159, 115-day relative maturity, 4 plant populations (approximately 18,000, 25,000, 32,000, and 39,000 plants/ac) and three nitrogen rates (180, 220, and 260 lb N/ac). Row spacing was 38-in. wide and plots were planted on raised beds for furrow irrigation. Pre-plant phosphorus, potassium, zinc, and sulfur fertilizer were applied at recommended levels. Nitrogen was applied at 85 lb N/ac preplant on all plots and the remainder was applied during sidedress at the V5 growth stage. At corn maturity, the two center rows of each plot were combine-harvested, and yields were adjusted to 15.5% moisture.

Plant Population × Row Spacing at the Southeast Research and Extension Center

A single trial evaluating corn plant population and row spacing was planted at the SEREC, near Rohwer, on 5 April 2021 on a Herbert silt loam soil. Treatments included plant populations of approximately 20,000, 25,000, 30,000, 35,000, 40,000, and 45,000 plants/ac and row spacings of 38-in. and 19-in. A single corn hybrid, DKC 65-95, 115-day relative maturity hybrid was used, and treatments were replicated 8 times. Plots with 38-in. row spacing were planted with a 4-row John Deere vacuum planter, while plots with 19-in. row spacing were planted with a John Deere vacuum planter with 13 rows spaced 19-in. apart. The plots with 38-in. row spacing were planted on raised beds, while plots planted with 19-in. row spacing were planted on flat ground (no raised bed) and were 13 rows wide. All plots were 50 ft long. After corn emergence, an irrigation furrow was pulled on plots with 19-in. row spacing every 38-in. to facilitate irrigation using a single furrow plow pulled with a tractor with narrow 12-in.-wide tires to avoid running over adjacent corn rows. At maturity, the two center rows of each plot with 38-in. row spacing were harvested with a plot combine, while rows 2–4 and 10–12 of the 13-row wide plots were harvested on plots with 19-in. row spacing. The same corn head with 38-in. row spacing was used to harvest all plots.

Results and Discussion

Plant Population Trial at the Lon Mann Cotton Research Station

Corn yield across all plant populations averaged 186 bu./ac for DKC 65–99 and 174.7 bu./ac for Pioneer 1847VYHR (Table 1). Heavy rainfall in early June caused extended soil saturation that likely reduced the overall yield potential of the plots. However, the yield response to plant population was still evident and consistent across the trial area. Both hybrids achieved maximum grain yields between 36,000 and 37,250 plants/ac, slightly higher than a recommended plant population. Yields of both hybrids declined once plant populations were higher than 40,000 plants/ac, even though lodging was not evident. The extremely low population of 20,750 plants/ac provided an acceptable yield but was not great enough to maximize yield. The number of seeds/ear declined with each increasing plant population as ear size decreased, presumably from intra-plant competition (Table 1). These results are consistent with past research in Arkansas that shows corn plant populations of less than 30,000 plants/ac are generally not enough to maximize yields in irrigated fields. Yields tend to reach a plateau at 36,000 to 38,000 plants/ac for most corn hybrids under irrigated conditions, and increasing plant populations beyond 40,000 generally has a negative impact on yield.

Plant Population × Nitrogen Rate at the Lon Mann Cotton Research Station

Hybrid and plant population both affected corn yield (Table 2). There was a strong yield response to plant population with DKC 67-44, with yields increasing from 187.3 bu./ac with a population of 20,500 plants/ac to 233.7 bu./ac when the population increased to 40,140 plants/ac, when averaged across 4 nitrogen rates. The hybrid DKC 67-44 exhibited a small numerical but not statistical response to nitrogen rate with 180 and 220 lb N/

ac rates yielding similar to 213.0 and 212.9 bu./ac, while the 260 lb N/ac rate increased corn yield to 220.1 bu./ac when averaged across plant populations. The hybrid MT-T159 also showed a clear but lesser yield response to plant population, with yields increasing from 172.4 bu./ac with 18,650 plants/ac to 208.4 bu./ac with 28,140 plants/ac when averaged across 3 nitrogen rates. However, yields of MB-T159 declined when populations were increased greater than 28,140 plants/ac. The hybrid MB-T159 showed a 10 bu./ac numerical increase when nitrogen rates were increased from 180 bu./ac to 260 lb N./ac but was not statistically significant. In both hybrids, yields were increased more by increasing plant populations than by increasing nitrogen rates. No late-season lodging was observed for any treatment.

Plant Population × Row Spacing at the Southeast Research and Extension Center

Corn yields ranged from a low of 162 bu./ac at 21,000 plants/ac on 38-in. rows to a high of 288 bu./ac at 44,000 plants/ac on 19-in. rows (Fig 1.). Corn yields averaged 211.1 bu./ac for 38-in.-wide rows and 205.5 bu./ac for 19-in. rows, averaged across plant populations. Average populations varied slightly between the 38-in. and 19-in. rows and were 29,628 plants/ac for 38-in. rows and 31,105 plants/ac for 19-in. rows. Overall, the yields between 38-in. rows and 19-in. rows showed a similar response when plant populations were increased (Fig 1.), and yields for both wide and narrow row corn were generally maximized by plant populations of approximately 40,000 plants/ac. Historic rainfall of approximately 15 in. during early June impacted the overall yield potential and quality of this trial, and it was flooded for approximately 2 days with 12-in. deep water. This flooding and subsequent saturated soil conditions may have impacted 19-in.-wide rows more than 38-in.-wide rows since the large, raised beds on the 38-in. rows would have helped facilitate drainage quicker. The lack of raised beds on the 19-in. row plots could be a limiting factor in our environment. The results from this one trial indicate that similar yields could be expected with wide and narrow-row corn. However, to implement narrow-row corn, a change in all equipment row spacing and tire size would be needed.

Practical Applications

Results from these irrigated trials demonstrate that the plant population needed to reach maximum corn yield can vary between hybrids, 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, but hybrid, weather conditions, and harvest timing will also play important roles, and lodging can still be a concern with high plant populations. In the plant population × nitrogen rate trial, yields were increased more with increasing plant populations than with nitrogen rate, indicating current nitrogen recommendations for corn are appropriate. For producers who are considering planting corn on a narrow row system, preliminary yield results from one trial indicate similar yields between traditional wide rows and 19-in. rows.

Acknowledgments

The authors appreciate the support provided by Arkansas corn producers through check-off funds administered by the Arkansas Corn and Grain Sorghum Promotion Board. Support was also provided by the University of Arkansas System Division of Agriculture. A special thanks for the support provided by the Lon Mann Cotton Research Station and the Southeast Research and Extension Center staff for assisting with this research.

Literature Cited

Licht, M., M. Parvej, and E. Wright. (2019), Corn Yield Response to Row Spacing and Plant Population in Iowa. Crop, Forage & Turfgrass Management, 5:1-7 190032. https://dx.doi.org/10.2134/cftm2019.05.0032

USDA-FSA. 2022. United States Department of Agriculture–Farm Service Agency. Planted corn acres in Arkansas, 2021. Accessed 5 April 2022. Available at: https://www.fsa.usda.gov/news-room/efoia/electronic-reading-room/frequently-requested-information/crop-acreage-data/index

USDA-NASS. 2021. United States Department of Agriculture–National Agricultural Statistics Service. Corn yield, Arkansas, 1990–2021. Accessed 5 April 2022. Available at: https://quickstats.nass.usda.gov/results/BE079F83-B320-3084-81BA-9D225AABB929

USDA-NASS. 2017. USDA –National Agricultural Statistics Service. Quick stats: Corn, plant population. USDA-NASS. https://quickstats.nass.usda.gov/results/8AA5AC5F-BE64-3483-A132-28849DB1DF0F

Watkins, B. 2022. University of Arkansas System Division of Agriculture Cooperative Extension Service Enterprise Crop Budgets. Accessed 5 April 2022. Available at: https://www.uaex.uada.edu/farm-ranch/economics-marketing/farm-planning/budgets/crop-budgets.aspx

Williams, J.J., D.M. Dodds, N.W. Buehring, J.S. Dhillon, and W.B. Henry. Corn response to row spacing and plant population in the Mid-South United States. Agron. J. 2021. 113:4132– 4141. https://dx.doi.org/10.1002/agj2.20817

Table 1. Impact of plant population on corn yield (bu./ac), grain moisture, seeds/ear, and percent lodging on DKC 65-99 and Pioneer 1847VHYR, University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, 2021.

	DKC 65-99				Pioneer 1847VYHR			
Plants/ac	Yield	Moisture	Seeds/ear	Lodging	Yield	Moisture	Seeds/ear	Lodging
	bu./ac	%	#/ear	%	bu./ac	%	#/ear	%
20,750	162.9	14.9	652	0	168.6	19.6	706	0
23,750	182.3	15.0	625	0	171.2	20.2	641	0
30,500	194.0	15.5	540	0	174.5	20.8	626	0
32,500	196.1	15.7	526	0	184.1	19.8	582	0
36,000	198.5	15.4	502	0	185.0	20.1	576	0
37,250	201.2	15.9	496	0	180.3	19.9	553	0
42,500	199.4	16.0	460	0	177.1	19.2	537	0
46,000	192.2	16.0	435	0	156.6	19.8	481	0
47,500	172.5	15.8	388	0	---	---	---	---
53,500	163.5	17.3	379	0	---	---	---	---
Mean	186.3	15.8	500	0	174.7	19.9	588	0

Table 2. 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, 2020.

	DKC 67-44					Master Farmer MB-T159			
Plants/ac	180	220	260	Mean[a]	Plants/ac	180	220	260	Mean[a]
	-------------lb N/ac-------------					-------------lb N/ac-------------			
20,520	187.2	184.0	190.8	187.3	18,650	171.6	173.2	172.4	172.4
24,880	212.3	209.2	216.3	212.6	22,525	183.8	189.6	194.4	189.3
31,620	222.1	227.3	234.0	227.8	28,140	201.1	212.3	211.9	208.4
40,140	230.4	231.4	239.4	233.7	33,130	194.0	204.3	210.6	203.0
LSD 0.05	--------------10.6--------------			---	---	--------------11.2--------------			---
Mean[b]	213.0	212.9	220.1	---	---	187.6	194.9	197.4	---

[a] Mean corn yield for each plant population, averaged across three nitrogen rates.
[b] Mean corn yield for each nitrogen rate, averaged across four plant populations.

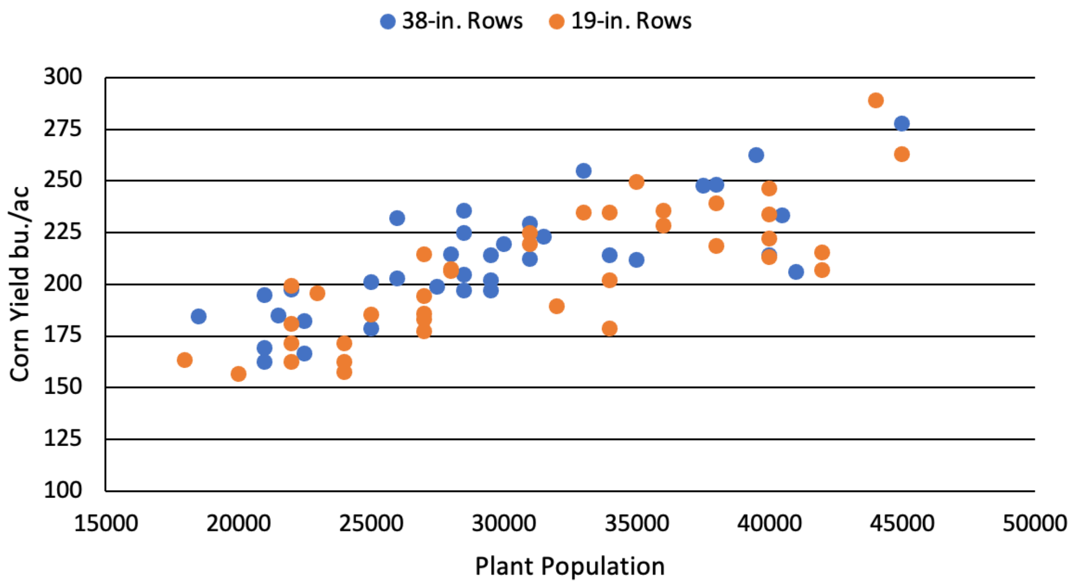

Fig. 1. Effect of row spacing and plant population on irrigated corn yield (bu./ac), University of Arkansas System Division of Agriculture's Rohwer Research Station, Rohwer, 2021.

Irrigated Rotational Cropping Systems, 2014–2021 Summary

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

Abstract

A large-plot field trial evaluating the impact of crop rotation on yields of winter wheat (*Triticum aestivum* L.) and irrigated corn (*Zea mays* L.), early planted soybean [*Glycine max* (L.) Merr], double-crop soybean, full-season grain sorghum [*Sorghum bicolor* (L.) Moench], and double-crop grain sorghum was conducted from 2013 to 2021 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station near Marianna, Arkansas. Yields of April-planted group IV soybean were 5 and 7 bu./ac, higher, respectively, when planted following corn or grain sorghum compared to continuous soybean. Crop rotation impacted June-planted, double-crop soybean yield 2 out of 8 years, and average yields were 4 bu./ac greater when following corn or grain sorghum than a previous double-crop soybean crop. Corn yields were impacted by the previous crop 2 out of 8 years, where corn following corn yield was 26 bu./ac lower than when following April-planted soybean in 2016. On average, corn following corn yielded 6 and 7 bu./ac less than when following April-planted soybean or double-crop soybean, respectively. Wheat yields were impacted by the previous crop in 5 out of 7 years of the trial. Wheat following full-season grain sorghum across all years yielded 9 bu./ac less than when following April-planted soybean and 5 or 6 bu./ac less than when following corn or double-crop soybean. Full-season grain sorghum was always planted following April-planted soybean or double-crop soybean, and yields averaged 114 bu./ac with no difference in yield between previous crops. Double-crop grain sorghum averaged 86 bu./ac across all years.

Introduction

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

Procedures

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

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

[1] Professor and Program Technician, respectively, Department of Crop, Soil, and Environmental Sciences, Little Rock.
[2] Resident Director and Program Assistant, respectively, Lon Mann Cotton Research Station, Marianna.

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

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

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

Summer crops were furrow irrigated as needed according to the University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) irrigation scheduler program. Normal production practices such as planting dates, seeding rates, weed control, insect control, and fertilizer recommendations for each crop followed current CES recommendations. Harvest yield data were collected from the center two rows of each 8-row wide plot at crop maturity, and the remaining standing crops were harvested with a commercial combine and the crop residue deposited back onto the plots. Soil nematode samples were collected at the trial initiation and each subsequent fall after crop harvest and submitted to the University of Arkansas System Division of Agriculture's nematode diagnostic lab at the Southwest Research and Extension Center at Hope, Arkansas, for analysis. Soybean-cyst nematode was the only nematode that was found to be above economic threshold levels during the course of this trial. No root-knot nematodes were found in the trial area.

Results and Discussion

Soybean

April-planted group IV soybean yields averaged 55 to 62 bu./ac depending on rotation over the 8-year period (Table 1). Yield of April-planted group IV soybean was statistically impacted by the previous crop in 4 out of 8 years of the trial. Continuously grown soybean without rotation yielded 55 bu./ac on average, while soybean rotated with corn or full-season grain sorghum the previous year yielded 60 and 62 bu./ac, respectively (Table 1). Similar trends were noted with June-planted double-crop soybean yields when following wheat. When double-crop soybean followed a previous crop of wheat/double-crop soybean, yields on average were only 42 bu./ac, while yields increased to 46 bu./ac when corn or full-season grain sorghum had been grown the previous year. However, double-crop soybean yields were only statistically influenced by the previous crop in 2 out of 8 years (Table 2). Early-planted group IV soybean averaged 59.3 bu./ac averaged across rotations, and double-crop soybeans averaged 44.7 bu./ac averaged across rotations. The 14.6 bu./ac difference between April soybean and June-planted double-crop soybean is similar to what many Arkansas soybean producers see on their farms between the early-planted production system and double-crop system.

Differences in early-planted and double-crop soybean yields between crop rotations can likely be partially attributed to lower Soybean-Cyst Nematode (SCN) numbers following corn or grain sorghum. The SCN egg numbers from soil samples collected in October of 2021, after soybean harvest, were highest in the double-crop soybean plots. Plots where double-crop soybean was grown previously each year had the highest level of SCN eggs with 1060/100 cc of soil, while plots that had been planted to corn or grain sorghum the previous year had SCN egg levels of 648 and 536/100 cc of soil, respectively. April-planted soybean plots showed variable SCN levels and averaged 518 SCN eggs/100cc of soil and no consistent SCN egg number differences between rotations. In comparison, analysis showed plots that had been continuously planted to corn since 2013 resulted in no SCN eggs detected. The general trend of lower SCN egg numbers in the double-crop soybean plots in 2021 indicates that rotation to a non-host for one year can reduce numbers temporarily but will not eliminate SCN.

Corn

Corn yields over the 8-year period averaged 202–209 bu./ac depending on rotation (Table 3). Yields were statistically influenced by rotation in 2 out of 8 years, with corn following corn yielding 26 bu./ac less than when following April-planted group IV soybean in 2016. Visually it was not apparent why there was a yield difference in 2016 as there were no notable differences in plant stands, foliar disease level, or late season lodging, and all inputs between rotations were constant. Over the 8-year period, corn following April-planted group IV soybean or June-planted double-crop soybean yielded 6 or 7 bu./ac more, respectively, than continuously grown corn. These results are similar to other trials in that corn grown in rotation with soybean often yields more than if grown without rotation (Sindelar et al., 2015). As corn is grown continuously for more years without rotation, yields may decline more, but that trend is not evident after 8 years of this trial.

Wheat

Wheat yields averaged 65 to 74 bu./ac (Table 4), depending on rotation. Wheat yield was influenced by previous crop 5 out of 7 years. Averaged across all years, wheat yield following April-planted soybean was 74 bu./ac, 9 bu./ac greater than wheat following full-season grain sorghum. The reason for lower wheat yields following full-season grain sorghum is not clear; however, fall and early winter growth was visibly reduced in most years. Grain sorghum has been reported to be possibly allelopathic to wheat under some circumstances. Although not definitive, allelopathy is suspected of having reduced wheat growth and yields in this study some years since all other management inputs such as tillage, seeding rate, fertilizer, foliar disease level, and plant stands were constant between treatments. Further investigation would be needed to confirm whether allelopathy was a factor. Wheat yield following corn was, on average, 4 bu./ac less than when following April-planted soybean and 1 bu./ac less than when following double-crop soybean.

Grain Sorghum

Full-season grain sorghum was grown as a rotational crop and was always planted following soybean or double-crop soybean. Yields of full-season grain sorghum averaged 114 bu./ac (Table 5) and did not differ between April-planted group IV soybean or double-crop soybean treatments over the 8-year period. State average grain sorghum yields generally range from 80–95 bu./ac (Table 5). June-planted double-crop grain sorghum planted following wheat averaged 86 bu./ac, a relatively low yield despite irrigation.

Practical Applications

Results from this ongoing trial provide Arkansas producers with local non-biased information on how long-term crop rotation can impact yields of corn, early-planted soybean, double-crop soybean, grain sorghum, double-crop grain sorghum, and wheat on their farms, which ultimately impacts the profitability of their farms. Over the duration of the trial, April-planted soybean averaged nearly 15 bu./ac higher yields compared to June-planted double-crop soybean, while April-planted grain sorghum yields were 28 bu./ac higher than June-planted double-crop grain sorghum, demonstrating the importance of early planting for maximum yields.

Acknowledgments

The authors appreciate the support provided by Arkansas corn producers through check-off funds administered by the Arkansas Corn and Grain Sorghum Promotion Board. Additional check-off fund support was provided by the Arkansas Soybean Promotion Board and the Arkansas Wheat Research Promotion Board. Support was also provided by the University of Arkansas System Division of Agriculture. A special thanks to the staff at the Lon Mann Cotton Research Station in Marianna for their invaluable assistance with this project.

Literature Cited

Reddy, K.N., R.M. Zablotowiez, and L.J. Krutz. 2013. Corn and Soybean Rotation under Reduced Tillage Management: Impacts on Soil Properties, Yield, and Net Return. Amer. J. Plant Sci. 2013, 4:10-17. Accessed 1 April 2021. Available at: https://www.scirp.org/html/2-2600731_32242.htm

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

Howard, D.D., A.Y. Chambers, and G.M. Lessman. 1998. Rotation and Fertilization Effects on Corn and Soybean Yields and Soybean Cyst Nematode Populations in a No-Tillage System. Agron. J. - AGRON J. 90. https://dx.doi.org/10.2134/agronj1998.00021962009000040013x

Table 1. The effect of the previous crop on the yield of April-planted irrigated group IV soybean yield grown at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas, 2014–2021.

	April-Planted Soybean Grain Yield								
Previous Crop	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**Avg.**
	(bu./ac)								
April-Planted Soybean	43	49	47	65	56	62	62	56	55
Corn	64	49	52	71	67	58	62	60	60
Full-Season Grain Sorghum	64	51	56	74	64	62	61	62	62
Wheat/Double-Crop Sorghum	--	50	54	71	65	58	66	58	60
$LSD_{0.05}$	13	NSD[a]	NSD	6	6	NSD	NSD	4	--

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

Table 2. The effect of the previous crop on the yield of June-planted irrigated double-crop soybean grown following wheat at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas, 2014–2021.

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

[a] Wheat was not planted during the fall of 2015, but soybean was planted in June 2016 during the normal time for double-crop planting.

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

Table 3. The effect of the previous crop on the yield of irrigated corn grown at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas, 2014–2021.

	Corn Grain Yield								
Previous Crop	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**Avg.**
	(bu./ac)								
April-Planted Soybean	250	221	207	205	196	181	194	216	209
Wheat/Double-Crop Soybean	250	214	198	207	199	186	196	216	208
Corn	245	224	181	201	191	173	196	205	202
$LSD_{0.05}$	NSD[a]	NSD	20	NSD	NSD	NSD	NSD	9	--

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

Table 4. The effect of the previous crop on the yield of winter wheat grown at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas, 2014–2021.

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

[a] NSD = no significant difference at $\alpha = 0.05$.

Table 5. The yield of irrigated full-season grain sorghum and double-crop grain sorghum grown at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, Marianna, Arkansas, 2014–2021.

	Grain Sorghum Grain Yield								
Crop	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**Avg.**
	(bu./ac)								
Full-Season Grain Sorghum	143	123	113	99	98	106	118	111	114
Double-Crop Sorghum	--	88	92	86	87	81	88	85	86

Extraction of High-Value Lipids and Phenolic Compounds from Sorghum Bran via a Sequential Supercritical Carbon Dioxide Approach

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

Abstract

This study offers a green approach to the valorization of sorghum bran, a byproduct of grain sorghum processing. Wax-rich lipids and phenolic compound fractions were generated from sorghum bran using a food-grade method based on a sequential pure supercritical carbon dioxide (SC-CO_2) and ethanol/water-modified SC-CO_2 extraction. The extraction conditions, namely, temperature (104 and 140 °F), pressure (4351 and 5802 psi), and cosolvent type (ethanol and ethanol-water mixture), were optimized for the highest lipids and phenolic extraction yields. In the first part of the extraction, pure SC-CO_2 at 5802 psi and 140 °F resulted in the highest lipid yield (5.7%, w/w), which contained about 5% (w/w) high-melting point waxes. In the second part of the extraction, using an ethanol-water mixture resulted in significantly higher phenolic recovery compared to using pure ethanol as a cosolvent. Therefore, the highest phenolics recovery (139 lb gallic acid equivalents (GAE)/10^5 lb bran) was achieved using ethanol-water-modified SC-CO_2 at 5802 psi and 104 °F. The phenolic extracts were mainly composed of phenolic acids (i.e., ferulic, caffeic, and coumaric) and flavonoids (i.e., apigeninidin and luteolinidin). Overall, this study provides a novel single-step extraction approach based on SC-CO_2 to extract and fractionate lipids and phenolic compounds from sorghum bran. The resulting phenolic-rich extract can be utilized in various food applications such as natural food colorants and health-promoting functional foods.

Introduction

Grain sorghum is mainly used for ethanol production and livestock feed in the U.S. while having limited use in the food industry (less than 5%). However, there is an increasing demand for food applications of grain sorghum due to its exceptional health benefits, including anticancer, antioxidant, anti-inflammatory, and anti-diabetes activities. Grain sorghum roughly consists of 75% starch, 12% protein, 3.6% oil, 2.7% fiber, and 0.3% wax (Hwang et al., 2002; Sanjari et al., 2021). Besides macronutrients, sorghum has been reported to contain various dietary polyphenols such as phenolic acids, stilbenes, and flavonoids (Aruna and Visarada, 2018). Such phytochemicals are reported to provide various health and pharmaceutical benefits (Awika and Rooney, 2004).

Grain sorghum is covered with a pericarp-testa layer called bran (approximately 7% of the whole grain), which contains non-starch polysaccharides, phenolic compounds, and the coating wax that could potentially be a source of natural wax (Hwang et al., 2002; Sruthi et al., 2021).

Particularly, sorghum with a black pericarp is famous for containing the highest amount of 3-deoxyanthocyanidins, which are more resistant to oxidation relative to other anthocyanidins, and are rare compounds in nature (Awika et al., 2005). Moreover, the oxidative resistance of 3-deoxyanthocyanidins makes them potential natural food colorants (Dykes et al., 2009). Therefore, there is a great potential to recover high-value compounds, i.e., phytochemicals and waxes, from grain sorghum bran to increase their utilization in various applications, including food and pharmaceutical applications. Wax-rich oils and phytochemicals have been traditionally extracted from grain sorghum using organic solvents like hexane, acetone, or methanol (Awika et al., 2005; Hwang et al., 2004). However, the toxicity of these solvents impedes their food applications. Therefore, there is a critical need for a food-grade extraction method to separate the waxes and phytochemicals from the sorghum bran.

Carbon dioxide is a green solvent that can be used in its supercritical state to extract nonpolar components from various materials. Unlike traditional extraction methods using toxic organic solvents such as hexane, chloroform, or petroleum ether, supercritical carbon dioxide (SC-CO_2) is an environmentally friendly, non-toxic, recyclable, readily available, and highly diffusive solvent that has been employed in extracting oils and waxes from grains, seeds, and plants (Athukorala and Mazza, 2011; Attard et al., 2016). In addition, solvating power of SC-CO_2 can be modified by introducing Generally Recognized as Safe (GRAS) cosolvents to extract phenolic compounds (Ubeyitogullari and Rizvi, 2020).

The goal of this study was to develop a sequential pure SC-CO_2 and ethanol/water-modified SC-CO_2 extraction to separate the wax-rich lipids in the first fraction and then collect the phytochemicals in the second fraction. This enables the extraction of wax-rich lipids and phytochemicals from sorghum bran using an innovative, green approach that can increase the utilization of sorghum bran in the food industry and add value to grain sorghum.

[1] Graduate Assistant and Assistant Professor, respectively, Department of Food Science, Fayetteville.
[2] Assistant Professor, Department of Biological and Agricultural Engineering, Fayetteville.

Procedures

$SC\text{-}CO_2$ Extraction

Milled black sorghum bran was kindly provided by Nu Life Market (Kansas, USA) in a particle size that passed through a 60-mesh sieve (250 µm), and it was used as-is for the extractions. The $SC\text{-}CO_2$ extractions were performed using a lab-scale $SC\text{-}CO_2$ extractor (SFT-120, Supercritical Fluid Technologies, Inc., Del., USA) equipped with a cosolvent pump. The vessel was heated to the set temperature (104–140 °F) and pressurized to the set pressure (4351–5802 psi). After a static extraction time of 20 min, the flow rate of CO_2 was adjusted to 0.07 ft^3/min (measured at ambient conditions). First, the nonpolar fraction, i.e., wax-rich lipid fraction, was extracted using pure $SC\text{-}CO_2$ for 3 hours. Next, phenolic compounds were extracted by introducing cosolvents, i.e., pure ethanol (100%) or ethanol-water (50%, v/v) mixture, into the vessel. Finally, the samples were flushed with nitrogen and stored in a freezer at -4 °F until further analysis.

Soxhlet Extraction of Sorghum Bran

Total lipids in milled black sorghum bran were extracted by a Soxhlet apparatus. Black sorghum bran (0.18 oz.) was wrapped in a filter paper, which was placed in a cellulose extraction thimble and fit in a Soxhlet apparatus. The solvent was refluxed for 6 h to recover all the lipids in the sample. Total wax was fractionated from the lipid extract based on the method of Hums and Moreau (2019).

Solvent Extraction of Phenolic Compounds

Total phenolic extraction was carried out by soaking 0.04 oz. of milled black sorghum bran into 45 mL of 80% methanol (v/v) for 1 h at 122 °F. The suspension was centrifuged at 3220 g and 39 °F for 10 min. The supernatant was collected, and the residue was resuspended in 80% methanol for a second extraction period. The supernatants were pooled. The extracts were analyzed for their total phenolic (TPC) and total flavonoid contents (TFC).

Characterization of the Extracts

The TPC determination was performed using the Folin-Ciocalteu method, where the absorbance was measured by a spectrophotometer at 760 nm. The results were presented as lb gallic acid equivalents (GAE) per 10^5 lb dry sample. The TFC was measured by the aluminum chloride colorimetric method according to Marinova (2005), and the absorbance was measured at 510 nm. The results were given as lb catechin equivalent (CAE) per 10^5 lb dry sample.

The HPLC analysis to identify the phenolic compounds was performed following the method of Xiong et al. (2020). A UFLC Shimadzu (SPD-20AV UV/Vis detector, Shimadzu, Japan) was used in the analysis via a C18 column (5 µm, 4.6 × 250 mm; Waters, Mass., USA).

Statistical Analysis

Statistical analysis was performed using JMP Pro v. 16.0.0 (SAS Institute, Inc, Cary, N.C., USA). Multiple comparisons of the means were conducted by Tukey's honestly significant difference test at $\alpha = 0.05$ level.

Results and Discussion

Wax-Rich Lipid Extraction Using Pure $SC\text{-}CO_2$

A sequential pure $SC\text{-}CO_2$ followed by ethanol/water-modified $SC\text{-}CO_2$ was carried out to extract wax-rich lipids and phytochemicals, respectively, from sorghum bran (Fig. 1). In the first part of the extraction, the effects of pure $SC\text{-}CO_2$ conditions, namely, pressure (1450–5802 psi) and temperature (104–176 °F), on the wax-rich lipid yields were investigated at a constant CO_2 flow rate of 0.07 ft^3/min (measured at ambient conditions). Based on preliminary data, two pressure (4351 and 5802 psi) and temperature (104 and 140 °F) values were chosen to further investigate the effect of pressure and temperature on the extraction yield and composition. Pure $SC\text{-}CO_2$ extraction time of 3 h was decided based on the extraction curves presented in Fig. 2. Approximately 95% of the lipids were collected in the first 2 h of the pure $SC\text{-}CO_2$ extraction at all the $SC\text{-}CO_2$ conditions investigated.

Figure 3 demonstrates the crude lipid and corresponding wax yields extracted using pure $SC\text{-}CO_2$ at various conditions. The total lipid yields varied between 5.1–5.7% (w/w), where the highest crude lipid yield was achieved at 5802 psi and 140 °F at 5.7% (w/w). The conventional hexane extraction provided a significantly higher crude lipid yield (7.0%, w/w) compared to the highest yield (5.7%, w/w) obtained via $SC\text{-}CO_2$ ($P < 0.05$). Nevertheless, hexane extraction time was 6 h, while $SC\text{-}CO_2$ extraction was carried out only for 3 h. Moreover, wax yields (0.2–0.3% w/w in dry bran) did not significantly differ from each other under the applied $SC\text{-}CO_2$ conditions ($P > 0.05$; Fig. 3).

Extraction of Phenolic Compounds Using Ethanol/Water-Modified $SC\text{-}CO_2$

After 3 hours of lipid extraction using pure $SC\text{-}CO_2$, dewaxed sorghum brans were subjected to further extraction by either ethanol (100%) or ethanol-water mixture (50% (v/v) ethanol) at 15% (w/w) cosolvent concentration in the extraction vessel along with $SC\text{-}CO_2$. Figure 4 presents the total phenolics and flavonoids extracted by ethanol- and ethanol-water-modified $SC\text{-}CO_2$ at various temperatures and pressures. Ethanol-water-modified $SC\text{-}CO_2$ surpassed ethanol-modified $SC\text{-}CO_2$ under all conditions in both total phenolic and flavonoid yields (Fig. 4). The highest TPC and TFC yields were achieved at 5802 psi and 104 °F using 15% (w/w) ethanol-water modified $SC\text{-}CO_2$ as 139 ± 3 (lb GAE/10^5 lb bran) and 92 ± 4 (lb CAE/10^5 lb bran), respectively. On the other hand, the lowest TPC and TFC yields obtained using ethanol-water modified $SC\text{-}CO_2$ were 45 ± 4 lb/10^5 lb bran and 27 ± 1 lb/105 lb bran, respectively, at 4351 psi and 140 °F.

Similar phenolic compounds were extracted via ethanol-water-modified $SC\text{-}CO_2$ and methanol. The major phenolic acids identified in the extracts were caffeic, p-coumaric, ferulic, and cinnamic acid. Luteolinidin, apigeninidin, 7-methoxyapigeninidin, luteolin, and apigenin were the predominant flavonoids present in the samples.

Practical Applications

Grain sorghum is a highly drought-resistant cereal and, therefore, can play a critical role in adapting to climate change. The expected outcomes of this research include (i) a sustainable source for high-value wax, (ii) health-promoting phenolic extract for developing functional foods, (iii) natural coloring for the food industry, and (iv) a food-grade method to simultaneously extract and fractionate bioactive compounds while eliminating the use of petroleum-based solvents. Converting sorghum bran to natural health-promoting ingredients will add value to grain sorghum. The developed novel approach can be applied to extract high-value lipids and phytochemicals from other sorghum varieties, including white, red, and brown grain sorghums.

Acknowledgments

This work was supported by Arkansas corn and grain sorghum producers through check-off funds administered by the Arkansas Corn and Grain Sorghum Promotion Board. This project was also supported, at least in part, by the USDA National Institute of Food and Agriculture, Multistate Project NC-1023, Accession number 1025907, and the University of Arkansas System Division of Agriculture.

Literature Cited

Aruna, C. and K.B.R.S. Visarada. 2018. Other industrial uses of sorghum in Breeding sorghum for diverse end uses (eds C. Aruna, K. B. R. S. Visarada, B. Venkatesh Bhat, and Vilas A. Tonapi), Woodhead Publishing, 271-292.

Athukorala, Y. and G. Mazza. 2011. Optimization of extraction of wax from flax straw by supercritical carbon dioxide. Sep. Sci. Technol. 46(2):247–253.

Attard, T.M., C.R. McElroy, R.J. Gammons, J.M. Slattery, N. Supanchaiyamat, C.L.A. Kamei, O. Dolstra, L.M. Trindade, N.C. Bruce, S.J. McQueen-Mason, S. Shimizu, S. and A.J. Hunt. 2016. Supercritical CO_2 extraction as an effective pretreatment step for wax extraction in a miscanthus biorefinery. ACS Sustain. Chem. Eng. 4(11):5979–5988.

Awika, J.M., and L.W. Rooney. 2004. Sorghum phytochemicals and their potential impact on human health. Phytochem. 65(9):1199–1221.

Awika, J.M., L.W. Rooney, and R.D. Waniska. 2005. Anthocyanins from black sorghum and their antioxidant properties. Food Chem. 90(1–2):293–301.

Dykes, L., L.M. Seitz, and W.L. Rooney. 2009. Flavonoid composition of red sorghum genotypes. Food Chem. 116(1): 313–317.

Hums, M.E. and R.A. Moreau. 2019. A Simplified Method for Fractionation and Analysis of Waxes and Oils from Sorghum (*Sorghum bicolor* (L.) Moench) Bran. J. Am. Oil Chem. Soc. 96(12):1357–1366.

Hwang, K.T., S.L. Cuppett, C.L. Weller, and M.A. Hanna. 2002. Properties, composition, and analysis of grain sorghum wax. JAOCS, J. Am.Oil Chem. Soc. 79(6):521–527.

Hwang, K.T., C.L. Weller, S.L. Cuppett, and M.A. Hanna. 2004. Changes in composition and thermal transition temperatures of grain sorghum wax during storage. Ind. Crops Prod. 19(2): 125–132.

Sanjari, S., Z.S. Shobbar, F. Ghanati, S. Afshari-Behbahanizadeh, M. Farajpour, M. Jokar, A. Khazaei, and M. Shahbazi. 2021. Molecular, chemical, and physiological analyses of sorghum leaf wax under post-flowering drought stress. Plant Physiol. Biochem. 159:383–391.

Sruthi, N.U., P.S. Rao, and B.D. Rao. 2021. Decortication induced changes in the physico-chemical, anti-nutrient, and functional properties of sorghum. J. Food Compost. Anal. 102, 104031.

Ubeyitogullari, A. and S.S.H. Rizvi. 2020. Production of high-purity phospholipid concentrate from buttermilk powder using ethanol-modified supercritical carbon dioxide. J. Dairy Sci. 103(10):8796–8807.

Weller, C.L., A. Gennadios, and R.A. Saraiva. 1998. Edible bilayer films from zein and grain sorghum wax or carnauba wax. LWT. 31(3):279–285.

Xiong, Y., P. Zhang, R.D. Warner, S. Shen, S. Johnson, and Z. Fang, 2020. Comprehensive profiling of phenolic compounds by HPLC-DAD-ESI-QTOF-MS/MS to reveal their location and form of presence in different sorghum grain genotypes. Food Res. Int. 137:109671.

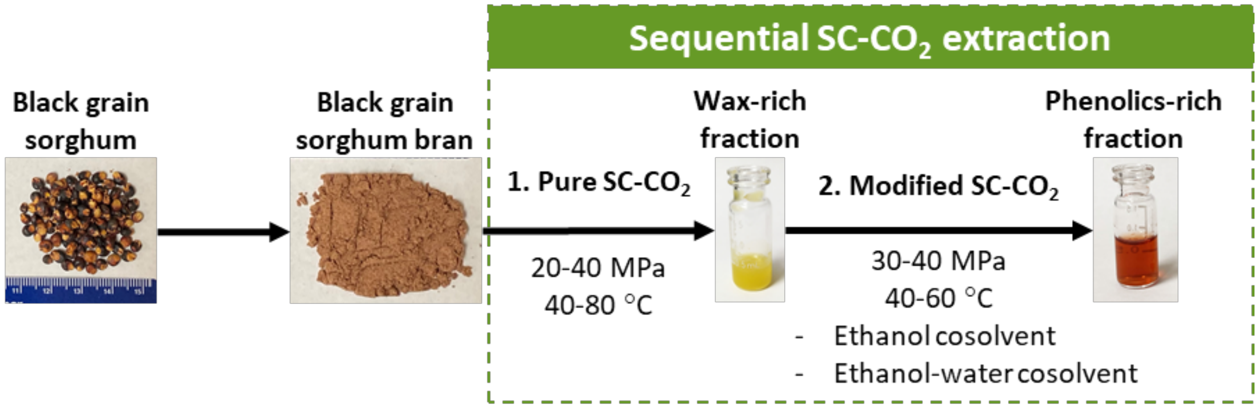

Fig. 1. Flow diagram of the sequential pure SC-CO_2 followed by ethanol/water-modified SC-CO_2 extraction. SC-CO_2 stands for supercritical carbon dioxide.

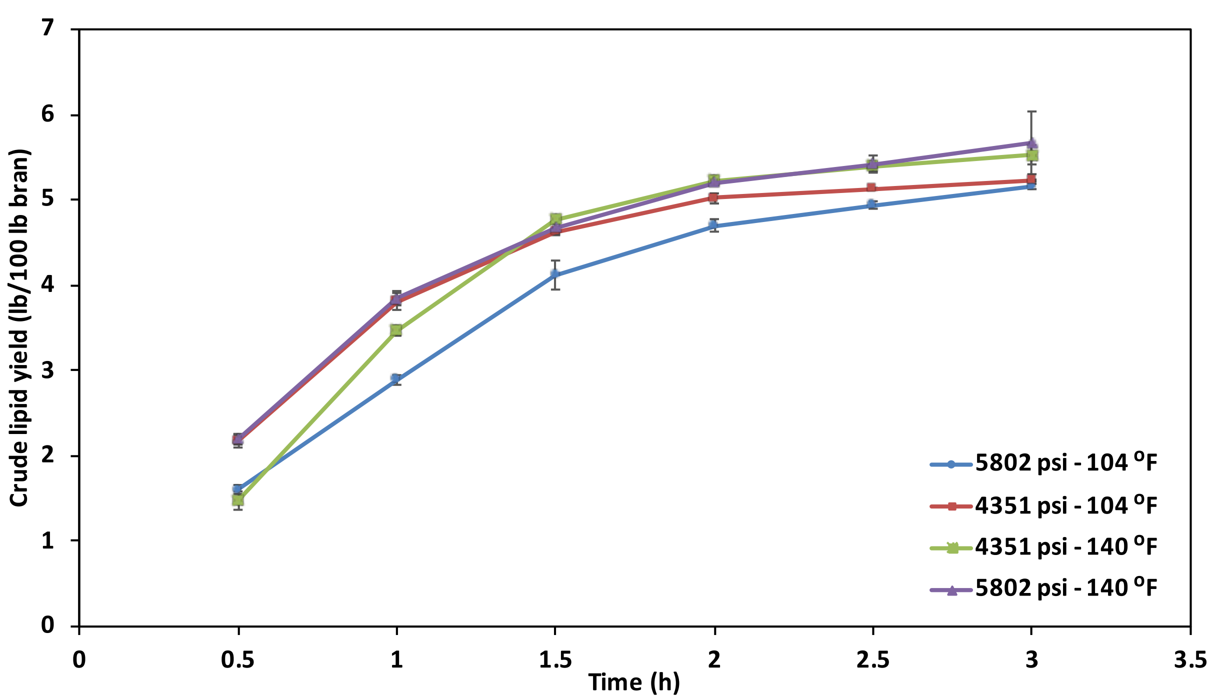

Fig. 2. Crude lipid extraction yield curves at different pressures and temperatures with a CO_2 flow rate of 0.07 ft^3/min (measured at ambient conditions).

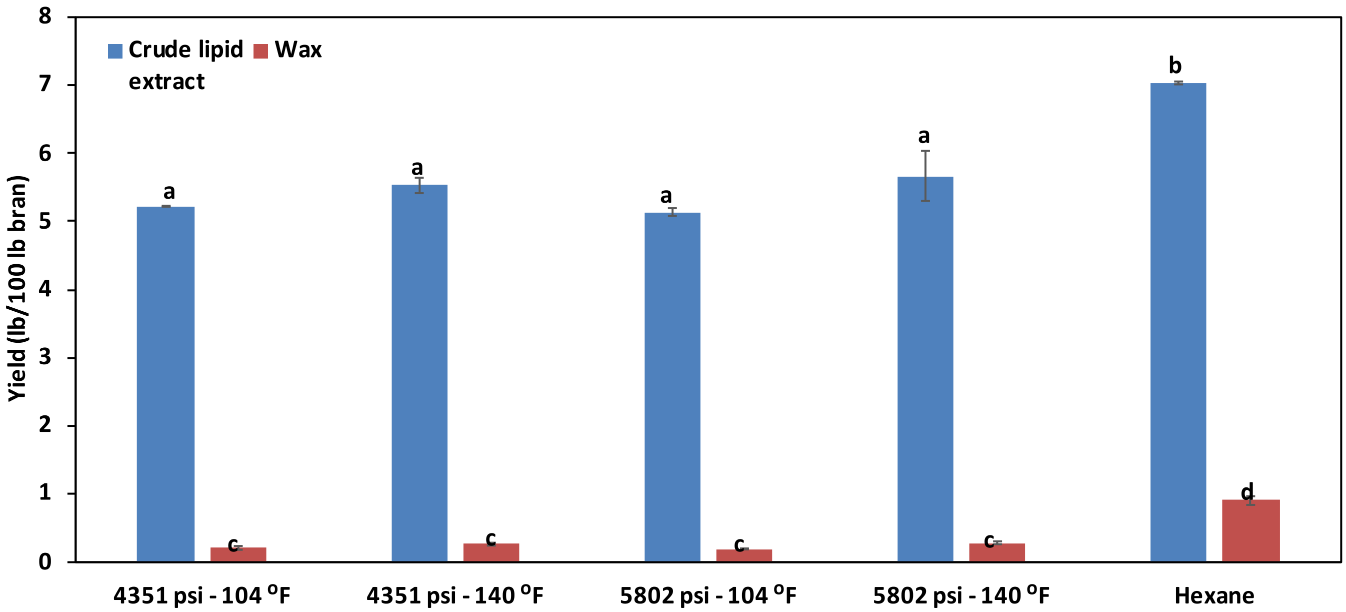

Fig. 3. Crude lipid and wax yields (lb/100 lb bran) obtained with pure SC-CO_2 extraction at different pressures and temperatures after 3 h and Soxhlet extraction using hexane after 6 h. Means with different letters are significantly different (P < 0.05). SC-CO_2 stands for supercritical carbon dioxide.

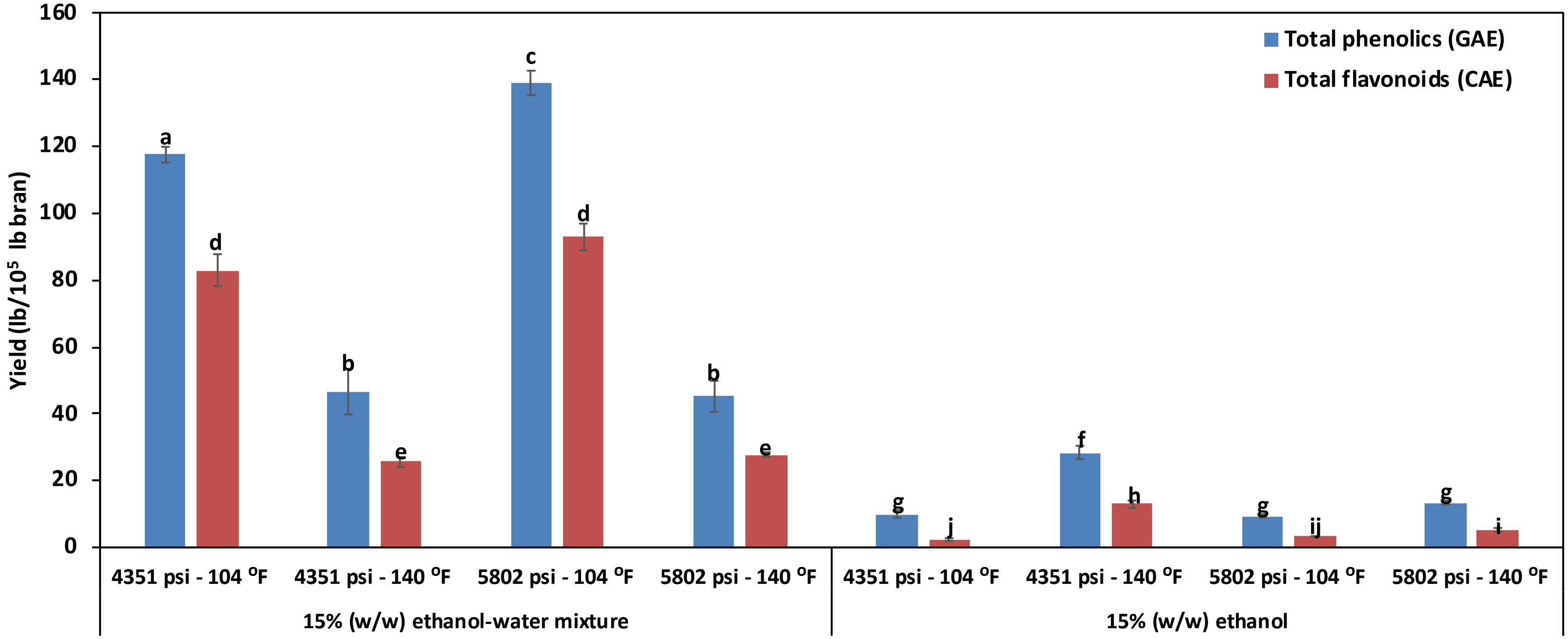

Fig. 4. Total phenolics (GAE: gallic acid equivalent) and flavonoids (CAE: catechin equivalent) contents obtained with ethanol and ethanol-water-modified SC-CO_2 at different pressures and temperatures. Means with different letters are significantly different ($P < 0.05$). SC-CO_2 stands for supercritical carbon dioxide.

Trends Between Runoff and Nitrogen Loss from Corn at the Edge of Field: Results from the Arkansas Discovery Farms Program

M. Daniels,[1] P. Webb,[1] Lee Riley,[1] A. Sharpley,[2] L. Berry,[2] and J. Burke[2]

Abstract

The overall goals of the Arkansas Discovery Farms program are to assess the need for and effectiveness of on-farm conservation practices and document nutrient and sediment loss reductions and water conservation in support of nutrient management planning and sound environmental farm stewardship. The specific objective of this study was to determine the trends, if any, between nitrate and total nitrogen (TN) in terms of both concentration and mass losses with respect to runoff volume from private corn production fields. Runoff volume, TN, and nitrate are monitored utilizing state-of-the-art, automated edge-of-field runoff monitoring on several fields on Discovery row crop farms. Over 200 individual pairs of runoff volume and associated nitrate and TN collected from Discovery Farms in Arkansas, Desha, Jefferson, Phillips, and Counties (16 site years in corn) were used to determine the relationship between individual runoff events and associated nitrogen losses. The trend for both nitrate and TN concentrations was to decrease as runoff volume increased, while the trend for nitrate and TN mass loss (nutrient concentration × runoff volume) was to increase as runoff volume increased. While there were trends, there were not any strong or significant mathematical relationships, i.e., linear or polynomial, that describe these trends, as r^2 values from linear regression ranged from 0.02 and 0.04 for nitrate and TN concentrations, respectively, while they ranged from 0.07 to 0.19 for mass losses per unit area for nitrate and TN concentrations, respectively. Nitrogen loss in runoff cannot be predicted based on the runoff volume alone as nitrogen loss is governed by a complex function of the interaction between available sources and hydrology that is influenced by many different parameters such as rainfall intensity and duration, antecedent soil moisture, inherent soil and hydrological properties, and ground cover.

Introduction

Row crop producers in the Lower Mississippi River Basin (LMRB) are under increased scrutiny to demonstrate that current production systems are environmentally viable with respect to water quality and sustainability (Daniels et al., 2018). These concerns are manifested from regional issues such as hypoxia in the Gulf of Mexico (US EPA, 2018a) and critical groundwater decline in the Lower Mississippi Alluvial Valley aquifer (LMAV, Reba et al., 2017; Czarnecki et al., 2018). Nutrient enrichment remains a major impairment of water quality for the designated uses of fresh and coastal waters of the U.S. (Schindler et al., 2008). Nutrient runoff from cropland is receiving greater attention as a major source of nutrients from non-point sources (Dubrovsky et al., 2010). This is especially true in the Mississippi River Basin (MRB) as recent model estimates suggest that up to 85% of the phosphorus (P) and nitrogen (N) entering the Gulf of Mexico originates from agriculture (Alexander et al., 2008). These estimates are based on large-scale modeling within the MRB, with limited localized calibration or verification of the field losses of P and N. Furthermore, there have been few farm-scale studies of P and N loss, particularly in the LMAV region of agriculture-dominant Arkansas and Mississippi (Dale et al., 2010; Kröger et al., 2012).

This scrutiny has prompted much activity aimed at reducing nutrients lost to the Gulf within the Mississippi River Basin, including the formation of the Mississippi River/Gulf of Mexico Hypoxia Task Force, a consortium of Federal agencies and States (US EPA, 2018a). This consortium developed an action plan to reduce nutrients entering the Gulf, which includes nutrient reduction strategies prepared by each member State (US EPA, 2018b).

Arkansas Discovery Farms are privately owned farms that have volunteered to help with on-farm research, verification, and demonstration of farming's impact on the environment and natural resource sustainability (Sharpley et al., 2015; 2016). The overall goal of the program is to assess the need for and effectiveness of on-farm conservation practices and document nutrient and sediment loss reductions and water conservation in support of nutrient management planning and sound environmental farm stewardship. Edge-of-field monitoring (EOFM) of runoff from individual agricultural fields is critical to improving our understanding of the fate and transport of nutrients applied as animal manures and fertilizer to agricultural lands along the complex watershed continuum (Reba et al., 2013; Harmel et al., 2016; Sharpley et al., 2016).

Additionally, EOFM helps producers more clearly see how their management systems affect in-stream water quality and

[1] Professor, Program Associate, and Program Associate, Department of Crop, Soil, and Environmental Sciences, Little Rock.
[2] Professor, Program Technician, and Program Associate, Department of Crop, Soil, and Environmental Sciences, Fayetteville.

watershed functions (Sharpley et al., 2015). Reporting nutrients in runoff in terms of concentration may have advantages as compared to mass losses, such as being able to compare the concentration of nutrients in receiving streams that have not been gauged for flow volume. Reporting nutrients in mass loss has the advantage of better understanding hydrology and its effect on nutrient losses. The specific objective of this study was to determine the trends, if any, between nitrate and total nitrogen (TN) in terms of both concentration and mass losses with respect to runoff volume from private corn production fields.

Procedures

Edge-of-field runoff monitoring stations were established on several row crops farms across Eastern Arkansas to observe runoff and nutrient losses for corn, cotton, rice, and soybean, including four fields on the Stevens Farm in Desha County, Arkansas from 2013 to 2017. At the lower end of each field, automated runoff water quality monitoring stations were established to 1) measure runoff flow volume, 2) collect water quality samples of runoff for water quality analysis, and 3) measure precipitation. In order to determine runoff volume, either a 60-degree, V-shaped, 8-in. trapezoidal flume was installed at the outlet of each field, or existing open-channel pipes were instrumented (Tracomm, 2018). The ISCO 6712, an automated portable water sampler (Teledyne-ISCO, 2018), was used to interface and integrate all the components of the flow station using an ISCO 720 pressure transducer and flow module for flumes and ISCO 750 area velocity for pipes. All samples were analyzed at the Arkansas Water Resources Laboratory (Arkansas Water Resources Center, 2018), an EPA-certified laboratory, for total nitrogen (TN), nitrate + nitrite-N (NO_{3-}), total phosphorus (TP), and soluble reactive phosphorus (SRP).

The relationships between runoff and associated nitrogen concentration and mass loss were determined using simple regression models, such as linear, polynomial, and logarithm to determine significance at the 0.05 level. These various models were used too determine trends and relationships for over 200 paired observations.

Results and Discussion

Regression analysis revealed a decreasing trend but not a significant relationship between nitrate and TN concentration with respect to runoff volume (Fig. 1). The analysis could not provide a reasonable fit ($r^2 = 0.02$ for nitrate and 0.04 for TN) for a mathematical model to describe the relationship, which indicated that runoff volume alone could not account for the complexity in the fate of nitrogen loss in runoff. Larger concentrations of TN and nitrate were associated with runoff volumes of 1 inch or less, which may indicate very little dilution of the source. For larger runoff values (>2 inches), concentrations of TN and nitrate were less than 2 mg/L and 1 mg/L, respectively.

Regression analysis revealed an increasing trend but not a significant relationship between nitrate and TN mass loading with respect to runoff volume (Fig. 2). The analysis could not provide a reasonable fit ($r^2 = 0.07$ for nitrate and 0.19 for TN) for a mathematical model to describe the relationship, which indicated that runoff volume alone could not account for the complexity in the fate of nitrogen loss in runoff. The trend determined from regression indicates that mass losses increase as runoff increases.

Practical Applications

Predicting nitrogen loss in runoff based on measured runoff volume is difficult as nitrogen losses in runoff are governed by some dynamic function of source and transport, both of which are influenced by different and often unrelated variables. Data can be reported as concentration in the runoff water or as mass if the runoff volume is known. Concentration data more readily compare nutrient levels in streams or lakes. The volume of a stream or lake is not known, while mass may be a better indicator of reduction resulting from implementing or changing a management practice. As the runoff volume increased, a decreasing trend in concentration levels was observed across all years and sites, incorporating a large degree of variability among factors that affect the fate of N loss in water. As the runoff volume increased, an increasing trend in mass losses was observed across all years and sites. This increasing trend indicates that management practices should not focus on reducing N inputs alone but also focus on practices such as improving soil health to decrease runoff volume.

Acknowledgments

The authors wish to acknowledge funding sources for the Arkansas Discovery Farm program, including the University of Arkansas System Division of Agriculture, soybean check-off funds administered by the Arkansas Soybean Research and Promotion Board, the USDA-Natural Resources Conservation Service, the Arkansas Corn and Grain Sorghum Promotion Board, the Arkansas Department of Agriculture–Natural Resources Division, and the Environmental Protection Agency. We also acknowledge our partner, the Arkansas Association of Conservation Districts, and the many volunteers who serve on our Stakeholder and Technical Advisory Committees. Most of all, we wish to acknowledge our cooperators, the Arkansas Discovery Farmers.

Literature Cited

Alexander, R.B., R.A. Smith, G.E. Schwarz, E.W. Boyer, J.V. Nolan, and J.W. Brakebill. 2008. Differences in phosphorus and nitrogen delivery to the Gulf of Mexico from the Mississippi River Basin. Environ. Sci. Technol. 42:822-830.

Arkansas Water Resources Center. 2018. Arkansas Water Resources Water Quality Lab Statement of Qualifications. University of Arkansas System Division of Agriculture. Accessed 12 June 2019. https://awrc.uada.edu/water-quality-lab/certification-and-quality-assurance/

Czarnecki, J.B., P.D. Hays, and P.W. McKee. 2018. USGS Fact Sheet. Accessed 12 June 2019. https://www.forrestcitywater.com/FCWUWebsite/information_links/2002.MississippiRiverValley.pdf

Dale, V.H., C.L. Kling, J.L. Meyer, J. Sanders, H. Stallworth, T. Armitage, T. Wangsness, T.S. Bianchi, A. Blumberg, W. Boynton, D.J. Conley, W. Crumpton, M.B. David, D. Gilbert, R.W. Howarth, R. Lowrance, K.R. Mankin, J. Opaluch, H.W. Paerl, K. Reckhow, A.N. Sharpley, T.W. Simpson, C. Snyder, and D. Wright. 2010. Hypoxia in the Northern Gulf of Mexico. Springer Series on Environmental Management. New York, NY: Springer Science.

Daniels, M.B., A. Sharpley, R.D. Harmel, and K. Anderson. 2018. The utilization of edge-of-field monitoring of agricultural runoff in addressing nonpoint source pollution. J. Soil Water Conserv. 73(1):1-8. Accessed 12 June 2019. http://www.jswconline.org/content/73/1/1.full.pdf+html?sid=207728cc-46be-4bfe-94ca-43a1b74a4d97

Dubrovsky N.M., K.R. Burow, G.M. Clark, J.M. Gronberg, P.A. Hamilton, K.J. Hitt, D.K. Mueller, M.D. Munn, B.T. Nolan, L.J. Puckett, M.G. Rupert, T.M. Short, N.E. Spahr, L.A. Sprague, and W.G. Wilber. 2010. The quality of our Nation's waters—Nutrients in the Nation's streams and groundwater, 1992– 2004: U.S. Geological Survey Circular 1350. 174 pp.

Harmel, R.D., L.E. Christianson, D.R. Smith, M.W. McBroom, and K.D. Higgs. 2016. Expansion of the MANAGE database with forest and drainage studies. J. Am. Water Resour. Assoc. 52(5):1275-1279.

Kröger, R., M. Perez, S. Walker, and A.N. Sharpley. 2012. Review of best management practice reduction efficiencies in the Lower Mississippi Alluvial Valley. J. Soil Water Conserv. 67(6):556-563.

Reba, M.L., J.H. Massey, M.A. Adviento-Borbe, D. Leslie, M.A. Yaeger, M. Anders, and J. Farris. 2017. Aquifer depletion in the Lower Mississippi River Basin: Challenges and solutions. Universities Council on Water Resources Journal of Contemporary Water Research & Education Issue 162:128-139.

Reba, M.L., M. Daniels, Y. Chen, A.N. Sharpley, J. Bouldin, T.G. Teague, P. Daniel, and C.G. Henry. 2013. A statewide network for monitoring agricultural water quality and water quantity in Arkansas. J. Soil Water Conserv. 68(2):45A-49A. https://dx.doi.org/10.2489/jswc.68.2.45A

Sharpley, A.N., M.B. Daniels, L. Berry, and C. Hallmark. 2015. Discovery Farms: Documenting water quality benefits of on-farm conservation management and empowering farmers. Acta Agriculturae Scandinavica, Section B–Soil Plant Science 65(Suppl. 2):186-198.

Sharpley, A.N., M. Daniels, L. Berry, C. Hallmark, and L. Riley. 2016. Proactive stakeholder program determines on-farm effectiveness of conservation practices that increases fertilizer-use efficiency. Better Crops 100(3):13-15.

Schindler, D.W., R.E. Hecky, D.L. Findlay, M.P. Stainton, B.R. Parker, M.J. Paterson, K.G. Beaty, M. Lyng, and S.E.M. Kasian. 2008. Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment. Proc. Nat. Acad. of Sci. 106:11254-11258.

Teledyne-Isco. 2018. The Full Size Portable Auto-Sampler. Accessed 30 July 2019. http://www.teledyneisco.com/en-us/waterandwastewater/Pages/6712-Sampler.aspx

TRACOM. 2018. Trapezoidal Flumes. Accessed 30 July 2019. https://tracomfrp.com/trapezoidal-flumes/

US EPA. 2018a. United States Environmental Protection Agency. The Hypoxia Task Force Fact Sheet. Accessed 30 July 2019. https://www.epa.gov/sites/production/files/2016-10/documents/hypoxia_task_force_factsheet.pdf

US EPA. 2018b. United States Environmental Protection Agency. Looking forward: The strategy of the Federal Members of the Hypoxia Task Force. 33 pp. Accessed 30 July 2019. https://www.epa.gov/sites/production/files/2016-12/documents/federal_strategy_updates_12.2.16.pdf

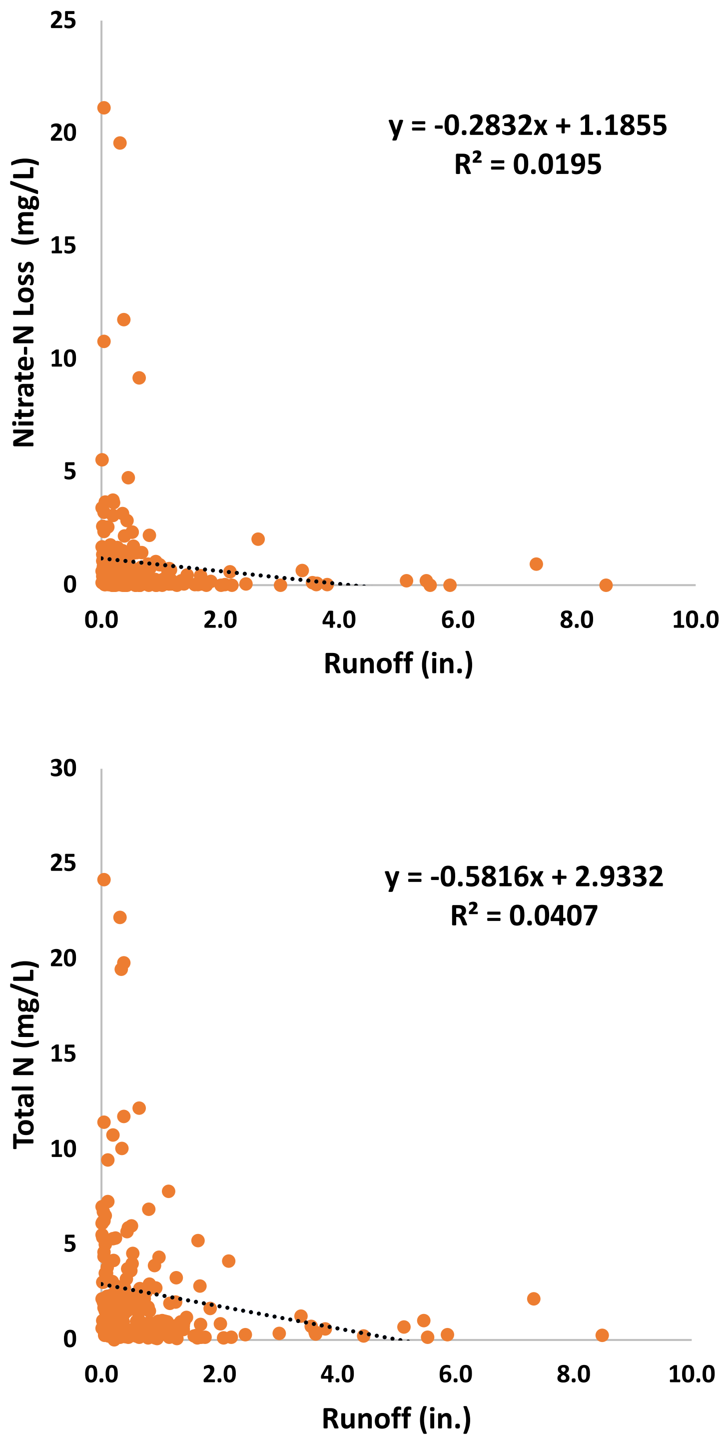

Fig. 1. Nitrate-N (Top) and Total N (Bottom) concentration in runoff water with respect to the associated runoff volume.

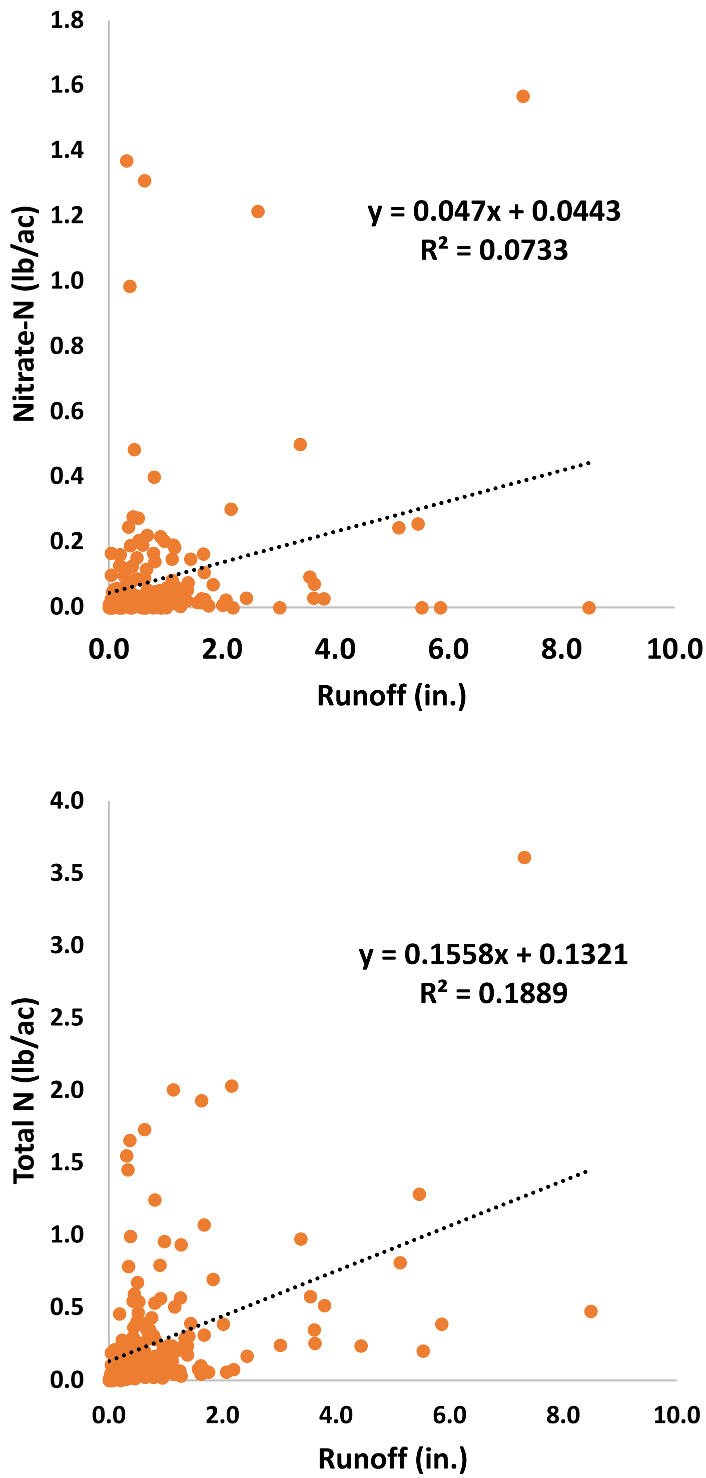

Fig. 2. Nitrate-N and Total N mass losses with respect to associated runoff volumes.

Corn and Grain Sorghum Enterprise Budgets and Production Economic Analysis

B.J. Watkins[1]

Abstract

Crop enterprise budgets are developed that are flexible for representing alternative production practices of Arkansas producers. Interactive budget programs apply methods that are consistent over all field crops. Production practices for base budgets represent the University of Arkansas System Division of Agriculture's Cooperative Extension recommendations from Crop Specialists and from the Corn and Grain Sorghum Research Verification Programs. Unique budgets can be customized by users based on either Extension recommendations or information from producers for their production practices. The budget program is utilized to conduct an economic analysis of field data from various corn and grain sorghum research plots as well as the research verification trials. The crop enterprise budgets are designed to evaluate the solvency of various field activities associated with crop production. Costs and returns analysis with budgets are extended by production economics analysis to investigate factors impacting farm profitability.

Introduction

Volatile input prices and supply availability of key herbicides and fertilizers present challenges for producers in maintaining not only profitability but solvency as well. Global trade issues, as well as historical flooding from hurricanes in the Gulf, have created an unprecedented profitability scenario. Producers need the means to calculate costs and returns of production alternatives to estimate potential profitability in changes producers seek to adapt for their unique operation. The objective of this research is to develop an interactive computational program that will enable stakeholders of the Arkansas rice industry to evaluate production methods for comparative costs and returns.

Procedures

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

Ownership costs and repair expenses for machinery are estimated by applying engineering formulas to representative prices of new equipment (Givan, 1991; Lazarus and Selly, 2002). Repair expenses in crop enterprise budgets should be regarded as value estimates of full-service repairs. Repairs and maintenance performed by hired farm labor will be partially realized as wages paid to employees. Machinery performance rates of field activities utilized for machinery costs are used to estimate the time requirements of an activity which is applied to an hourly wage rate for determining labor costs (USDA-NASS, 2021). Labor costs in crop enterprise budgets represent time devoted, and recently, labor costs associated with irrigation have been added to the rice budgets.

Ownership costs of machinery are determined by the capital recovery method, which determines the amount of money that should be set aside each year to replace the value of equipment used in production (Kay and Edwards, 1999). This measure differs from typical depreciation methods, as well as actual cash expenses for machinery. Amortization factors applied for capital recovery estimation coincide with prevailing long-term interest rates (Edwards, 2005). Interest rates in this report are from Arkansas lenders as reported from September to October 2021. Representative prices for machinery and equipment are based on contacts with Arkansas dealers, industry list prices, and reference sources (Deere & Company, 2021; MSU, 2021). Revenue in crop enterprise budgets is the product of expected yields from following Extension practices under optimal growing conditions and commodity prices received data.

Results and Discussion

The University of Arkansas System Division of Agriculture develops annual crop enterprise budgets to assist Arkansas producers and other agricultural stakeholders in evaluating expected costs and returns for the upcoming field crop production year. Production methods analyzed represent typical field activities as determined by consultations with farmers, County Extension Agents, and information from Crop Research Verifi-

[1] Instructor, Department of Agricultural Economics and Agribusiness, Jonesboro.

cation Program Coordinators in the Department of Crop, Soil, and Environmental Sciences. Actual production practices vary greatly among individual farms due to management preferences. Analyses are for generalized circumstances with a focus on the consistent and coordinated application of budget methods for all field crops. This approach results in meaningful costs and returns comparisons for decision-making related to acreage allocations among field crops. Results should be regarded only as a guide and basis, as individual farmers should develop budgets for their production practices, soil types, and other unique circumstances within the budget tool to more accurately represent each unique operation.

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

Practical Applications

The benefits provided by the economic analysis of alternative corn and grain sorghum production methods provide a significant reduction in financial risk faced by producers. Arkansas producers have the capability with the budget program to develop economic analyses of their individual production activities. Unique crop enterprise budgets developed for individual farms are useful for determining credit requirements and for planning production methods with the greatest potential for financial success. Flexible budgets enable farm financial outlooks to be revised during the production season as inputs, input prices, yields, and commodity prices change. For the 2022 crop budgets, a spring update of fuel and fertilizer prices was made. The update also included updates to commodity prices with an increase in expected net revenue. Incorporating changing information and circumstances into budget analysis assists producers and lenders in making decisions that manage financial risks inherent in agricultural production.

Acknowledgments

This research is made possible by funding from the University of Arkansas System Division of Agriculture, the Arkansas Rice Research and Promotion Board, the Arkansas Corn and Grain Sorghum Promotion Board, the Arkansas Soybean Promotion Board, and the Natural Resources Conservation Service.

Literature Cited

Deere & Company. Products, Agriculture. Moline, Ill. Accessed September 2021. Available at: http://www.deere.com/en_US/industry/agriculture/agriculture.page?

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

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

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

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

Mississippi State University. Planning Budgets. Department of Agricultural Economics, Mississippi State University, Starkville, Miss. Accessed October 2021. Available at: http://www.agecon.msstate.edu/whatwedo/budgets.php

USDA-NASS. United States Department of Agriculture, National Agricultural Statistics Service. Farm Labor. Washington, D.C. October 2021.

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

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

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

[b] Estimate based on machinery and equipment.

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

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

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

[b] Estimate based on machinery and equipment.

APPENDIX: CORN AND GRAIN SORGHUM RESEARCH PROPOSALS

2021–2022 Corn and Grain Sorghum Research Proposals

Principal Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
A. Poncet	L. Purcell, T. Roberts, and J. Kelley	A web tool to calculate pre-tassel nitrogen fertilizer rate recommendations from aerial images	1 of 3	54,122
T. Roberts	J. Kelley and L. Purcell	Comparing the effects of nitrogen sources and Improving application strategies on corn performance	1 of 3	71,645
T. Spurlock	J. Kelley	Determining the value added of starter fertilizer with in-furrow fungicide on corn	1 of 3	26,000
A. Ubeyitogullari		Developing a green integrated approach to enhance the utilization of grain sorghum in foods	1 of 3	42,205
J. Kelley	T. Faske, T. Spurlock, L. Espinoza, T. Roberts, T. Barber, G. Studebaker, and C. Henry	Arkansas corn and grain sorghum research verification program	Completed 3 of 3 New project period	126,000
V. Ford	B. Watkins	Corn and grain sorghum enterprise budgets and production economic analysis	Ongoing	10,000
J. Kelley	T. Roberts, T. Faske, G. Studebaker, and T. Barber	Developing profitable irrigated rotational cropping systems for Arkansas	3 of 3	25,000
J. Kelley	L. Espinoza and T. Roberts	Overcoming yield limitations in corn	3 of 3	28,000
T. Faske	K. Korth	Assess management options for corn nematodes in Arkansas	3 of 3	50,149
S. Sadaka	G. Atungulu	Utilization of ozone fumigation to reduce aflatoxin and mycotoxins contamination from corn	3 of 3	46,000
N. Bateman	B. Thrash, G. Lorenz, and G. Studebaker	Evaluating the efficacy of *Bt* corn traits by survival of corn earworm and fall armyworm	3 of 3	20,000
G. Lorenz	N. Joshi, N. Bateman, and G. Studebaker	Insect management in on-farm grain storage	3 of 3	20,000
L. Espinoza	A. Poncet and C. Henry	Implementation of remote and proximal sensing driven practices in corn production	Completed 3 of 3 New project period	29,633
J. Kelley	T. Roberts, T. Faske, T. Barber, C. Henry, and G. Studebaker	Development of a corn Degree-Day 50 program	2 of 3	7,500
L. Purcell	T. Roberts	Calibrating mid-season N fertilizer rates based upon leaf N concentration and remote sensing	2 of 3	39,000
C. Henry	R. Mane, T. Spurlock, B. Watkins, J. Kelley, and L. Espinoza	Improving irrigation scheduling and irrigation efficiency for corn production in Arkansas	2 of 3	174,500
T. Barber	J. Norsworthy	Evaluation of herbicides, corn hybrid technologies and cultural methods to improve season-long weed control in corn	2 of 3	72,000

Continued

2021–2022 Corn and Grain Sorghum Research Proposals, continued.

Principal Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
B. Bluhm		Gene editing: A new approach to overcome Mycotoxins and environmental stress in Arkansas corn production (Phase II)	2 of 3	40,000
M. Daniels	A. Sharpley	The Arkansas Discovery Farm Program	3 of 3	5,000
S. Green	J. Massey, A. Hashem, and E. Brown	Timing cover crop termination to optimize corn yields and water-use efficiency	3 of 3	15,592
J. Kelley	N. McKinney and V. Ford	Arkansas Corn and Grain Sorghum Research Studies Series, an annual report and archival system for all Board-funded research	Ongoing	5,011
T. Roberts	T. Spurlock, T. Faske, and A. Rojas	Implementing cover crops into corn rotations and the impact on soil health	2 of 3	57,825
			Total Funding:	**965,182**

DIVISION OF AGRICULTURE

RESEARCH & EXTENSION

University of Arkansas System