Arkansas
Corn and Grain Sorghum Research Studies 2020

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

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Cover: Furrow irrigation of corn using polypiping at Marianna, Arkansas, near the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station.

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CORN AND GRAIN SORGHUM
RESEARCH STUDIES
– 2020 –

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

Arkansas Agricultural Experiment Station
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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; feral hog control; 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/

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2020 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 2020, the Corn and Grain Sorghum Research Verification Program (CGSRVP) was conducted on 9 irrigated cornfields. Counties that were participating included Ashley, Chicot, Drew, Lawrence, Lonoke, Mississippi (2), Poinsett, and White. Average yields were 202.0 bu./ac for irrigated corn. State average irrigated corn yields for 2020 was 184 bu./ac respectively (USDA-NASS, 2020). Economic returns to total costs/acre were $160.55 when no land charges were applied. Seed cost and fertilizer/nutrients accounted for 24% and 30% of total expenses, respectively.

Introduction

The Arkansas Corn and Grain Sorghum Research Verification Program (CGSRVP) represents a public demonstration of research-based Extension recommendations on actual working farms at 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 check-off 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 158 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 find cooperators who want to be part of the program and agree to pay production expenses, provide crop expense information for economic analysis, and implement recommended production practices in a timely manner throughout the growing season. During the winter months, the program coordinator and county extension agent meet with the producer to discuss field expectations, review soil fertility, weed control, irrigation, insect control, hybrid recommendations, and provide details of the program. As the planting season begins, the program coordinator, along with the county agent and cooperator, scout each field weekly and discuss management decisions that are needed that week and the upcoming week. The program coordinator provides the county extension agent and producer with an electronic crop scouting report that outlines recommendations for the week and future expectations.

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

Results and Discussions

Overall corn yields during the 2020 growing season ranged from 165.0 bu./ac in Lawrence County to a high of 241.2 bu./ac in White County (Table 1). The overall average yield of cornfields was 202.0 bu./ac. The state average corn yield for 2020 was 184 bu./ac (USDA-NASS, 2020). All corn fields were planted within the recommended planting date ranges. The average planting date for all fields was 13 April, with an average harvest date of 16 September. Plant populations averaged 33,711 plants/ac, which would be at a recommended level for most fields and hybrids.

Fertilizers were applied to fields closely following current University of Arkansas System Division of Agriculture Cooperative Extension Service (CES) recommendations and based on soil analysis and yield goals (Table 2). Preplant fertilizer applied to cornfields averaged 33-36-83-10-4 lb/ac of nitrogen-

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phosphorus-potassium-sulfur-zinc, where nitrogen applied preplant or at planting totaled approximately 15% of the total nitrogen applied during the season. Side-dressed nitrogen applied at the V4–V8 growth stage averaged 138 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 and R1 growth stage and is a common and recommended nitrogen management practice in Arkansas. Total nitrogen applied to cornfields was 225 lb nitrogen/ac when averaged across all fields. Applied nitrogen fertilizer resulted in an average yield of 202 bu./ac, which led to 1 bushel of corn grain for every 1.1 lb of nitrogen fertilizer applied.

Pest management practices followed current CES recommendations. None of the cornfields met thresholds requiring an insecticide application during the season, and only 2 fields were sprayed with a foliar fungicide at the R2 stage for southern rust control. Herbicides applied to cornfields varied but most commonly consisted of a combination of glyphosate, metolachlor, atrazine, and mesotrione that was applied in a one- or two-pass program. The cornfield in White County in 2020 was planted to a conventional hybrid, and no glyphosate was used.

Irrigation is an important management practice for Arkansas corn. Statewide, approximately 90–95% of the corn grown in the state is irrigated (USDA-FSA, 2020). 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 2020, overall irrigation requirements for corn were generally less than in previous years, and on average, each field was irrigated 5.2 times (Table 3). Each furrow irrigation was estimated to provide 2 ac-in. of irrigation water. Average rainfall on cornfields in 2020 from planting to maturity was 16.29 in., demonstrating that total rainfall may be adequate for corn production, but the poor distribution of rainfall during the growing season is the reason such a high percentage of Arkansas corn is irrigated.

On-site weather stations provided high- and low-temperature data to allow for accurate measurement 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 2020 average GDDs accumulated by each growth stage listed. These values align closely with reported GDDs needed to reach maturity for full-season hybrids (110–120 day) that we typically grow in Arkansas. Use of GDDs can accurately predict corn growth stages and assist in management decisions such as irrigation termination.

Economic Analysis

Records of field operations on each field that were compiled by the CGSRVP coordinator, county extension agent, and producer serve as the basis for estimating costs and economic returns that are discussed in this section. Production data from the 9 irrigated cornfields 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 2020 Crop Enterprise Budgets published by the Cooperative Extension Service and information provided by the producer cooperators. Fuel and repair costs for machinery are calculated using a budget calculator based on parameters and standards established by the American Society of Agricultural and Biological Engineers. Machinery repair costs should be regarded as estimated values for full-service repairs, and actual cash outlays could differ as producers utilize employee labor or provide unpaid labor for equipment maintenance.

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

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

Operating costs, total costs, costs per bushel, and returns are presented in Table 5. 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 $3.75/bu. and was the three-week average for the most active weeks of the harvest period each year. The average corn yield from the irrigated corn verification fields was 202.0 bu./ac.

The production expenses for irrigated cornfields harvested for grain was $517.54/ac in 2020. On average, fertilizers and nutrients were the largest expense category at $154.34/ac, or 30% of production expenses for irrigated cornfields (Table 6). Seed costs averaged $123.80/ac which was 24% of production expenses on irrigated cornfields (Table 6).

With an average corn yield of 202.0 bu./ac for all irrigated fields, operating costs were $517.49/ac for 2020. Return to operating costs for all irrigated cornfields for 2020 was $240.11/acre. Fixed costs for irrigated fields were $79.56. Returns to total cost for irrigated fields was $160.55. Total specified costs for all irrigated cornfields during 2020 averaged $3.00/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 included 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 cornfields 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 to potential pest problems.

The Corn Research Verification Program highlighted that corn can be a profitable crop for Arkansas growers. Following current extension recommendations and providing timely inputs can lead to high-yielding and profitable corn production.

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 are enrolled in the program. Support was also provided by the University of Arkansas System Division of Agriculture.

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Table 1. 2020 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	DeKalb 70-27VT2P	43	38	soybean	35,700	4/15	9/7	175.8
Chicot[a]	Dyna-Gro D57VC51	84	38	soybean	33,200	3/27	9/9	105[b]
Drew	Croplan 5678VT2P	140	38	soybean	33,250	5/3	9/14	213.7
Lawrence	Pioneer P1870AM	40	30	soybean	35,800	4/8	9/7	165.0
Lonoke	Croplan 5678VT2P	40	30	soybean	32,750	5/2	9/20	195.0
Mississippi1	Progeny 6116VT2P	32	38	soybean	32,300	4/5	9/7	187.3
Mississippi2	DeKalb 70-27VT2P	82	38	soybean	34,000	4/6	9/17	197.3
Poinsett	Pioneer 2089VYHR	80	30	soybean	32,000	4/7	10/21	241.0
White	Dyna-Gro D57CC51 Conv	50	30	soybean	35,300	4/18	9/15	241.2
Mean	---	**65.7**	**---**	**---**	**33,711**	**4/13**	**9/16**	**202.0**

[a] 75% of the field suffered severe wind damage ranging from complete lodging to topping of plants.
[b] The yield is not included in the overall program average or economic analysis.

Table 2. 2020 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	33-60-90-12-3	131-0-0-30-2	46-0-0-0-0	210-60-90-42-5	Calhoun Silt Loam
Chicot	74-60-90-0-5	120-0-0-0-0	46-0-0-0-0	240-60-90-0-5	Commerce Loam
Drew[b]	19-23-60-12-5	147-28-36-24-0	46-0-0-0-0	212-51-96-36-5	Calhoun Silt Loam
Lawrence	15-60-60-0-0	157-0-0-48-0	46-0-0-0-0	218-60-60-48-0	Beulah Sandy Loam
Lonoke	33-0-100-33-10	138-0-0-0-0	46-0-0-0-0	217-0-100-33-10	Hebert Silt Loam
Mississippi1	23-30-70-0-0	138-0-0-0-0	46-0-0-0-0	207-30-70-0-0	Tipton & Dabbs Silt Loam
Mississippi2	60-0-34-5-1	159-0-0-24-1	60-0-0-0-0	279-0-34-29-2	Sharkey-Steele Clay
Poinsett	21-90-120-24-8	149-0-0-12-0	46-0-0-0-0	216-90-120-36-8	Calloway Silt Loam
White	23-0-120-0-0	102-0-0-19-0	105-0-0-0-0	230-0-120-19-0	Calhoun Silt Loam
Mean	**33-36-83-10-4**	**138-3-4-17-0**	**54-0-0-0-0**	**225-39-87-27-4**	-

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

[b] One ton of chicken litter applied.

Table 3. 2020 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 (in.)
Ashley	Furrow	5	18.34
Chicot	Furrow	4	25.19
Drew	Furrow	6	9.63
Lawrence	Furrow	6	15.05
Lonoke	Furrow	5	14.54
Mississippi1	Furrow	6	14.40
Mississippi2	Furrow	4	13.83
Poinsett	Furrow	6	16.01
White	Furrow	5	19.59
Mean	-	**5.2**	**16.29**

[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 2020.

Corn Growth Stage	Accumulated Growing Degree Days From Planting
VE – Emergence	128
V2	263
V4	409
V6	585
V8	739
V10	901
V12	1034
V14	1182
V16	1292
R1 – Silking	1464
R2 – Blister	1610
R3 – Milk	1776
R4 – Dough	1970
R5 – Dent	2176
R6 – Physiological Maturity (Black Layer)	2846

Table 5. Operating costs, total costs, and returns for corn research verification program fields, 2020.

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	530.40	3.02	128.70	79.46	609.85	49.25	3.47
Drew	531.36	2.49	270.13	80.74	612.10	189.39	2.86
Lawrence	518.78	3.14	99.97	80.74	599.52	19.23	3.63
Lonoke	527.20	2.70	204.05	82.13	609.33	121.92	3.12
Mississippi1	482.86	2.58	219.51	80.74	563.61	138.77	3.01
Mississippi2	495.15	2.51	244.61	80.59	575.74	164.02	2.92
Poinsett	568.61	2.36	335.29	65.36	633.96	269.94	2.63
White	485.94	2.01	418.59	86.88	572.52	331.91	2.37
Mean	**517.54**	**2.60**	**240.11**	**79.58**	**597.08**	**160.55**	**3.00**

Table 6. Summary of operating costs, total costs, and returns for corn research verification program fields, 2020.

	Ashley	Drew	Lawrence	Lonoke	Miss 1	Miss 2	Poinsett	White	Mean
Yield (bu./ac)	175.8	213.7	165.0	195.0	187.3	197.3	241.0	241.2	**202.04**
Price ($/bu.)	3.75	3.75	3.75	3.75	3.75	3.75	3.75	3.75	**3.75**
Total Crop Revenue	**659.10**	**801.49**	**618.75**	**731.25**	**702.38**	**739.76**	**903.90**	**904.43**	**757.63**
Expenses	----------	----------	----------	----------	**$/ac**	----------	----------	----------	----------
Seed	131.40	133.23	133.23	116.80	127.75	124.10	124.10	99.75	**123.80**
Fertilizers & Nutrients	171.95	137.63	137.88	181.25	144.98	137.22	181.03	142.76	**154.34**
Herbicides	40.52	35.67	70.80	24.68	24.45	47.86	29.45	38.76	**39.02**
Insecticide	-	-	-	-	-	-	-	-	-
Fungicide	-	10.28	-	10.28	-	-	-	-	**2.57**
Other Chemicals	-	-	-	-	-	-	-	-	-
Custom Application	16.00	24.00	8.00	16.00	8.00	0	38.00	7.50	**14.69**
Diesel Fuel, Field Activities	14.33	14.33	14.33	14.03	14.33	13.88	11.15	13.84	**13.78**
Irrigation Energy Costs	15.28	18.34	18.34	15.28	18.34	22.21	18.34	15.28	**17.68**
Other Inputs, Pre-harvest	3.88	3.88	3.88	3.88	3.88	3.88	3.88	3.88	**3.88**
Input Costs	----------	----------	----------	----------	**$/ac**	----------	----------	----------	----------
Fees	7.00	7.00	7.00	7.00	7.00	7.00	7.00	7.00	**7.00**
Crop Insurance	13.00	13.00	13.00	13.00	13.00	13.00	13.00	13.00	**13.00**
Repairs & Maint.	16.90	17.15	17.15	17.26	17.15	17.48	14.94	17.26	**16.91**
Labor, Field Activities	8.97	9.04	9.04	8.23	9.04	8.88	6.94	8.18	**8.54**

Continued

Table 6. Continued.

	Ashley	Drew	Lawrence	Lonoke	Miss 1	Miss 2	Poinsett	White	Mean
	----------	----------	----------	----------	$/ac	----------	----------	----------	----------
Production Expenses									
Interest	12.08	11.65	11.90	11.76	10.67	10.88	12.32	10.10	**11.42**
Post-harvest Expenses	79.09	96.18	74.25	87.75	84.29	88.77	108.47	108.53	**90.92**
Custom Harvest	-	-	-	-	-	-	-	-	-
Total Operating Expenses	530.40	531.36	518.78	527.20	482.86	495.15	568.61	485.54	**517.49**
Returns to Operating Expenses	128.70	270.13	99.97	204.05	219.51	244.61	335.29	418.59	**240.11**
Capital Recovery & Fixed Costs	79.46	80.74	80.74	82.13	80.74	80.59	65.36	86.68	**79.56**
Total Specified Expenses	609.85	612.10	599.52	609.33	563.61	575.74	633.96	572.52	**597.08**
Returns to Specified Expenses	49.25	189.39	19.23	121.92	138.77	164.02	269.94	331.91	**160.55**
Operating Expenses Per bu.	3.02	2.49	3.14	2.70	2.58	2.51	2.36	2.01	**2.60**
Total Specified Expenses Per bu.	3.47	2.86	3.63	3.12	3.01	2.92	2.63	2.37	**3.00**

Gene Editing: A New Approach to Overcome Mycotoxins and Environmental Stress in Arkansas Corn Production, 2020

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

Abstract

Mycotoxins are a consistent challenge for corn producers in Arkansas. Mycotoxin contamination can vary wildly from year to year and location to location, and thus represents an unpredictable risk to corn production. Outbreaks happen periodically in Arkansas and other U.S. states, which reduce producer profits, cause long-term shifts in production away from corn into other crops, and can even drive individual growers bankrupt in a single season. Aflatoxins, one of the most highly regulated classes of mycotoxins in corn, are frequently associated with pre-harvest infections caused by *A. flavus*. High levels of environmental stress, especially heat and drought, are frequently associated with high levels of aflatoxin accumulation in corn, presumably because of compromised plant health. Environmental stress also reduces yield and predisposes corn to other biotic stresses. Thus, novel tools to increase stress tolerance in corn are needed urgently to protect yields and reduce aflatoxins to manageable levels. Gene editing, a breakthrough technology for non-transgenic manipulation of plant genes, is a powerful tool to increase corn's ability to tolerate environmental stress. The overall goal of this project is to utilize gene editing to improve the resistance of corn to aflatoxin contamination, in part by augmenting resistance to environmental stress. The specific objectives 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 this end, we recently refined tissue-culture-based approaches for gene editing in corn and utilized new approaches to identify corn genes involved in augmenting stress tolerance. These activities have provided critical tools and information to advance gene editing for aflatoxin control in corn.

Introduction

Aflatoxin is the most carcinogenic naturally occurring compound known to mankind, and its presence in food and raw agricultural commodities is strictly regulated throughout the world. In many parts of the U.S., including Arkansas, aflatoxin contamination is a chronic, annual concern for corn producers. Aflatoxin contamination of corn is mostly a pre-harvest issue in U.S. production, although aflatoxin levels can increase during improper grain harvesting and storage. Pre-harvest aflatoxin contamination of corn is closely associated with heat and/or drought stress, particularly during the early stages of grain fill. The natural climate of the Southeastern U.S. is difficult enough for corn production due to the annual risk of excessive heat and drought. Of perhaps even greater concern is the projected trend of climate change within the state, in which extreme weather events—including heat and drought—may become even more frequent and intense. The long-term viability of growing corn in Arkansas is threatened unless new technologies are developed to mitigate biotic and abiotic stresses associated with aflatoxin contamination, heat stress, drought, and the changing climate within the region.

Aflatoxin mitigation tools are few in number and only partially effective at best. Traits that control insect damage, such as production of *Bacillus thuringiensis* (*Bt*) toxin in corn, are inconsistent for aflatoxin control. Biological control products for *A. flavus*, such as Afla-Guard, offer a degree of protection when applied correctly, but they provide variable levels of control and are often ineffective in the face of high disease pressure and/or extreme environmental conditions (such as heat or drought). None of these options, alone or in combination, adequately reduces the risk of aflatoxins in corn to an acceptable level.

Decades of conventional breeding have failed to produce satisfactory aflatoxin resistance in commercial corn hybrids. Although breeding efforts have been extensive, spanning numerous decades and research programs around the world, U.S. corn growers cannot guarantee their crops will be free of aflatoxin. Based on the lack of progress thus far, it is not clear when or even if conventional breeding will provide a viable solution to aflatoxin in corn.

Gene editing is a revolutionary new technique for crop improvement and has been demonstrated to function in corn and sorghum (Jaganathan et al., 2018; Kelliher et al., 2019). For gene editing to work, a technology known as CRISPR-Cas9 is used to change (edit) the sequence of specific plant genes in order to improve desired traits (Ran et al., 2013). Importantly, gene editing is separate and distinct from transgenic corn production. A key distinction is that gene editing modifies genes already present in the plant genome, whereas transgenic approaches introduce new (foreign) genes into plant genomes. Gene editing is very versatile, as it can be used to inactivate genes underlying stress sensitivity, increase the expression of

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genes involved in stress resistance, or change the DNA sequence of individual genes to make them more efficient and/or effective at combating environmental stress. Gene editing can be performed without transgenic approaches, which allows new, edited hybrids to be regulated much less strictly than transgenic plants. Notably, in 2020 the USDA released revised regulations regarding genetically engineered plants, in which gene edited plants are broadly exempted from governmental oversight (Clayton, 2020). Because of this stipulation, increasing stress resistance in corn via gene editing will greatly accelerate the availability of improved hybrids to corn growers.

Thus, 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

An ongoing focus of this project is creating tools, skills, and resources required for efficient and effective gene editing in corn. This included the establishment of a robust tissue culture system for corn, 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. As gene editing is a rapidly evolving field of study, with new advancements being reported continually, adjusting protocols to incorporate new information is a constant consideration during this process.

A key focus is the design of DNA/RNA constructs utilized for gene editing. Because these constructs essentially serve as an 'instruction manual' for how genes are edited at the cellular level, optimizing their design is crucial to obtain desired results quickly and consistently. We explored several approaches to edit corn genes, including 1) creating null alleles (inactive genes) by editing out a substantial portion of corn genes, thus making them unable to express properly; 2) increasing the expression of beneficial corn genes by targeting their promoter regions for gene editing; and 3) altering specific domains within the corn genes, with the goal of making them function more efficiently/effectively.

Objective 2

Ultimately, gene editing is most effective at modifying plant traits when the most suitable genes are chosen for editing. Thus, identifying which genes in corn regulate stress responses is crucial for project success. Corn has approximately 32,000 genes in its genome, as compared to approximately 20,000 for humans (Llaca et al., 2011; Willyard, 2018). The large number of genes in the corn genome makes the early and accurate identification of genes involved in stress tolerance a crucial component of this project. Thus far, we have 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 have been utilizing 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.

Results and Discussion

In earlier work on this project, many of the fundamental protocols and procedures for efficient genome editing in corn were established, including cell culture protocols, delivery of editing constructs into corn cells, regeneration of edited plants, and screening plants for gene editing events. Most recently, we have focused on designing gene editing constructs to be efficient at 1) inactivating genes that convey susceptibility to environmental stress; 2) increasing the expression of genes that convey resistance to environmental stress, and 3) increasing the efficacy of genes involved in environmental responsiveness. For gene inactivation, we developed a tandem editing construct, in which two distinct regions of the gene to be edited are targeted. The idea is that, during editing, a large region of the gene will be deleted by getting 'knitted out' of the genome after corn's natural DNA repair mechanism ties together the two regions of the gene being edited. In our experiments, over 80% of editing events with a tandem construct resulted in the deletion of 1–2 kb of the target gene, more than enough to ensure the inactivation of the gene. For increased expression, we targeted the promoter of selected genes. The promoter region of a gene is essentially a 'rheostat' that controls the level of gene expression. In many cases, the exact DNA bases within the promoter that control gene expression are not known. Thus, we developed a technique to edit promoters randomly; the resulting gene edited lines will be evaluated via molecular techniques to evaluate whether expression of the target gene increased, and edited lines will be evaluated in field experiments to assess stress tolerance and aflatoxin resistance.

In prior work, candidate genes for editing were identified based on predicted molecular function (transcriptional regulators) and putative involvement in environmental stress responses (drought, heat tolerance, etc.). More recently, we created and tested a novel approach to identify and prioritize candidate genes for gene editing. We turned the historical difficulties faced by corn breeders trying to break genetic linkage between desirable agronomic traits (such as yield) and undesirable traits (such as susceptibility to stress) into an advantage for target gene evaluation. We positioned known corn genes associated with desirable agronomic traits on a genetic map and searched for candidate genes (previously identified in this project, as well as novel categories) that co-localized in the genome (and thus are presumably linked). Although these analyses are ongoing, approximately 5% of previously identified genes associated with stress responses are potentially linked with yield. We predict that these genes are a rich source of targets for genome editing. Recently, a gene (*waxy*) involved in endosperm starch structure was edited in elite corn germplasm; the resulting lines were agronomically superior to introgressed hybrids, thus confirming linkage drag as a likely hindrance to trait improvement in commercial corn hybrids (Gao et al., 2020). Expression profiles of transcription factors of candidate genes were cross-referenced in other data sets, including responsiveness to infection by *A. flavus* (Jiang et al., 2011; Kelly et al., 2012; Dhakal et al., 2017; Shu et al., 2017).

In a complementary approach to the bioinformatic approaches described above, we are identifying regions of the corn genome involved in stress tolerance in Arkansas by evaluating multiple-parent advanced-generation inter-cross ('MAGIC') lines of maize (Holland, 2015). MAGIC lines allow us to map genes associated with environmental stress responses more quickly and with greater confidence compared to other genetic resources and approaches (Dell'Acqua et al., 2015). MAGIC lines are phenotyped in field conditions for tolerance of heat and drought stress, as well as aflatoxin accumulation. Then, phenotyping results are combined with genetic data for each line to identify regions of the corn genome that are closely associated with stress tolerance (or susceptibility). This approach provides an avenue to confirm candidate genes identified as described above, and potentially identify completely novel genes/genomic regions in corn associated with stress responses.

Practical Applications

Environmental conditions in Arkansas are often challenging for corn production, which introduces unpredictable risks for growers. Aflatoxin is consistently one of the most difficult potential problems for corn production in Arkansas. Past efforts to control aflatoxin have largely failed, in large part because conventional breeding has not yet provided acceptable levels of resistance while maintaining yield. As time goes on, it looks increasingly likely that conventional breeding will not be able to provide resistance, and thus other approaches (such as gene editing) are needed urgently. In the context of climate change, unpredictable environmental stress—which is intricately linked to aflatoxin contamination—will likely be even more common. Through gene editing, our overarching goal is to develop new corn hybrids that will be customized specifically for 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.

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Effect of Foliar Fungicides in the Absence of Disease on Hybrid Corn Yield

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Abstract

Fifteen commercially available foliar fungicides were applied in 2018 and 2019 across six field experiments in a furrow irrigated field near Pine Bluff, Arkansas. The Dekalb corn hybrid 'DKC 68-26' was used in this study. Fungicides were applied in 2018 at silking (R1) and in 2019 at blister (R2). Environmental conditions did not favor foliar disease development, and the only disease observed was a trace amount of common rust caused by *Puccinia sorghi* Schweinitz in the lower canopy. Fungicides provided at least a 5 bu./ac grain yield benefit 41% of the time in 2018 and 50% of the time in 2019. These data support the inconsistency among fungicides to provide a yield benefit in the absence of a yield-limiting foliar disease.

Introduction

Foliar fungicide use on corn has increased since the mid-2000s across the U.S., which is partially due to increased disease development, fungicide availability, but also reports of physiological benefits that contribute to a grain yield increase (Wise and Mueller, 2011; Tedford et al., 2017). Foliar fungicides are marketed for use on hybrid corn at two main growth stages: early vegetative (V4–V10) and tassel/silking (VT/R1). Fungicide classes marketed for use in corn include quinone outside inhibitors (QoI; also known as strobilurin), demethylation inhibitors (DMI; also known as triazole), and succinate dehydrogenase inhibitor (SDHI) fungicides (Faske, 2020). Fungicides provide the best grain yield protection when applied prior to disease development; however, the onset of disease development is inconsistent from year to year. Southern rust (caused by *Puccinia polysora* Underwood) is an important yield-limiting disease that can arrive as early as June or as late as August in Arkansas. Southern corn rust is monitored and reported annually by many Extension scientists across the Southern states. Information on where southern rust is detected is made available to farmers in an electronic format, which is used as an early warning system of rust development (Mueller et al., 2018). Alternately, automatic applications of corn fungicides are often applied in the absence of disease for physiological benefits to increase grain yield. The number of fungicides that have become available has increased, but little is known about their benefits in the absence of disease. The objective of this study was to evaluate the yield benefit of fifteen foliar fungicides applied in the absence of disease over a two-year period on hybrid corn in Arkansas.

Procedures

The field efficacy of fifteen fungicides was evaluated in six experiments in 2018 and 2019 in an on-farm trial in Jefferson County, Arkansas (Table 1). The Dekalb corn hybrid 'DKC 68-26' (118-day maturity) was planted on 20 May 2018; 25 May 2019 at a seeding rate of 32,000 seed/ac. The previous crop was soybean, and the fields were furrow irrigated. 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 4 replications separated by a 5-ft fallow alley. Fungicides were broadcast through flat-fan nozzles (Tee-Jet 80015VS) spaced 20-in. apart on the two center rows per plot using an air pressurized multi-boom plot sprayer. The sprayer was calibrated to deliver 15 gal/ac. Treatments were applied at the silking stage of growth (R1) in 2018 and blister (R2) in 2019. A non-ionic surfactant (Induce, Helena Agri-Enterprises, LLC, Collierville, Tenn.) was used (0.25% v/v) in four of the six trials (Table 2). Foliar diseases were assessed at the dent growth stage (R5). The center two rows of each plot were harvested on 18 October 2018 and 12 September 2019 using a modified K Gleaner combine (1969–1976, Allis-Chalmers Manufacturing Company, West Allis, Wis.) equipped with a HarvestMaster Single BDS HiCap HM800 Weigh System (HarvestMaster Logan, Utah). Data were analyzed by analysis of variance using Agricultural Research Manager Software v. 9.0, and means were separated with Tukey's honestly significant difference test ($P = 0.05$).

Results and Discussion

No foliar corn disease was detected in the upper canopy, but trace amounts of common rust caused by *Puccinia sorghi* Schweintz were observed in the lower canopy. A greater yield was observed 58% of the time in 2018 with a range of -11.7 to 16.6 bu./ac from fungicide treated compared to the nontreated control across experiments (Table 2). A yield benefit of >5 bu./ac was observed 41% of the time with a range of 5.1 to 16.6 bu./ac, and >10 bu./ac was observed 20% of the time. Of the fungicides tested in 2018, Trivapro 2.21 SE was used in most experiments and had a positive yield benefit of >5 bu./ac 50% of the time.

A greater yield was observed 66% of the time in 2019 with a range of -4.0 to 20.2 bu./ac from fungicide treated compared to the nontreated control across experiments (Table 2). A yield

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benefit of >5 bu./ac was observed 58% of the time with a range of 7.4 to 20.2 bu./ac and >10 bu./ac was observed 25% of the time. Of the fungicides tested in 2019, Quilt Xcel 2.2 SE was used twice and had a positive yield benefit of >5 bu./ac once.

In one of the 2018 trials (18-4), grain yield from all fungicide treatments were lower than the nontreated control. A non-ionic surfactant (NIS) was used in the trial, which has been reported to cause arrested ear development when applied early V10 to V14 prior to VT (Stetzel et al., 2011). Arrested ears have shortened cobs and less grain production when fungicides are applied with an NIS in the V14 to pre-tassel window. Furthermore, poor pollination has been associated with the use of NIS applied one week before tassel (Nafziger, 2008). All fungicides were applied in the morning on the same day, and statistically, there was no effect of fungicide on yield. Thus, variation in yield was due to factors other than fungicides + NIS. However, the trial without a NIS (18-1) had an average yield difference of 13.3 bu./ac, while trials with a NIS (18-2 to 18-4), grain yield difference averaged 0.4 bu./ac (range of -5.7 to 4.7 bu./ac). Silks can emerge before the tassel growth stage (e.g., lowermost tassel branch is fully expanded) in some hybrids, and pollen shed can occur before tassel. Thus NIS applied at the silking (R1) growth stage could impact pollination. Further research is needed to understand the effect of NIS at these growth stages in Arkansas corn.

These data support the inconsistency among fungicides to provide a yield benefit in the absence of a yield-limiting foliar disease. Thus, utilizing a fungicide to increase grain yield is unlikely to consistently exceed the break-even cost (fungicide and application) in the absence of a disease.

Practical Applications

Fungicides do not consistently provide a yield benefit when used to increase yield in the absence of disease. Moreover, the misuse of fungicides increases production costs and contributes to the development of diseases that are resistant to corn fungicides.

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Table 1. Trade names, rates, active ingredient, and Fungicide Resistance Action Committee (FRAC) codes for fungicides used in 2018 and 2019 corn fungicide trials in Jefferson County.

Trade name and formulation	Rate	Active ingredient	FRAC code[a]
	(fl oz/ac)		
Quadris 2.08 SC	6	azoxystrobin	11
Headline 2.09 SC	6	pyraclostrobin	11
Lucento 4.17 SC	5	flutriafol + bixafen	3 + 7
Topguard EQ 4.29 SC	5	flutriafol + azoxystrobin	3 + 11
Preemptor 3.22 SC	5	flutriafol + fluoxastrobin	3 + 11
Aproach Prima 2.34 SC	6.8	cyproconazole + picoxystrobin	3 + 11
Headline AMP 1.68 SC	10	metconazole + pyraclostrobin	3 + 11
Quilt Xcel 2.2 SE	10.5	propiconazole + azoxystrobin	3 + 11
Delaro 2.78 SC	8	prothioconazole + trifloxystrobin	3 + 11
Priaxor 4.17 SC	5	fluxapyroxad + pyraclostrobin	7 + 11
Priaxor 4.17 SC + Tilt 41.8 SC	4 + 4	fluxapyroxad + pyraclostrobin + propiconazole	7 + 11 + 3
Veltyma 3.34 SC	7	mefentrifluconazole + pyraclostrobin	3 + 11
Trivapro 2.21 SE	13.7	propiconazole + benzovindiflupyr + azoxystrobin	3 + 7 + 11
Miravis Neo 2.5 SE	13.7	propiconazole + pydiflumetofen + azoxystrobin	3 + 7 + 11
Revytek 3.33 SC	8	mefentrifluconazole + fluxapyroxad + pyraclostrobin	3 + 7 + 11

[a] Values relate to specific fungicide mode of action.

Table 2. Yield response of Dekalb DKC68-26 to various foliar fungicides applied at silking growth stage (R2) in 2018 and blister growth stage (R2) in 2019 in the absence of disease in Jefferson County.

		Trial year-number					
Fungicide	Rate	18-1[a]	18-2	18-3	18-4	19-1	19-2
	(fl oz/ac)	(bu./ac)					
Nontreated control		217.7	224.8	234.2	245.2	201.2	191.3
Quadris 2.08 SC	6	…	…	…	…	…	205.0
Headline 2.09 SC	6	…	…	…	243.5	…	
Lucento 4.17 SC	5	233.8	…	238.9	233.5	…	211.5
Topguard EQ 4.29 SC	5	…	…	238.6	…	…	
Preemptor 3.22 SC	5	235.1	…	…	…	…	198.7
Aproach Prima 2.34 SC	6.8	…	219.8	…	…	…	…
Headline AMP 1.68 SC	10	…	…	…	239.5	202.7	…
Quilt Xcel 2.2 SE	10.5	234.3	…	…	…	197.2	199.7
Delaro 2.78 SC	8	234.4	…	…	…		…
Priaxor 4.17 SC	5	232.5	…	…	238.9	199.3	193.1
Priaxor 4.17 SC + Tilt 41.8 SC	4 + 4	…	…	…	241.1	…	…
Veltyma 3.34 SC	7	…	…	…	…	199.9	…
Trivapro 2.21 SE	13.7	215.8	234.3	239.3	244.2	…	200.0
Miravis Neo 2.5 SE	13.7	…	…	…	…	211.5	…
Revytek 3.33 SC	8	…	…	…	235.6	200.8	…
P > F		0.46	0.29	0.80	046	0.78	0.59

[a] Trial = year-experiment number. A non-ionic surfactant (0.25% v/v) was used in trial 18-2, 18-3, 18-4, and 19-1.

Comparison of Corn Traits for Control of Corn Earworm

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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 2020 to determine the efficacy of Double Pro (VT2P) and Vip3a corn traits on corn earworm control compared to a non-*Bt* hybrid. A strip trial was planted near Marianna, Arkansas, with hybrids containing multiple Vip3a hybrids, a Double Pro 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 hybrid with the Double Pro proteins had more corn earworms than the non-*Bt* hybrid but less kernel damage. The Vip3a hybrids had less than 1 damaged kernel per 100 ears and less than 5 larvae per 100 ears. A similar study was planted in Pine Bluff, comparing multiple non-*Bt*, Double Pro, 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 Double Pro 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 for 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 for corn earworm control, including; Double Pro, Viptera, Leptera, and Trecepta compared to non-*Bt* hybrids.

Procedures

Studies were conducted during 2020 to determine the efficacy of different *Bt* traits in corn on 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 near Marianna, Arkansas. Mulitple corn hybrids were planted at each date and consisted of a non-*Bt* (DKC 67-70), a Double Pro (DKC 67-72), and three Viptera containing hybrids (P 1637, NK 1822, and DKC 67-99). 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. An additional study was planted on a producer's field near Pine Bluff, Arkansas, to further evaluate the efficacy of multiple *Bt* traits in corn for control of corn earworm. Multiple non-*Bt*, Double Pro, 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 the 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 were 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.

Results and Discussion

Marianna Location

Larval densities at the R3 stage ranged from 1 to 60 per 100 ears across all hybrids for the 17 April planting date, and

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at the R4 stage, damaged kernels per 100 ears ranged from 0.2 to 6.6. Similar larval densities (0 to 41 per 100 ears) and damaged kernels (0.1 to 5.6 per 100 ears) were observed for the 4 May planting. A 2–3 fold increase in larval density (1 to 203 per 100 ears) and damaged kernels (0 to 16.4 per 100 ears) was present in the 18 May planting compared to the two earlier plantings (Table 2). A general trend was observed across all planting dates that the Double Pro hybrid (DKC 67-72) had more corn earworms present than the non-*Bt* (DKC 67-70), although damaged kernel counts were consistently higher for the non-*Bt*. All corn hybrids containing the Vip3a gene averaged less than 1 damaged kernel per 100 ears and less than 5 corn earworms per 100 ears.

Pine Bluff Location

The non-*Bt* hybrids had higher total corn earworm densities per 10 ears compared to the Double Pro and Vip3a hybrids at the corn R3 growth stage. The Double Pro hybrids had higher densities of corn earworm per 10 ears than the Vip3a hybrids. The non-*Bt* hybrid P1870R had more damaged kernels per 10 ears than all other hybrids. No difference was observed between the non-*Bt* DKC 62-05RR2 and either Double Pro hybrids for damaged kernels per 10 ears. Both hybrids containing the Vip3a gene had fewer damaged kernels per 10 ears compared to all other hybrids (Table 3).

Practical Applications

In general, the hybrids containing the Vip3a gene had fewer larvae and damaged kernels compared to the Double Pro 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.

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Table 1. Corn hybrid names and trait packages used in corn earworm efficacy studies conducted near Marianna and Pine Bluff, Arkansas in 2020.

	Marianna	
Hybrid	**Trait Package**	***Bt* toxins**
DKC 67-70	RR2	None
DKC 67-72	VT2P	Cry1A.105, Cry2Ab2
NK 1822	Viptera	Cry1Ab, Vip3A
P 1637	Leptra	Cry1Ab, Cry1F, Vip3A
DKC 67-99	Treceptra	Cry1A.105, Cry2Ab2, Vip3A
	Pine Bluff	
Hybrid	**Trait Package**	***Bt* toxins**
DKC 62-05	RR2	None
DKC 70-27	VT2P	Cry1A.105, Cry2Ab2
DKC 65-99	Treceptra	Cry1A.105, Cry2Ab2, Vip3A
P 1870R	RR2	None
P 1870HR	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, Marianna, Arkansas 2020.

Plating Date	Hybrid	Trait Package	CEW† Larvae/100 ears	Damaged Kernels/100 ears
17 April	DKC 67-70	RR2	60	6.6
	DKC 67-72	VT2P	78	6.4
	NK 1822	Viptera	2	0.1
	P 1637	Leptra	3	0.6
	DKC 67-99	Treceptra	1	0.2
4 May	DKC 67-70	RR2	26	5.6
	DKC 67-72	VT2P	41	1.9
	NK 1822	Viptera	0	0.1
	P 1637	Leptra	0	0.4
	DKC 67-99	Treceptra	1	0.3
18 May	DKC 67-70	RR2	122	16.4
	DKC 67-72	VT2P	203	14.6
	NK 1822	Viptera	4	0.0
	P 1637	Leptra	5	0.01
	DKC 67-99	Treceptra	1	0.1

† CEW = corn earworm.

Table 3. Corn earworm densities and kernel damage per 10 ears for multiple corn hybrids and planting dates, Pine Bluff, Arkansas 2020.

Plating Date	Hybrid	Trait Package	CEW† Larvae/10 ears	Damaged Kernels/10 ears
1 May	DKC 62-05	RR2	15.5 b‡	15.5 bc
	DKC 70-27	VT2P	26.3 a	13.3 c
	DKC 65-99	Treceptra	0.5 c	0.0 d
	P 1870R	RR2	18.3 b	23.9 a
	P 1870HR	YHR	27.0 a	17.1 b
	P 2089VYHR	Leptra	1.3 c	1.3 d
1 June	DKC 62-05	RR2	.	9.4 ab
	DKC 70-27	VT2P	.	9.9 ab
	DKC 65-99	Treceptra	.	1.4 c
	P 1870R	RR2	.	11.8 a
	P 1870HR	YHR	.	14.7 a
	P 2089VYHR	Leptra	.	3.4 bc

† CEW = corn earworm.

‡ Means followed by the same letter are not significantly different at $P = 0.10$.

Insect management in on-farm grain storage: Survey of insect pests infesting corn in on-farm storage in Arkansas

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Abstract

Stored grains are attacked by numerous species of insects in on-farm bins and other storage facilities. After harvest, corn grains are susceptible to infestation by several species of insect pests that can cause economic damage. This includes primary pests such as maize weevil, rice weevil, and lesser grain borer, and secondary pests such as red flour beetle and confused flour beetle. This study was conducted to identify insect pests associated with corn in on-farm storage bins and determine their abundance and diversity. Surveys were conducted in various corn-producing regions in Arkansas and were continued through the duration of the storage period using different standard sampling techniques for stored insect pests. Corn grain samples were also collected to examine hidden infestations. In this study, over 95% of insect samples recorded were adults of the red flour beetle (*Tribolium castaneum*). This stored grain pest was the most abundant pest, as it was recorded from several grain samples as well as the insect traps that were deployed in on-farm bins. In this report, the findings of these surveys are presented, and potential pest management strategies are discussed.

Introduction

Several insect pests are known to attack corn in a storage environment (Rees, 2004). Among them are primary and secondary pests. Primary such as the maize weevil, granary weevil, rice weevil, angoumois grain moth, and lesser grain borers are the most economically important because they feed internally on intact kernels (Arbogast and Throne, 1997). In general, both the adult and larval stages of these pests damage corn grains causing significant losses in a storage environment. In many insect species infesting stored grains, adult insects destroy whole grains, eventually converting them into waste flour, and the larvae feed on the starch contents of the corn grains. If not managed effectively, many of these insect pests have the potential to cause a total loss in stored grain commodities. Numerous other pests such as the Indian meal moth larva, confused flour beetle, and red flour beetle are also known to infest stored corn and are considered secondary pests (Storey et al., 1983). The current knowledge-base and management recommendations for stored-corn insect pests in Arkansas are based on limited information and need to be strengthened by conducting new studies determining the status and bionomics of these pests in corn-growing regions of the state. In Arkansas, information about the abundance of stored grain insect pests is limited to a survey of rice mills (conducted several years ago), where researchers found numerous species of stored-product insects (White, 2011, McKay et al., 2017, 2019). However, such information is lacking in other valuable commodities (such as corn) of the state. Taking into consideration the knowledge gap and increasing incidences/reports of insect pest infestation in stored corn in recent years, it is crucial to conduct the proposed study in Arkansas corn. In this context, the major objectives of this study were to identify insect pests associated with corn while in on-farm storage bins in different corn-growing regions in Arkansas, determine the abundance and diversity of pests in stored corn, and increase awareness of the impact of stored grain insects pests. The findings of this study will help us to identify and develop sustainable management recommendations for the major stored-insect pests infesting corn grains in a storage environment.

Procedures

Multiple season-long surveys were conducted in corn-growing regions of Arkansas to identify various insect pests associated with corn while in on-farm storage bins. Surveys were conducted by collecting grain samples and using probe traps in corn storage to monitor the population dynamics of stored insect pests. Grain samples were collected in plastic containers and were transferred to insect rearing jars (with fine mesh lids) in a laboratory. All samples were examined after 30 days, and all insects that emerged from samples were collected. These insects were identified to species level, and their abundance in each sample was recorded. The process was repeated again, and all grain samples were examined further for insect emergence. Hidden infestations of stored pests were determined by

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randomly selecting 50 grains from each sample. These grains were carefully checked for the signs of insect infestations, such as the presence of entrance hole/plug, and were cracked further to check the presence of internally feeding larva. The number of infested grains was recorded in each sample, and the percent infestation rate was calculated. Samples from insect traps were collected in glass or plastic vials containing 70% ethanol and were brought to the laboratory for processing. All adult insect samples were identified to species level.

Results and Discussion

In this study, over 95% of insect samples recorded from the on-farm corn grain storage were adults of the red flour beetle (*Tribolium castaneum*) (Table 1). This stored grain pest was the most abundant pest as it was recorded from several grain samples as well as in the insect samples collected from traps deployed in on-farm bins (Tables 1 and 2). Among other stored-insect pests, confused flour beetle (*Tribolium confusum*) and the Angoumois grain moth (*Sitotroga cerealella*) adults were also found in corn grain samples (Tables 1 and 2). However, the abundance of these two pests was very low compared to the red flour beetle. Both species of flour beetles look similar and infest a variety of stored-grain commodities and processed grains/food (Weston and Rattlingourd, 2000). However, the results of this study reveal a higher abundance of the red flour beetle in this region compared to the confused flour beetle, which is known to be widely distributed in the northern states (Smith and Whitman, 1992). In contrast, the red flour beetle is generally known to be present in higher abundance across the southern states due to favorable weather/temperature conditions. For instance, adult populations of the red flour beetle can increase with increasing temperature, especially if it equals or exceeds 80.6 °F (27 °C) (Arthur et al., 2019). Favorable weather could be one of the reasons for a higher abundance of this beetle in our survey samples and trap captures. Angoumois grain moth adults, as well as larvae, were also found in corn grain samples, but fewer in numbers compared to flour beetles. The larva of the Angoumois grain moth feeds on grains and causes damage to grain kernels. It is considered a serious pest of various stored grains, and in higher abundance, it has the potential to cause significant losses in commercial grain storage bins. Hidden infestation (primarily due to Angoumois grain moth) in sample grains was recorded only in few samples (Table 2). Like many other stored-grain pests, the Angoumois grain moth prefers grains with higher moisture, and therefore maintaining the dryness of grains is important in preventing population buildup in storage bins.

On-farm storage is essential for growers to capture the best price possible for their commodities. As per a survey estimate, post-harvest losses exceed well over $500 million per year in the United States (Harein and Meronuck, 1995). A combination of several factors, such as broken grain kernels, high temperatures, and moisture provide favorable conditions for rapid insect development and population buildup in on-farm storage. Storage infestations originate in the field, or insects may move to newly stored grain and infest grain bins. If the insect infestation is not detected or controlled timely, stored-insect pests can reach extremely high population levels in on-farm grain bins and could establish populations in grain-moving equipment, subfloors, or other parts of storage, and discarded grains. Maintaining proper sanitation in and around storage structures is the key for the successful management of stored insect pests. Many growers, while knowledgeable on pest management in the field, have limited knowledge about management strategies related to stored grain insects. As per the standard, grains are graded as "infested" if two live insects per 1,000 grams of grains of field crops (such as wheat) are found during inspection (Mason and McDonough, 2012). Infested grade grains usually result in significant economic losses to the seller. However, the numerical grade of the grain and the standard varies from crop to crop. In field crops such as corn and sorghum, the presence of "one live weevil, a live weevil plus any five or more other live insects, or no live weevils but 10 other live insects injurious to stored grain "results in designating grain in infested category (Mason and McDonough, 2012). Many growers resort to fumigation for controlling stored-grain pests; however, the cost is high and treating when not needed results in a lower return on investment. Growers could minimize insect management costs and economic losses from stored-grain pests by selective treating of bins only if insect populations exceed economic threshold levels. Such a strategy would also minimize the risk of unexpected pest problems, and most importantly, the use of fumigant chemicals in storage bins (Flinn et al., 2003). Based on the findings of this study, we plan to develop appropriate management recommendations for the major insect pests of stored corn grains in Arkansas farms and provide an educational program available to growers and other interested agricultural clientele. Based on our results, we also aim to refine sampling and monitoring techniques for timely detection and thereby management of these pests, which will be delivered to growers via various extension platforms, and will also be incorporated into the University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations/publications.

Practical Applications

In this statewide survey study, we document the status of various insect pests that infest corn and other commodities while in storage on Arkansas farms. Considering the higher incidences of insect pest infestation in stored corn in Arkansas, this study is essential in identifying such pest problems and developing cost-effective and sustainable pest management recommendations for these pests causing losses to stored corn and other commodities in Arkansas. The findings of this study will help us to identify and develop sustainable management recommendations for the major stored-insect pest infesting corn grains in a storage environment and provide growers and other decision-makers with the proper methods to control stored grain insects on the farm and make better management decisions on control. It will also help us in determining the effectiveness of selected methods for control of stored grain pests and develop and deliver information on appropriate management recommendations, including sampling and monitoring techniques for timely management of insect pests infesting stored corn on Arkansas farms.

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Table 1. Insect abundance in samples collected in traps deployed in on-farm storage bins in different corn-growing regions in Arkansas.

Sample date	Sample location/ID	Red flour beetle adults	Confused flour beetle adults	Larvae	Pupae	Sap Beetle	Angoumois Grain Moth
11/8/2018	Brinkley#2	85	4	0	1	0	0
11/8/2018	Brinkley#1	21	0	0	2	0	0
11/8/2018	Lodges Corner#1	5	0	0	0	0	0
11/8/2018	Almyra#1	0	0	0	0	0	0
11/8/2018	Lodges Corner#3	6	0	0	0	0	0
11/8/2018	Lodges Corner#2	3	0	0	0	0	0
11/8/2018	Brinkley#3	58	0	0	4	0	0
11/8/2018	Almyra#2	2	0	0	0	0	0
11/8/2018	Almyra#3	0	0	0	0	0	0
11/8/2018	Lodges Corner	34	2	0	0	0	0
10/25/2018	Brinkley	3	0	0	0	0	0
10/23/2018	B252	483	2	0	0	0	0
10/23/2018	B253	464	1	0	0	0	0
10/23/2018	B152	2730	52	4	2	0	0
10/23/2018	B153	792	1	1	0	0	0
10/23/2018	B151	1549	135	3	1	0	0
10/23/2018	B251	553	90	0	0	0	0
11/8/2018	Brinkley	10	7	0	4	10	0
	Tillar Bin #2	0	0	0	0	0	0
10/19/2018	Almyra	0	0	0	0	0	0
	Tillar Bin #3	0	0	0	0	1	7
10/14/2018	Conway	0	0	0	0	0	0
10/24/2018	Lodges Corner	0	0	0	0	0	0
10/24/2018	Manila	0	0	0	0	0	0
	Tillar Bin #1	0	0	0	0	0	0
9/27/2018	Craighead Co.	0	0	0	0	0	0
9/27/2018	Greene Co.	0	0	0	0	0	0
11/8/2018	Almyra	0	0	0	0	0	0
	Tillar Bin #1	0	0	0	0	0	0
	Tillar Bin #2	0	0	0	0	0	0
10/24/2018	Greene Co.	0	0	0	0	0	0
9/21/2018	Manila	0	0	0	0	0	0
	Tillar Bin #2	0	0	0	0	0	0
10/24/2018	Craighead Co.	0	0	0	0	0	0

Table 2. Insect abundance and infestation in grain samples collected from on-farm storage bins in different corn-growing regions in Arkansas.

Bin/Sample ID (Date)	Red flour beetle adults	Confused flour beetle adults	Angoumois Grain Moth	Beetle larva	Hidden infestation (%)
Almyra Grain Sample (10/19/18)	0	0	0	0	0
Almyra Grain Sample (11/8/18)	1	0	0	0	0
Almyra Grain Sample (12/12/18)	0	0	0	0	0
Almyra Grain Sample (1/25/19)	0	0	0	0	0
Almyra Grain Sample (2/20/19)	1	0	0	0	0
Bin # 1, Tillar (1)	0	0	0	0	0
Bin # 1, Tillar (2)	0	0	0	0	0
Bin # 1, Tillar (3)	0	0	5	0	2
Bin # 2, Tillar(1)	0	0	0	0	0
Bin # 2, Tillar (2)	0	0	3	1	2
Bin # 2, Tillar (3)	0	0	10	0	6
Brinkley Grain Sample 10/25/18	10	0	1	0	0
Brinkley Grain Sample 11/8/18	55	3	5	22	8
Brinkley Grain Sample 12/11/18	11	6	7	59	6
Brinkley Grain Sample 1/24/19	1	0	0	0	0
Brinkley Grain Sample 2/23/19	0	0	3	0	0
Craighead Co. (10/24/18)	0	0	0	0	0
Craighead County (11/26/18)	0	0	0	0	0
Craighead Co.(11/9/20)	6	0	0	0	0
Craighead Co.(10/8/20)	1	0	1	0	0
Greene Co. (10/24/2018)	0	0	0	0	0
Greene Co. (11/26/2018)	0	0	0	0	0
Greene Co. (10/8/2020)	11	0	0	0	0
Greene Co. (11/9/2020)	0	0	0	0	0
Lodges Corner Grain Sample (10/24/18)	0	0	0	0	0
Lodges Corner Grain Sample (11/8/18)	1	2	0	0	0
Lodges Corner Grain Sample (12/12/18)	1	0	0	0	0
Lodges Corner Grain Sample (1/25/19)	0	0	0	0	0
Conway (10/14/18)	0	0	0	0	0
Craighead Co. (9/27/18)	0	0	0	0	0
Greene Co. (9/27/18)	0	0	0	0	0
Manila (9/21/18)	0	0	0	0	0
Manila (10/24/18)	0	0	0	0	0
Manila (12/12/18)	0	0	0	0	0
Manila (10/17/20)	9	1	0	0	0
Manila (11/9/20)	3	0	0	2	0

Conventional Corn Tolerance to Low Levels of Roundup Powermax (Glyphosate)

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Abstract

Conventional (non-GMO) corn production has significantly increased in portions of Arkansas. These conventional hybrids do not contain the Roundup Ready trait, and thus, they are at risk from off-target movement of Roundup (glyphosate) from surrounding crops. Arkansas corn growers can benefit from growing conventional corn hybrids if the impact from off-target movement of Roundup can be understood and minimalized. Trials were conducted in 2019 and 2020 to evaluate the crop response following low rates of Roundup PowerMax applied to a conventional corn hybrid. In 2019, one trial was established with Gateway 7157 conventional hybrid at Tillar, Arkansas in a Hebert silt loam soil. In 2020, trials were established with the same hybrid at Tillar, Arkansas, in a Hebert silt loam soil, Marianna, Arkansas in a Loring Silt loam soil, and Fayetteville, Arkansas in a Captina silt loam soil. Trials were arranged in a randomized complete block design with four replications. Due to uniformity of data across location and years, data were pooled, and means were separated using Tukey-Kramer grouping for treatment least squares means at α = 0.05. All treatments received Aatrex at 64 oz/ac plus Dual II Magnum at 16 oz/ac applied preemergence followed by a Roundup PowerMax treatment at either stage V2 or V6 corn (Barber et al., 2020). Roundup PowerMax rates ranged from 0.32 oz/ac (1/100X) to 6.4 (1/5X) at each stage. Visual corn injury 14 days after V2 applications was highest, with Roundup at 6.4 oz/ac causing 91% and lowest with Roundup at 0.32 oz/ac causing 4%. Stage V2 corn injury increased as the herbicide rate increased, which was expected. Visual corn injury from V2 applications continued 14 days after V6 applications in a similar trend with Roundup applied at 6.4 and 3.2 oz/ac to V2 corn causing the highest injury at 72% and 53%, respectively. These two rates also caused the highest injury when sprayed at V6. Overall injury was higher when Roundup was applied at V2 vs. V6 growth stage. Roundup applied at 6.4 and 3.2 oz/ac rates to V2 corn caused the highest yield reduction, with corn yielding 21 and 68 bu./ac, respectively. Corn yields were not reduced from Roundup rates 1.6 oz/ac or lower for any growth stage.

Introduction

Roundup Ready technology is present in over 90% of corn, soybean, and cotton acres planted in Arkansas. Conventional corn hybrid acres are increasing in some areas of the state due to niche markets that have become available (Barber pers. comm.). Off-target movement of Roundup to conventional corn is a major concern due to the sensitivity of non-traited hybrids to Roundup (Ellis et al., 2003). In addition, the majority of neighboring fields contain herbicide programs that are predominantly Roundup-based. Conventional corn producers in Arkansas have voiced concerns that low-level rates of off-target glyphosate are resulting in reduced corn yields. Conventional corn provides a necessary refuge for insects and can be a great rotation for some weed species found in Arkansas. In 2019 and 2020, the research objective was to establish the level of conventional corn tolerance to Roundup when applied at lower drift simulating rates.

Procedures

In 2019, one trial was established with Gateway 7157 conventional corn at Tillar, Arkansas, in a Hebert silt loam soil. In 2020 similar trials were established with Gateway 7157 in three locations. The locations were in Tillar, Arkansas in a Hebert silt loam soil, Marianna, Arkansas in a Loring Silt loam soil, and Fayetteville, Arkansas in a Captina silt loam soil. All trials were planted at a rate of 35,000 seeds per acre the second week in May. Experimental plots were arranged in a randomized complete block design with four replications. Means were separated using Tukey-Kramer grouping for treatment least squares means at α = 0.05. All treatments received Aatrex at 64 oz/ac plus Dual II Magnum at 16 oz/ac applied preemergence followed by a Roundup PowerMax treatment at V2 or V6 stage corn (Table 1). Roundup Powermax rates applied were 20%, 10%, 5%, 2.5% and 1% of the labeled rate of 32 oz/ac (Table 1). Visual crop injury was evaluated 14 days after the V2 applications and again 14 days after the V6 applications. Visual crop injury may consist of stunting, chlorosis, or necrosis. The trial was taken to yield, and the center 2 rows of the four-row plot were harvested with a plot combine (Table 2). Fertility and pest management were maintained throughout the period of the experiment based on University of Arkansas System Division of Agriculture's Cooperative Extension Service recommendations, and corn yield was collected for each plot and analyzed to determine if any lasting effects occurred from Roundup injury.

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Results and Discussions

At 14 days after V2 application, corn injury increased as the Roundup rate increased. Visual injury ranged from 4%, with Roundup applied at 0.32 oz/ac, to 91%, with Roundup at 6.4 oz/ac. Roundup applied V2 at 3.2, 1.6, and 0.8 oz/ac caused 74%, 41%, and 16% visual injury, respectively. At 14 days after V6 application, injury in corn treatments from V2 applications had decreased across all treatments and ranged from 0 to 72% with Roundup at 6.4 oz/ac still causing the highest visual injury. Injury from V6 applications followed the same trend as the earlier application, with Roundup at 6.4 oz/ac causing the most injury at 36%. Roundup applied to V6 corn at 3.2, 1.6, 0.8, and 0.32 oz/ac caused 30%, 13%, 4%, and 2% injury respectively, 14 days after V6 application. Conventional corn yield reduction followed the same trend as visual injury. When Roundup was applied at 6.4 or 3.2 oz/ac at stage V2 or V6, corn yield was less than the untreated check and ranged from 21 to 77 bu./ac. Roundup applied V2 or V6 at 1.6, 0.8, and 0.32 oz/ac did not result in significant yield reduction (Table 2). Data from this research across four site years suggest that Roundup PowerMax rates that are lower than 1.6 oz/ac (5% of the label) cause significantly lower visual injury and do not negatively affect conventional corn yields. Corn plants that are exposed early (V2) to rates similar to 1.6 oz/ac will show significant injury, but the yield will not likely be reduced. The data also suggest that younger corn is generally more susceptible to off-target movement from Roundup.

Practical Applications

Preliminary data supports the idea of low levels of Roundup tolerance in conventional corn. Extra care should be exercised when growing conventional corn adjacent to fields sprayed with Roundup. If the off-target movement of Roundup does occur to conventional corn, yield penalties will be dependent on the actual rate of exposure, and if not severe, corn plants should recover in two to four weeks. It is important to note that off-target events are rarely uniform and seldom affect entire fields.

Acknowledgments

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Table 1. 2019 and 2020 Roundup application timing and rate at Tillar, Marianna, and Fayetteville, Arkansas.

Treatment Number	Herbicide	Rate	Timing
		oz product/ac	
1	Untreated		V2[†]
2	Untreated		V6
3	Roundup PowerMax	6.4	V2
4	Roundup PowerMax	6.4	V6
5	Roundup PowerMax	3.2	V2
6	Roundup PowerMax	3.2	V6
7	Roundup PowerMax	1.6	V2
8	Roundup PowerMax	1.6	V6
9	Roundup PowerMax	0.8	V2
10	Roundup PowerMax	0.8	V6
11	Roundup PowerMax	0.32	V2
12	Roundup PowerMax	0.32	V6

[†] V2 = vegetative stage of 2 leaves, V6 = vegetative stage of 6 leaves.

Table 2. Visual corn injury (%) 14 days following V2 and V6 applications and yield (bu./ac). Data were pooled across locations and years.

Treatment Number	Visual Injury[†] 14 Days After V2[‡]	Visual Injury 14 Days After V6	Yield
	(%)	(%)	(bu./ac)
1	0 e[§]	0 e	188 ab
2	.	0 e	171 ab
3	91 a	72 a	21 e
4	.	36 bc	25 de
5	74 b	53 ab	68 cd
6	.	30 cd	77 c
7	41 c	19 cde	147 b
8	.	13 de	162 ab
9	16 d	10 de	188 ab
10	.	4 e	195 a
11	4 de	0 e	195 a
12	.	2 e	170 ab

[†] Visual injury percentage is derived from comparing the treated plot to the untreated plot. The untreated plot represents a plot with no injury present. 0 equals no injury while 100 would be complete death of the crop.

[‡] V2-vegetative stage of 2 leaves, V6-vegetative stage of 6 leaves.

[§] Values with the same letter indicate no significant difference.

Irrigation Timing, Intercropping, and Tillage Effects on Corn Yield

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

Abstract

Two studies were conducted in furrow-irrigated corn at the University of Arkansas System Division of Agriculture's Arkansas Rice Research and Extension Center near Stuttgart, Arkansas. An irrigation timing study comparing the calendar-based method of irrigation timing to soil moisture sensor decision-based irrigation was evaluated in 2020 in Stuttgart, Marianna, and Rohwer, Arkansas. Another study conducted near Stuttgart, Arkansas, compared no-till, tillage, and clover intercropping treatments. The calendar-based method consisted of irrigating every 7–10 days. The sensor-based method consisted of irrigating when the soil moisture sensors indicated. The sensor-based irrigation achieved a significantly higher yield of 20.5 bu./ac ($P = 0.02$; $P = 0.01$) and 60% less irrigation water using sensor-based irrigation than the calendar method (12 ac-in./ac) in Stuttgart. In Marianna, sensor-based irrigation resulted in a 12.1 bu./ac significantly higher yield ($P = 0.01$) and 47% less water (8 ac-in./ac) than the calendar method. In Rohwer, yield and water use were not significantly different between the treatments. The tillage study measured the effects of no-till on water use and yield as well as the potential of intercropping for reducing water use. The intercropping treatment was treated as the no-till treatment until 20 May 2020, when clover was broadcast seeded at the V8 stage. There was no significant difference observed in yield between any of the three treatments. The intercrop treatment required less water than the tillage and no-till treatments when irrigation was scheduled with soil moisture sensors.

Introduction

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%.

Halvorson et al. (2006) found 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 the continuous tillage system than in the no-till system, but lower yield in the no-tillage system may have been as a result of slower early spring development and delayed tasseling. Sainju and Singh (2001) found that yields between chisel plow (tillage) and no-till corn 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.

The purpose of this study was to evaluate the improvement in yield and irrigation water use between the widely utilized calendar (weekly) method of timing irrigation compared to soil moisture sensor-based irrigation decision making. Infiltration improvements from no-till and cover crops are expected to reduce irrigation frequency through improved water holding capacity. In order to test this theory, the tillage treatments were implemented to compare yield and water use.

Procedures

Corn P1563VYHR Pioneer hybrid was planted at the University of Arkansas System Division of Agriculture's 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 in 2019. Plots were four rows wide and 550 ft long, and the middle two rows were harvested for yield. The same hybrid was planted at the Rice Research and Extension Center near Stuttgart, on a 30-in. row spacing furrow-irrigated field on a soil mapped as a DeWitt silt loam soil in 2017 through 2019. Plots in Stuttgart were 1200 ft long and 8 rows wide, and the middle four rows were harvested for yield. Planting dates were in late April or early May, generally towards the end of when local farmers were finishing planting corn. This was done to increase the probability that irrigation treatment effects could be created. The study area was in continuous corn for the four-year period of the study. Plots in Rohwer were on 38-in. row

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spacing furrow-irrigated fields on a Sharkey clay with 1,000 ft long 4 row wide rows. The previous crop was soybeans.

Plots were randomized with three replications in a split-plot design and irrigated using lay-flat pipe (Delta Plastics, Little Rock, Ark.). Field preparation, fertilization, planting, and herbicide/pesticide treatments were practiced according to the University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) recommendations. Irrigation treatments in Marianna and Rohwer were tilled, but in Stuttgart, there was no tillage before planting, albeit a Perkins furrow runner was used to clean out the middles of the furrows.

Irrigation treatments included sensor-based irrigation and calendar-based or weekly irrigation. Granular matric potential soil moisture sensors were installed at 6, 12, 18, and 30 in. depths in all sensor base irrigation plots. Treatments were replicated four times. Sensors were read and logged with a 900M Watermark monitor data loggers (Irrometer, Riverside, Calif.) in Marianna. At the site near Stuttgart and Rohwer, Agsense telemetry units (Huron, S.D.) were used.

Weather parameters were recorded with a WatchDog 2900 ET Weather Station (Spectrum Technologies, Aurora, Ill.) installed adjacent to the fields in Rohwer and Marianna. In Stuttgart, a Davis Weather-link Station was used (Vernon Hills, Ill.).

Sensor-based irrigation was scheduled using the CES mobile app, "Arkansas Soil moisture calculator" using a 50% allowable depletion and a silt loam with a pan soil type for Stuttgart and Marianna and clay soil type in Rohwer. The app calculates the remaining available water, and irrigation decisions were based on this information. In Stuttgart and Rohwer, the effective rooting zone was assumed to be 30 in., in Marianna, because of the presence of a fragipan, the rooting zone was assumed to be 24 in. and were based on sensor responses.

The calendar-based irrigation method included irrigating every Monday unless rain provided adequate soil water. The weekly-based irrigation method was applied in accordance with local farmer decisions about irrigation in the area. Thus, if farmers around the station locations were irrigating, the calendar treatments were irrigated. All data were analyzed using analysis of variance in JMP Pro. The measured outcomes were tested by the assumptions of the mathematical model (normality and homogeneity of variance). The factor means for each response variable, when significant, were compared by Tukey's honestly significant difference test at a 5% probability.

A dry fertilizer mix was applied in Stuttgart on 18 April 2020. The mix contained 80 lb N – 110 lb P – 115 lb K – 25 lb S – 0.27 lb Mg – 15 lb Zn – 0.29 lb Mn – 0.95 lb Fe. On 20 May 2020, when the corn was in V3–V4 stage, an application of 50 lb N as ESN and 90 lb N as urea was applied for a total of 220 lb of N. On 30 June 2020, leaf tissue samples were taken and analyzed for cell tissue N. A need for more nitrogen was shown, and on 5 July 2020, 50 lb of N was aerially applied. On 3 July 2020, 13.7 oz/ac of the herbicide Trivapro was applied by air. Similar herbicide and fertility programs were applied in Rohwer and Marianna using glyphosate, glufosinate, atrazine, and Acuron herbicides. Emergence in Stuttgart occurred 26 April 2020, and the resulting population was 35,000 at all three locations. Hole sizes for the study were determined using Pipe Planner (Delta Plastics, Little Rock, Ark.) for the maximum flow rate delivered to the study.

Irrigation Timing Study

A furrow runner was used to clean the furrows and provide a more consistent flow between the different treatments. The calendar irrigation timing treatment was irrigated roughly once every 7 days. This irrigation timing is consistent with the timing used by many farmers in the surrounding area. Irrigation was initiated for the calendar method on 16 June 2020. The first irrigation based on the soil moisture sensors was on 7 July 2020.

Tillage Study Procedures

The Tillage study consisted of 3 treatments: conventional/till, no-till, and no-till intercrop. Irrigation was scheduled using soil moisture sensors in the same way as the sensor-based scheduling treatment in the irrigation timing study. For the tillage treatment, a field cultivator and bedder-roller were used to incorporate residues and reform beds. Corn was seeded directly into the 4-year existing beds in the no-till and intercrop treatments without the furrow runner. On 20 May 2020, when the corn was a V5, a mix of glufosinate at 22 oz/ac with 1% ammonium sulfate was sprayed on the field. Then on the same day, a mix of red, crimson, and white clover was inter-seeded at a rate of 20 lb per acre (Acuron and atrazine applications were omitted from the intercrop treatments). Morning glories pressure from the lack of herbicide control in the intercrop treatments required treatment. On 20 June 2020, a mix of 32 oz/ac of glyphosate was applied, and the clover reseeded; however, the corn was at V8 and the canopy nearly closed, so little clover emerged.

Results and Discussion

Irrigation Study Results

In Stuttgart, the sensor-based irrigation was not irrigated until 3 weeks later than the calendar-based irrigation method and also received fewer total irrigation events. This resulted in a 57% (12 ac-in./ac) reduction in irrigation water use, where the sensor-based treatment had 9 ac-in./ac applied, and the calendar-based treatment had 21 ac-in./ac applied (Table 1). Additionally, the sensor-based treatment also averaged a significantly higher yield ($P = 0.02$) at 179.3 bu./ac compared to the average yield of the calendar-based treatment at 158.8 (Table 1).

In Marianna, the sensor-based irrigation treatments yielded 242.3 bu./ac, which was significantly higher than the calendar treatment yield of 229.9 bu./ac ($P = 0.01$). The irrigation water use of 9 ac-in./ac for the sensor-based treatments and 17 ac-in./ac for the calendar treatments, resulting in 8 ac-in./ac less water.

In Rohwer, the sensor-based irrigation yielded 251.3 bu./ac, and the calendar method yielded 246.5 bu./ac, but the difference was not significant. Irrigation water use was 13 ac-in./ac for both the calendar and sensor methods (Table 1).

Tillage Study Results

When comparing the average yields of the till, no-till, and intercrop studies; no significant difference is found ($P = 0.49$).

These results are the same for the previous 3 years. For water use, till and no-till received nearly the same amount of irrigation at 12.3 ac-in./ac and 12.1 ac-in./ac respectively (Table 2). Only 9.7 ac-in./ac of irrigation was needed for the intercrop treatment.

Practical Applications

Irrigation timing by sensors shows great promise in reducing water use in corn. A significant increase in yield of 12–20 bu./ac was observed in two of the three locations. The results indicate that sensor-based scheduling can result in improved profitability, as was found in Spencer et al. (2019). Water use was also around half in two of the three locations by 8–12 ac-in./ac.

The data from the last four years shows that no significant difference in yield between tillage and no-till treatments. The cost savings from reducing tillage improves profitability with the no-till production system. In the Stuttgart location, using both no-till and sensor-based irrigation resulted in the highest yield and irrigation water use differences.

The study has only been able to successfully implement cover crop or intercrop treatments in 1 out of 4 years and always with a yield penalty, additional research and work is needed to develop this production system.

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Table 1. Irrigation treatment yields in bushels per acre (bu./ac) between soil moisture sensor- and calendar-based scheduling at Stuttgart, Marianna, and Rohwer between 2018–2020.

Year	Location	Sensor-based Scheduling	Calendar	Sensor-based Scheduling	Calendar
		(bu./ac)	(bu./ac)	ac-in./ac	ac-in./ac
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		

[†] Letters denote significant difference for the row ($\alpha = 0.05$).

Table 2. Tillage treatment yields in bushels per acre (bu./ac) by year at Stuttgart, 2017–2020.

Year	Tillage/Conventional	No-Till	Cover-Crop and No-Till
	(bu./ac)	(bu./ac)	(bu./ac)
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 Three Years of the University of Arkansas System Division of Agriculture Corn Irrigation Yield Contest

C.G. Henry,[1] T. Clark,[1] G.D. Simpson,[1] P.N. Gahr,[1] and J.P. Pimentel[2]

Abstract

The University of Arkansas System Division of Agriculture Irrigation Yield Contest was conducted between 2018 and 2020. The contest was designed to promote better use of irrigation water as well as to record data on water use and water use efficiency for various crops. Unlike yield contests where winners are decided by yield alone, the irrigation contest results are ranked by the highest calculated total water use efficiency (WUE) achieved. 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- or 10-in. portable propeller mechanical flow meters. Rainfall totals were calculated using Farmlogs™. The contest average water use efficiency of 2018–2020 for corn was 8.34 bu./in. The winning WUE was 11.53 bu./in. for 2020, 11.36 bu./in. for 2019, and 10.55 bu./in. for 2018. The adoption of irrigation water management (IWM) practices such as computerized hole selection (CHS), Surge irrigation, and soil moisture sensors is increasing. Corn contest participants report using on average 9.0 ac-in./ac of irrigation per year.

Introduction

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

A study was conducted from 2013 to 2017 in primarily corn and soybean fields to assess the water-saving potential of implementing 3 irrigation water management (IWM) tools: computerized hole selection, surge irrigation, and soil moisture sensors (Spencer et al., 2019). Paired fields were set up, with one using the IWM tools and one using conventional irrigation methods. It was found that the implementation of all 3 IWM tools reduced water use in the soybean fields by 21%, while not reducing yields. This resulted in an increase in water use efficiency (WUE) of 36%. For the cornfields, a 40% reduction in water use was observed, and WUE increased by 51%.

The University of Arkansas System Division of Agriculture's Irrigation Yield Contest was designed as a novel way of encouraging the use of water-saving methods by Arkansas corn growers. The competition aimed at promoting 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 in multiple crop types under irrigated production in Arkansas, and by recognizing producers who achieved a high water use efficiency.

Procedures

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

A portable propeller-style mechanical flowmeter was used to record water use. All flowmeters were checked for proper installation and sealed using stamped polypipe tape and serialized tamper-proof cables. Rainfall was recorded using Farmlogs™, an online software that provides rainfall data for a given location. Rainfall amounts were totaled from the date of corn emergence to the date of physiological maturity. Emergence was assumed to be 7 days after the planting date provided on contestant entry forms. For physiological maturity, the seed companies published days to maturity was used. Rainfall adjustments were made for events in excess of 3 inches.

The harvest operations were observed by a third-party observer, often a County Extension Agent, Natural Resources Conservation Service (NRCS) employee, or University of Arkansas System Division of Agriculture staff. For the yield estimate, a minimum of 3 acres was harvested from the contest field.

The equation used for calculating WUE for the contest was:

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

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

Results and Discussion

Detailed results are published on the contest website (https://www.uaex.uada.edu/environment-nature/water/agriculture-irrigation/irrigation-contest.aspx) for each year of the contest. Over the three years that the competition has been conducted, there have been 30 fields entered for corn. The average WUE over the 3 years was 8.34 bu./in. By year, the average WUE was 8.08 bu./in. for 2020 with 14 contestants, 8.06 bu./in. for 2019 with 10 contestants, and 9.36 bu./in. for 2018 with 8 contestants (Table 1). The year 2018 had a higher average WUE than 2020. In 2020 and 2019, there were more contestants in corn than in 2018. This may partially explain the lower WUE because more variation is expected with a larger number of growers. The winning WUE was higher in 2020 than in 2018 and 2019. The winning WUE for each year was 11.53 bu./in. for 2020, 11.36 bu./in. for 2019, and 10.55 bu./in. for 2018.

It is a common belief that a higher or lower yield will help obtain a better WUE. Pearson's correlation coefficient was used to test the relationship between yield and WUE and was found to be 0.29. There is a poor positive correlation between yield and WUE, indicating that contestants with higher yields do not necessarily result in a higher WUE. Another commonly held belief by contestants is that a higher amount of rainfall received relative to other contestants will help to increase WUE. The Pearson correlation coefficient was found to be -0.30, indicating a poor negative correlation between rainfall and WUE. The lack of correlation suggests that neither precipitation nor yield is a factor in achieving high WUE, and achieving high WUE is dependent on how contestants manage irrigation.

In 2015, a survey was conducted across the mid-South to determine the adoption rate of various IWM tools (Henry 2020). On the entry form for the contest, a similar survey was included to compare the usage of IWM tools among the participants in the contest to the average in use in the mid-South and in Arkansas. In the 2015 survey, 40% reported using computerized hole selection and 66% of the Arkansas growers reported using computerized hole selection. Twenty-four percent of respondents said they used soil moisture sensors in the region on their farm, and only 9% of Arkansas irrigators reported using soil moisture sensors.

Contestants are asked about their adoption of IWM tools when they enter the contest. In total, 64% of the participants across all three crop contest 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 89% across all three years, with 88% in 2018, 72% in 2019, and 100% in 2020. Fifty-four percent of respondents from all three years said that they used soil moisture sensors on their farm, with 60% in 2018, 67% in 2019, and 42% in 2020. Surge valves were the least used IWM tool, with 28% of respondents from all 3 years indicating they used surge valves. This included 44% from 2018, 28% from 2019, and 16% from 2020.

Practical Applications

On average, corn growers in the contest across the three years averaged 218 bu./ac, an average WUE of 8.3 bu./in., 9.3 ac-in./ac of irrigation applied, and a total water use of 27.1 in. for corn. Irrigation water use efficiency (WUE) of working farms is not a common metric available in the literature, and it is not a metric familiar to corn farmers. The data recorded from the Arkansas Irrigation Yield Contest provides direct feedback to irrigators about their irrigation performance in maintaining high yields and low irrigation water use by providing their individual WUE from the contest entered field. Such direct feedback of 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. The adoption of IWM practices is high for contest participants, 89% for CHS, 54% for soil moisture monitoring, and 28% for surge irrigation.

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Table 1. Maximum, average, and minimum for 2018, 2019, and 2020 of various water and yield data points for corn from the Arkansas Irrigation Yield Contest.

Year		Water Use Efficiency	Yield	Adjusted Rainfall	Irrigation Water	Total Water
		(bu./in.)	(bu./ac)	(in.)	(ac-in./ac)	(in.)
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
3 Yr.	**Average**	8.34	218	17.8	9.3	27.1

Preliminary Evaluation of Soil Sampling Methods for Variable Rate Fertilization

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Abstract

Soil samples were collected from nine fields during 2018–2020 to evaluate different soil sampling methodologies, including two of the most popular interpolation methods. The interpolation methods used in this study were inverse distance weighting (ID) and Kriging (Kr). The ID method assumes that soil samples close to one another are more alike than those farther apart. In contrast, the Kr method considers the distance and how much variability exists among known soil sampling locations. Soil samples were collected in a 1-acre grid fashion in nine fields across Arkansas, representing different soil series and crop rotation practices. It appears that the choice of interpolation method may not only affect the total amount of nutrient recommended but also how the nutrient is distributed across a field. Empirical semivariograms were fit to both raw and log-transformed data using ArcGIS Geostatistical Analyst (ESRI, Redlands, Calif.), with Stable, Gaussian, and spherical (only for non-transformed data). The fitted model's selection was mainly based on which model had a resulting root mean squared standardized errors (RMSE) closest to 1. Semivariograms were used to determine the range, which is the distance that assures independent readings. Based on the spatial variability of the nutrients in the fields sampled as a part of this study, the estimated ranges for phosphorus (P) varied between 276 and 801 feet, corresponding to sampling grids of about 1 to 4 acres. In comparison, the calculated range values for potassium (K) varied between 401 and 1495 feet, which corresponds to sampling grids of about 2 to 8 acres. Apparent electrical conductivity (ECa) values were obtained to test the relationship between nutrient concentrations and ECa values. Results showed that, for the fields sampled as part of this study, the history of variable-rate fertilization appears to lessen the effect of soil type on nutrient concentration.

Introduction

The majority of the soil samples received by the University of Arkansas Soil Testing Laboratory in Marianna are collected for variable rate fertilization (VRF) purposes. It has been shown that landscape position, soil type, land forming, and previous management history affect the concentration of nutrients across a field. Properly accounting for the variability of a nutrient in a given field is critical for successful VRF. In Arkansas, soil samples are collected based on georeferenced grids between 2.5 to 10 acres in size, with 4–8 cores composited to represent the sampling unit. Alternatively, apparent electrical conductivity and perhaps yield maps are used to develop management zones where composite soil samples are collected. However, even with the large expenditures in VRF by farmers in Arkansas, information on the proper soil sampling method for VRF is minimal. Therefore, the choice of soil sampling method can become a significant source of error and negate the potential benefits of VRF. An additional error source is the choice of interpolation method to convert point estimates into continuous maps. How well an interpolation map predicts nutrient concentrations at unsampled locations is a function of the dataset's characteristics for each field. The most common interpolation methods used by providers in Arkansas are inverse distance weighting (ID) and Kriging (Kr). The ID method assumes that soil samples close to one another are more alike than those farther apart. In contrast, the Kr method considers the distance and how much variability exists among known soil sampling locations.

This study's objectives were 1) to conduct a preliminary evaluation of the different soil sampling methodologies used and 2) to evaluate the implications of using ID or Kr regarding the amount of fertilizer recommended for specific fields.

Procedures

Soil samples were collected from nine fields (nearly 1,000 acres) in Arkansas between 2018–2020. Fields were sampled with a Falcon automated soil sampler (www.falconsoil.com). This machine uses a steel drum to collect cores every 15 feet. Each sample was a composite of about 15 cores. When possible, the unit was pulled at a 45 degrees angle in each grid polygon. The soil was extracted for plant available nutrients using the Mehlich-3 procedure.

Field Descriptions

The fields were chosen as they included several soil series, and historical data showed significant spatial variability in the concentration of nutrients. All of these fields are irrigated, and some of them precision-leveled several years ago. Fertilizers, particularly K, have been applied with variable rate technology intermittently, for the last five years, except for field 6.

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Statistical Analysis

Descriptive statistics were estimated with the Univariate procedure in SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.), including the Shapiro-Wilk statistic, which was used to test for normality. When the normality test failed ($P < 0.05$), the data were log-transformed to stabilize the variance. Empirical semivariograms were fit to both raw and log-transformed data using ArcGIS Geostatistical Analyst (ESRI, Redlands, Calif.), with Stable, Gaussian, and spherical (only for non-transformed data) models tested. The fitted model's selection was mainly based on which model had a resulting root mean squared standardized errors (RMSE) closest to 1. A semivariogram describes the nature of spatial autocorrelation of soil samples at a specific distance and direction from each other. A semivariogram is composed of three parameters, including the range, which defines the minimum separation between soil samples to ensure the two samples are independent. Soil samples collected at distances closer than the range are assumed to be spatially autocorrelated. The *y*-axis (dependent variable) value corresponding to the range is called the sill. The sill represents the maximum semivariance between two sampling points and should approximate the population variance. It indicates the degree of uncertainty when interpolating the points. Theoretically, the model should intercept at the 0 value; however, in real life, measurement errors prevent this from occurring. The point at which the line intercepts the *y*-axis is called the nugget and it is a measure of experimental or human error.

Two interpolation methods were compared in terms of the total amount of fertilizer applied and the distribution of fertilizer according to soil test level category for soil samples collected on a 1-acre grid basis. Prescription maps were developed assuming corn was the intended crop. Additionally, the percent of the total amount of fertilizer falling into the currently used soil test categories "very low" (0–16 ppm for P; 0-60 ppm for K), "low" (16–25 ppm for P; 60–90 ppm for K), "medium" (26–35 ppm for P; 91-130 ppm for K), and "optimum" (36–50 ppm for P; 131–175 ppm for K) for each of the interpolation methods were estimated. An interpolation method is used to predict nutrient concentrations at non-sampled locations. The two interpolation methods evaluated were kriging (Kr) and inverse distance weighted (ID). Kriging (Kr) is a geostatistical interpolation technique that uses the known locations' statistical attributes to predict values at non-sampled locations. Kriging uses semivariograms to account for spatial autocorrelation. The inverse distance interpolation method is a deterministic (mathematical) technique. Inverse distance assumes that samples closest to the "prediction" location have more influence than those farther apart and assign a weight to the number of sites chosen to predict values at non-sampled locations. This method assumes that the weight decreases with distance. The weights are proportional to the inverse of the distance.

For each of the fields, 100% of the samples were used to generate maps of P and K, then the population was re-sampled, and maps were generated using soil samples collected at grid sizes equivalent to 2.5, 5, and 10 acres. The unused samples' nutrient concentration values were compared to the estimated values generated by each interpolation method. An EMP-400 unit (www.gsssi.com) was used to scan fields and collect apparent electrical conductivity (ECa) values. ECa readings were collected at approximately 50 feet intervals. The resultant information was used to test the relationship between nutrient concentrations and ECa values.

Results and Discussion

Table 1 shows some of the characteristics of the sampled fields. The fields ranged in size from 55 (field 6) to 135 acres (field 7). Three of the fields are mapped as silt loams in their entirety, while the rest of the fields have a mixture of several textural classes. Crops grown in these fields include corn (*Zea mays* L.), cotton (*Gossypium hirsutum* L.), soybean (*Glycine max* L.), and rice (*Oryza sativa* L.).

The average P and K concentrations and associated standard deviations are shown in Table 2. Seven of the fields had average P levels in the optimum range, with the other two being in the insufficient range. Fields 4 and 8 exhibited significant variability in the concentration of P, as evidenced by the respective standard deviations. Fields 1, 2, 3, and 7 have K levels in the sufficient range, as commonly seen in fields rotated with cotton. Fields 4, 5, and 9 had no history of variable rate fertilization.

The distribution of soil-test P failed the normality test for each site, based on the Shapiro-Wilk statistic (Table 3). In the case of K, fields 1 and 8 were the only locations that showed normal distributions. In those fields where the test for normality failed, soil-test P and K concentrations were log-transformed to reduce the variance (skewness) and calculate the empirical semivariograms.

The choice of the semivariogram model was based on the root mean square error (RMSE). The root mean square error is used as a qualitative measure for model selection, with RMSE values close to 1.0 considered a sign of appropriate model choice. The stable model was used to fit the empirical semivariogram as all of the fields failed the normality test. The spherical model was fitted only to fields 1 and 8. There was considerable variability in the value of the range among the fields for both P and K. The range defines the minimum distance needed between two samples. Samples collected at distances closer than the range are not considered independent. The estimated ranges for P varied between 276 and 801 feet, which corresponds to grids of about 1 to 4 acres, while the calculated range values for K varied between 401 and 1495 feet, which corresponds to grids of about 2 to 8 acres in size. It is evident that the grid size that best characterizes P and K's variability in a given field are typically different. The reasons for the discrepancies, even among fields with similar soil types, can be several, including the history of variable rate fertilization, rotational crops, irrigation, and weather, among others.

One of this study's objectives was to evaluate the use of management zones to guide sample collection, with such zones being defined by apparent electrical conductivity. We evaluated the relationship between ECa readings and soil test P and K. We divided the fields into two groups, one included fields with a history of VRF, while the other included fields with VRF history. Figure 1 shows the fitted regression model for fields with a previous history of VRF. The small coefficient of determination (R^2) is an indication of the lack of relationship between

ECa readings and soil test K. These results would question the validity of using management zones in the fields sampled in this study. Its use to direct soil sampling could give an inaccurate characterization of the spatial dependence of soil test K. Figure 2 shows the relationship between ECa and soil test K in fields with no history of VRF. The larger R^2 indicates a stronger connection between ECa and soil test K in these fields. Thus, these preliminary observations suggest that the dynamics of K in fields with a history of VRF may no longer be affected by textural class and associated soil types.

The implications of choosing a particular interpolation method over the other were also a subject of evaluation. The calculated amount of nutrient to be applied for a specific field, using the same information, varied depending on the interpolation method. In some instances, such a difference was minimal, but in other cases was significantly higher. The Kr method would typically result in more nutrient recommended than the ID method; however, that was not always the case. Figure 3 shows a K prescription map using the 1-acre grid information. When the Kr method was used, a total of 9188 lb of K_2O was prescribed, compared to 9562 lb of K_2O when the ID method was used. Although the difference of 374 lb of K_2O may not be considered significant, there is an additional consideration when selecting the interpolation method. The Kr method estimates 30% of the area as being in the "very low" category, compared to only 10% by the ID method. Therefore, for this particular case, one could assume that the risk of yield loss for under fertilization is higher when using the ID method. Figure 4 shows prescription maps based on 5-acre grids. In this case, the amount of nutrient recommended is basically the same; however, the ID method identifies no area testing "very low" compared to the 30% identified by the Kr method.

Practical Applications

Successful variable rate fertilization depends on prescription maps that accurately characterize the variability in a given field. Our preliminary results show that in the majority of the cases, the grid method that describes the variability in the concentration of potassium may not be the same for phosphorus. The grid size that described the variability for P varied between 1 and 4 acres and between 2 and 8 acres for potassium. Under the conditions of this study, it appears that the behavior of potassium in soil may no longer be affected by soil type if variable-rate fertilization has been practiced for several years. The effect of selecting an interpolation method over the other needs further evaluation. Different interpolation methods can suggest different amounts of nutrients to be applied to a particular field, and different interpolation methods can allocate the same amount of fertilizer differently in a particular field.

Acknowledgments

This research was funded by Fertilizer Tonnage Fees administered by the Arkansas Soil Test Research Board, the Corn and Grain Sorghum Research Board, and the University of Arkansas System Division of Agriculture. We acknowledge the Falcon Soil Technologies Group for providing a Falcon unit for collecting soil samples. We would also like to thank our farmer collaborators.

Table 1. Field number, size, previous crop, land forming practices, and proportion of each textural class in each field sampled.

					Proportion of the field under each textural class (%)			
Field	Size	Previous crop	Precision leveled?	County	Silt loam	Silty Clay	Clay	Fine Sandy Loam
	(ac)							
1	132	Soybean	No	Lee	62	15	23	
2	96	Corn	No	Lee		60	35	5
3	115	Cotton	Yes	Lee		85	5	11
4	113	Rice	Yes	Cross	57		43	
5	58	Soybean	Yes	Cross	58		42	
6	55	Corn	Yes	Cross	13		87	
7	135	Soybean	Yes	Lee	100			
8	112	Corn	No	St. Francis	100			
9	123	Cotton	No	St. Francis	100			

Table 2. Average phosphorus (P) and potassium (K) concentration (ppm) and standard deviation (ppm) in fields sampled on a one-acre grid basis. Samples were analyzed with the Mehlich-3 procedure.

	Field								
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
	Phosphorus								
Mean	53.2	40.8	42.2	35.5	21.1	19.9	80.3	55.3	21.1
Standard Deviation	10.7	9.1	8.5	18.4	5.4	5.8	8.2	18.7	6.2
	Potassium								
Mean	276.2	265.2	312.6	176.2	104.3	109.3	312.6	211.1	72.7
Standard Deviation	51.8	41.4	48.3	68.7	17.8	25.9	29.3	56.1	10.2

Table 3. Shapiro-Wilk statistic, resulting semivariogram range, approximate sampling grid size, and root mean square error associated with the fitted semivariogram model, for soil-test P and K in the sampled fields.

	Shapiro-Wilk Statistic		Range		Approximate sampling grid size		Root mean square error (RMSE)	
	-------(*P*-value)-------		----------(ft)---------		----------(ac)----------			
Field	**P**	**K**	**P**	**K**	**P**	**K**	**P**	**K**
1	<0.0001	0.0614	425	443	2	2	0.88	0.96
2	<0.0001	0.005	301	635	1	3	0.99	0.88
3	<0.0001	<0.0001	801	592	4	3	1.02	1
4	<0.0001	0.0003	428	733	2	4	1	1.04
5	<0.0001	<0.0001	601	401	3	2	0.97	0.92
6	<0.0001	0.0004	799	601	4	3	0.88	0.9
7	<0.0001	<0.0001	455	550	2	3	0.95	0.99
8	<0.0001	0.212	625	701	3	5	1.01	1
9	<0.0001	0.0012	276	1495	1	8	0.99	0.98

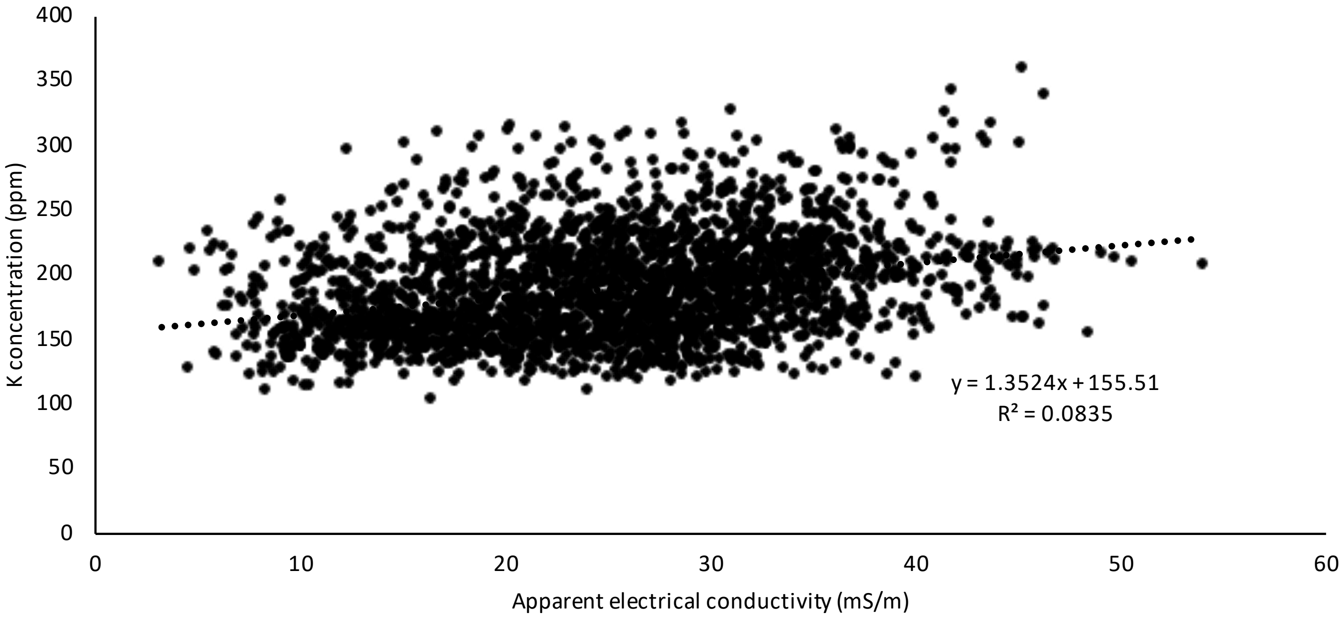

Fig. 1. Relationship between apparent soil electrical conductivity (mS/m) and soil test K (ppm) in soils with a history of variable rate fertilization with potassium.

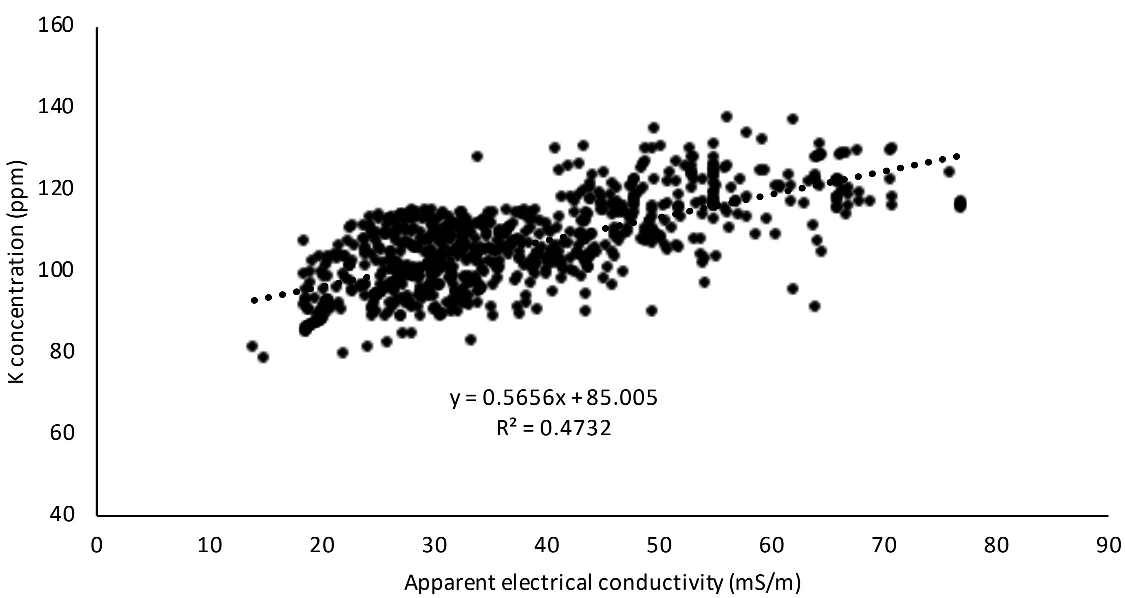

Fig. 2. Relationship between apparent electrical conductivity (mS/m) and soil test K (ppm) in soils with no history of variable rate fertilization.

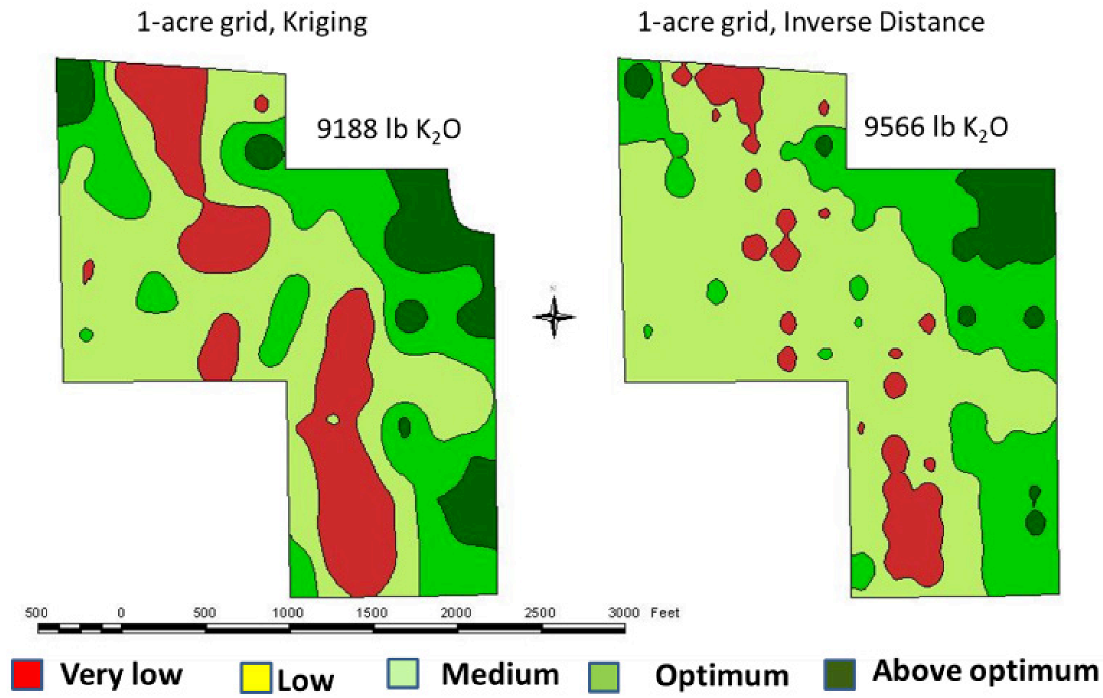

Fig. 3. Potassium prescription maps generated with the 1-acre grid soil test results, using the Kriging and Inverse Distance interpolation methods. The numbers represent the resultant amount of the nutrient to be applied according to each method. The maps were developed based on the soil test categories used by the University of Arkansas System Division of Agriculture and represented by the different colors at the bottom of the graph.

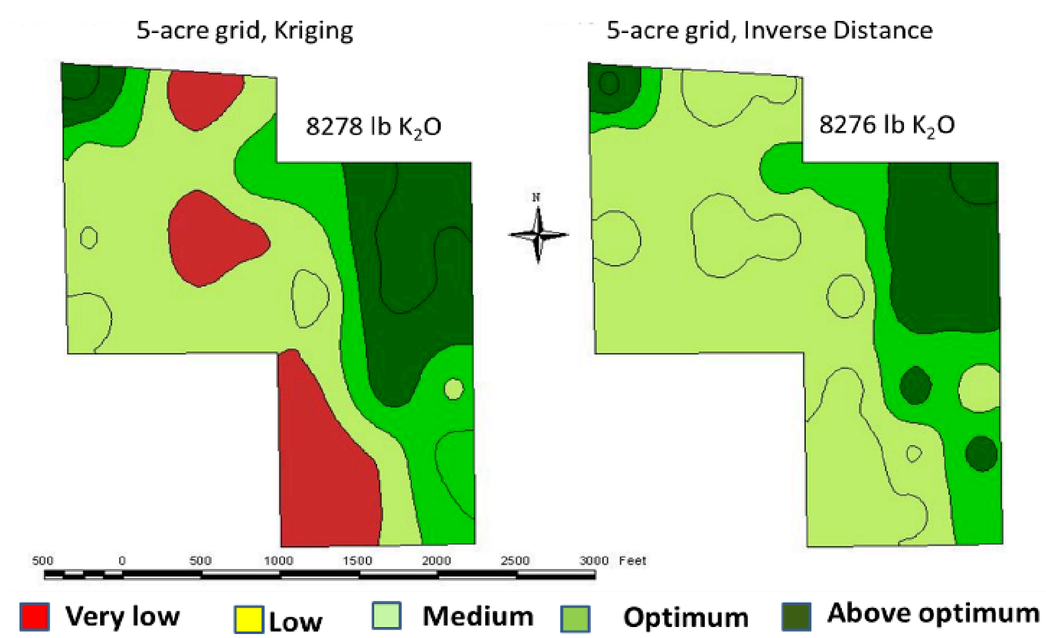

Fig. 4. Potassium prescription maps generated with the 5-acre grid soil test results, using the Kriging and Inverse Distance interpolation methods. The numbers represent the resultant amount of the nutrient to be applied according to each method. The maps were developed based on the soil test categories used by the University of Arkansas System Division of Agriculture and represented by the different colors at the bottom of the graph.

Effect of Cover Crop Termination Timing on Corn Population and Yield

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Abstract

Winter cover crops are used to address soil degradation issues. However, impacts of cover crop biomass on cash crop growth are not fully understood on soils common to the Arkansas Delta. In 2020, 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. Investigated were 1) cash crop plant population, 2) cover crop carbon to nitrogen (C:N) ratios 3), and cash crop yield. No differences in crop yields were observed among cover crop termination timing treatments for corn. 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 cash crop yields. Moreover, biomass from cover crop residues may increase soil health benefits over time.

Introduction

Soil degradation is associated with many current crop production systems. Soil degradation includes 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. As cover crop biomass is proportional to cover crop termination timing (Mirsky et al., 2017; Alonso-Ayuso et al., 2014; Balkcom et al., 2015; Acharya et al., 2017), 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 are still debated by farmers.

The carbon-to-nitrogen ratio 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 cereal rye (*Secale cereal*) used throughout sites in this study) generally have a high C:N (C:N > 24:1). 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 N early in the growing season could be detrimental to cash crop yield potential.

Additional relationships between C:N and corn production have been found. A study in Pennsylvania, on a silt loam soil, found 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).

The objective of this study was to determine the effects of cover crop termination timing (levels of cover crop biomass production) on cash crop growth and development in the Arkansas Delta. We hypothesized that delayed cover crop termination timing would not negatively impact cash crop production, including plant populations and yield.

Procedures

Cover crop termination timing studies were established in the fall of 2019 on row crop farms at 1 field site each at Walcott, Cotton Plant, and Oil Trough, Arkansas (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 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.

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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. Crop rotations for each of the sites were 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 cash crops were fertilized based according to standard practices of each farmer.

The corn cash crop was planted at a row spacing of 38 inches 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's Cooperative Extension Service recommendations.

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 four 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 using dry combustion method with a LECO CN (Leco, CNS 2000, St. Joseph, Mich.) analyzer (Kopp, & 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. Cash crop plant populations were determined by sampling three locations within each plot at every site. Plant population was determined during early growth stages (V1 to V3) using a chain of known length to measure a distance within a single cash crop row. Healthy cash crops within the same row were counted and then multiplied by a conversion factor to determine the cash crop 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 eight 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 of treatment effects on cash crop plant population, cover crop C:N, and cash crop 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

There were no issues chemically terminating the cover crop mixes for any of the termination timing treatments at any site. Cover crop biomass at all sites was significantly influenced by late-termination timing (Table 3). Maximum and minimum cover crop biomass across all sites and timings was 2335 and 244 lb/ac respectively. The results on cover crop biomass support other findings 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 aboveground 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 observable when cover crop biomass levels reached >4500 lb/ac (Keene et al., 2017; Hubbard et al., 2013). The lower cover crop biomass (<2400 lb/ac) produced in this study were 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.

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 (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 (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 inorganic N supply to the point that had any negative effects on cash crop yield.

Corn yields were not significantly different among cover crop termination treatments (Table 5). Corn yield across all sites ranged from 150 bu./ac at Cotton Plant to 208 bu./ac at Walcott.

Practical Applications

Crop yield is dependent on a number of environmental factors as well as farm management practices. While we did not observe significant increases in yields, we did not observe decreases in yields either. These results are important to producers because profits could potentially increase from cover crop use if they reduce other input costs. Delaying cover crop termination will increase cover crop biomass, which will supply more organic material to 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.

In addition to environmental factors, there has been evidence of correlation between yield and the number of years 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 increases in crop yields, 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.

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Table 1. Cover crop details for all sites, 2020.

Site	Year	Cover crop mixture†	Termination timing	Termination date	Growth stage‡
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,	Early	29-Feb.	late-tillering
		Austrian winter pea,	Mid	2-April	late-stem extension
		crimson clover, radish	Late	10-April	full-head
Walcott Middle	2020	winter wheat,	Early	7-March	tillering
		crimson clover	Mid	4-April	stem extension
			Late	29-April	mid-boot

† Cover crops were: Austrian winter pea (*Pisum sativum* L.), barley (*Hordeum vulgare* L.), black oats (*Avena sativa* L.), cereal 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. Cash crop details for all sites, 2020.

Site	Year	Cash crop	Variety	Seeding rate	Planting date	Row spacing	Harvest date
				(seeds/ac)		(in.)	
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 6744	34400	1-May	30	01-Oct.

Table 3. Cover crop biomass for all sites, 2020.

Site	Year	*P*-value	Treatment	Biomass
				(lb/ac)
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

[†] 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. Cash crop plant populations for all sites, 2020.

Site	Year	*P*-value	Treatment	Plant Population
				plants/ac
Cotton Plant	2020	0.4769	Control	27665 ns[†]
			Early	30238
			Mid	28340
			Late	28340
Oil Trough	2020	0.4913	Control	–
			Early	30927
			Mid	29352
			Late	30589
Walcott	2020	0.1353	Control	32501
			Early	33626
			Mid	31604
			Late	33513

[†] ns = not significant at the $\alpha = 0.05$ level within a site-year. Dash indicates nonexistent treatments at corresponding site.

Table 5. Corn grain yield for all sites, 2020.

Site	Year	*P*-value	Treatment	Yield[†]
				bu./ac
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 Middle	2020	0.3059	Control	203
			Early	208
			Mid	170
			Late	170

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

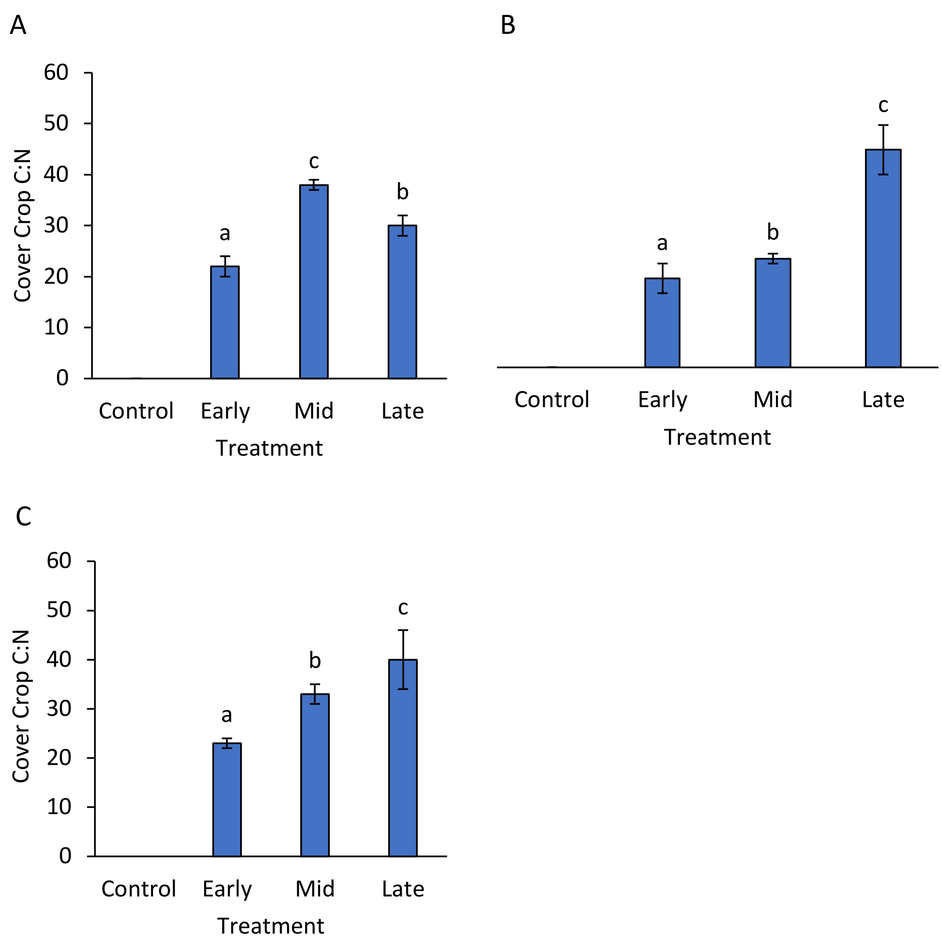

Fig. 1. Cover crop carbon to nitrogen ratio (C:N) for the termination timing treatments, 2020. Walcott (A), Cotton Plant (B), Oil Trough (C). Values with different letters within a site are significantly different by Tukey's honestly significant difference mean comparison (α = 0.05). Error bars represent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

Irrigated Rotational Cropping Systems, 2014–2020 Summary

J.P. Kelley[1] *and T.D. Keene*[1]

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 2013–2020 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 yields were 5 and 7 bu./ac, respectively, when planted following corn or grain sorghum compared to continuous soybean. Crop rotation impacted June-planted, double-crop soybean yield 1 out of 7 years, and average yields were 3 and 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 1 out of 7 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 4 out of 6 years of the trial. Wheat following full-season grain sorghum across all years yielded 8 bu./ac less than when following April-planted soybean, and 3 or 5 bu./ac less 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 82 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 found that corn yields following soybean were 15–31% higher than when corn was continuously grown; however, soybean yields were not statistically greater but trended to higher yields when planted following corn. In Tennessee, Howard et al., 1998 found that soybean following corn yielded 11% higher than compared to continuous soybean and attributed soybean yield increases following corn to reduced levels of soybean-cyst nematodes. As crop acreage continues to shift based on economic decisions, more information is needed for producers on which crop rotation produces the greatest yields and profitability under mid-South irrigated 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 Divisions 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 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 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 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 planted in April every year.
6. **Continuous Soybean**. Early planted group IV soybean planted in April every year.

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7. **Full-Season Grain Sorghum/Early Planted Soybean.** Full-season grain sorghum 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 a 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 varied by year, and maturity ranged from 112 to 117 days. Full-season grain sorghum was Pioneer 84P80 from 2014–2018 and DKS51-01 in 2019–2020. Double-crop grain sorghum hybrids grown included; Sorghum Partners 7715 and DKS 37-07, which are sugarcane aphid tolerant hybrids. In each year of the trial, Pioneer 26R41 soft red winter wheat 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 plot at crop maturity and remaining standing crops were harvested with a commercial combine. 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 thresholds levels during the course of this trial, and levels were generally greater than 500 nematodes/100cm^3 of soil (data not shown). No root-knot nematodes were found in the trial area.

Results and Discussion

Soybean

April-planted group IV soybean yields were good each year, with an average yield of 55 to 62 bu./ac depending on rotation over the 7-year period (Table 1). The yield of April-planted group IV soybean was statistically impacted by the previous crop in 3 out of 7 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 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 was following a previous crop of wheat/double-crop soybean, yields on average were only 42 bu./ac, while yields increased to 46 and 45 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 1 out of 7 years (Table 2). The average yield across rotations of 59.5 bu./ac for early planted group IV soybean and 44.3 bu./ac for double-crop soybean are similar yield differences that many Arkansas producers see on their farms between the early planted production system and double-crop system.

Differences in early planted and double-crop soybean yields between crop rotations can likely be partially attributed in part to lower Soybean-Cyst Nematode (SCN) numbers following corn or grain sorghum. The SCN egg numbers from soil samples collected in the fall of 2020 were 110 eggs/100 cc of soil in continuous April-planted soybean plots compared to 19 and 58/100 cc of soil where the previous crop was corn or grain sorghum, respectively. The SCN egg numbers in continuous double-crop soybean plots were 358/100 cc of soil and 85 and 289/100 cc of soil in plots that previously had corn and wheat or grain sorghum and wheat planted previously. The SCN egg numbers indicate that rotation to a non-host for one year will reduce numbers, but will not eliminate SCN.

Corn

Corn yields were generally good over the 7-year period and averaged 201–208 bu./ac depending on rotation (Table 3). Yields were statistically influenced by rotation in 1 out of 7 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 7-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 greater, but that trend is not evident after 7 years of this trial.

Wheat

Wheat yields were generally good, with an average yield of 65 to 73 bu./ac (Table 4), depending on rotation. Wheat yield was influenced by previous crop 4 out of 6 years. Averaged across all years, wheat yield following April-planted soybean was 73 bu./ac, 8 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 some 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. Wheat yield following corn was on average 5 bu./ac less than when following April-planted soybean and 2 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 the April-planted group IV soybean or double-crop soybean treatments over the 7-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 82 bu./ac (Table 5), 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 profitability of their farms.

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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, 2014–2020.

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

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

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 2014–2020.

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

[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 $\alpha = 0.05$.

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 2014–2020.

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

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

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 2014–2020.

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

[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 2014–2020.

Crop	Grain Sorghum Grain Yield							
	2014	2015	2016	2017	2018	2019	2020	Avg.
	(bu./ac)							
Full-Season Grain Sorghum	143	123	113	99	98	106	118	114
Double-Crop Sorghum	--	88	92	86	87	81	88	82

Impact of Plant Population on Corn Yield

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

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 on yield and late-season lodging potential were conducted in 2019 and 2020 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, near Marianna, Arkansas, and the Rohwer Research Station, near Rohwer, Arkansas. In 2019 at both Marianna and Rohwer, under high-yielding conditions, corn yield was highly responsive to increasing plant population from 15,000 to 35,000 plants/ac, and then yields plateaued at approximately 35,000 plants/ac, and little yield gain was realized from populations greater than 35,000 plants/ac. Yields, however, did not decline even with populations above 40,000 plants/ac. In 2020 at Marianna, under lower yield potential conditions (160–200 bu./ac), maximum yield potential was achieved at populations of 20,000 to 25,000 plants/ac, which was hybrid-dependent. Late-season plant lodging was not evident in 2019 at either location regardless of plant population or hybrid. In 2020 after delayed harvest and two tropical storms, moderate lodging (20–30%) was noted at Marianna, and lodging was more dependent on hybrid than plant population. At Rohwer in 2020, significant lodging (up to 40%) was noted. Lodging increased as the plant population increased and was also hybrid-dependent.

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 2020 (USDA-NASS, 2021). 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. Irrigation also encourages producers to utilize 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/year per year (USDA-NASS, 2017). Increasing plant populations have been given partial credit for the overall increase of corn yields. The downside to increasing populations is that seed cost is now generally the largest input cost for corn, surpassing fertilizer costs in many fields (Watkins, 2021). 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 determine if increasing plant populations increase the risk of late-season plant lodging.

Procedures

Field trials evaluating the impact of corn plant population on yield and late-season plant lodging were conducted in 2019 and 2020 at the University of Arkansas System Division of Agriculture's Lon Mann Cotton Research Station, near Marianna, Arkansas, and the Rohwer Research Station, near Rohwer, Arkansas. Plot size for all trials was 4 rows × 30–35 ft long with four replications in a randomized complete block design. Row spacing was 38-in. wide, and plots were planted on raised beds for furrow irrigation. Mixed fertilizer was applied at recommended levels, and nitrogen was split applied (preplant and V5) with total nitrogen of 250 lb/ac. Plots were 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.

In 2019 at Rohwer, the following full-season commonly grown corn hybrids were evaluated: Pioneer 1870YHR, DKC 70-27, Progeny 9117, DKC 67-72, and Dyna-Gro 58VC65. In 2020, Pioneer 1847VYHR, Pioneer 2042VYHR, DKC 66-75, and Progeny 8116SS. At Marianna in 2019, the following hybrids were evaluated: Pioneer 2089VYHR, DKC 67-44, Armor 1447, DKC 67-72, and AgriGold 6659. In 2020, the hybrids DKC 65-99 and Pioneer 1464VYHR were evaluated. Trials in 2019 were planted 2 April and 3 April at Rohwer and Marianna, respectively. In 2020, wet weather delayed planting until 1 May at Marianna and 5 May at Rohwer.

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Soon after emergence each year, plant counts were taken from the center two rows of each plot to determine plant populations. Populations varied each year slightly, but final plant populations generally ranged from near 15,000 to 45,000 plants/ac. Late-season plant lodging was visually estimated prior to harvest when lodging occurred (2020). The center two rows of each plot were harvested after maturity with a small plot combine, and yields were adjusted to 15.5% moisture.

Results and Discussions

2019

Corn yields were very high (250 bu./ac) with good growing conditions at Marianna and Rohwer and were very responsive to increasing plant populations (Figs. 1and 2). At Marianna when all hybrid-by-plant population yield data points were included in the analysis, corn yields steadily increased from plant populations of 15,000 to approximately 35,000 plants/ac when the rate of yield increase plateaued, and overall, little additional yield was produced by plant populations greater than 35,000 plants/acre. Hybrids generally responded the same to increasing plant population with the exception of Pioneer 2089VYHR, which showed the least response to increasing plant populations.

Corn yields at Rohwer in 2019 were also highly responsive to increasing plant populations from plant populations of 15,000 to 35,000 plants/ac and showed a similar response that corn yields tended to plateau once plant populations exceeded 35,000 plants/ac. All hybrids evaluated at Rohwer in 2019 generally followed a similar plant population response. Due to timely harvest and lack of rain and wind events after maturity and prior to harvest, no lodging was seen for any hybrid or plant population combination at Marianna or Rohwer.

2020

Corn yields in 2020 at Marianna were considerably lower than in 2019. A relatively late planting date of 1 May and irrigation well issues that provided a limited amount of water are likely contributing factors. Even with relatively moderate maximum yield levels (160–200 bu./ac), similar trends were seen in the previous year. Yields were very responsive to increasing plant populations up to 20,000 or 25,000 plants/ac, depending on hybrid (Fig. 3). Lodging was an issue at Marianna in 2020 after tropical storms Laura and Beta came through after maturity. Lodging was influenced by hybrid more than plant population. DKC 65-99 exhibited no lodging regardless of plant population, while Pioneer 1464VYHR had 20–30% lodging that was not dependent on plant population. At Rohwer, abnormally high lodging levels after tropical storms Laura and Beta impacted yield results; therefore, grain yields are not reported. Visually estimated lodging percent for DKC 66-75 and Progeny 8116SS was never greater than 7% at populations up to 42,000 plants/ac. With Pioneer 1847VYHR and Pioneer 2042VYHR, lodging was nearly zero at populations of 24,000 plants/ac or less but increased incrementally as plant populations increased from 24,000 to 42,000 plants/ac with a maximum lodging of 38% and 33% for Pioneer 1847VYHR and Pioneer 2042VYHR, respectively, at 42,000 plants/ac.

Practical Applications

Results from these trials demonstrate that the optimum corn plant population can vary greatly based on the field yield potential, hybrid planted, and potential for late-season plant lodging. Currently recommended plant populations of 32,000 to 34,000 plants/ac for irrigated fields appear to be appropriate in most situations. One of the challenges is knowing how new hybrids will respond to the plant population since new hybrids are brought to the market annually.

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.

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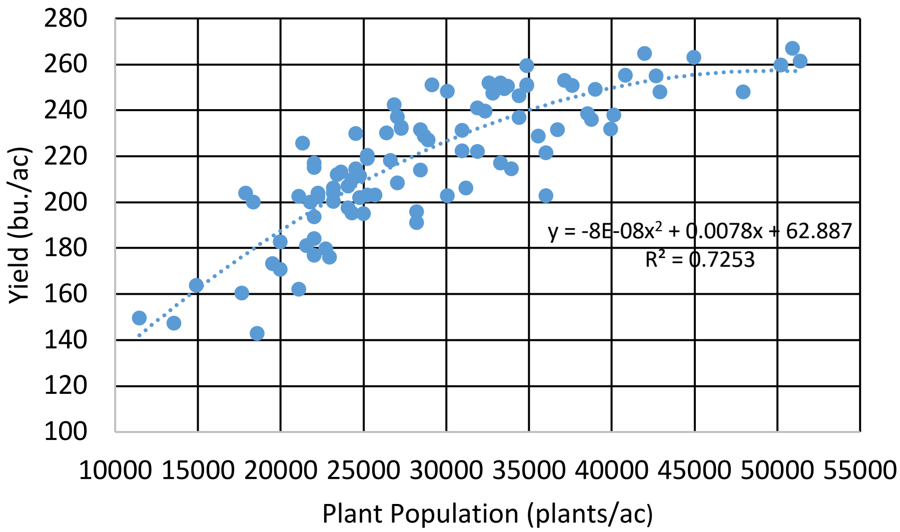

Fig. 1. Effect of plant population on corn yield, Marianna, 2019.

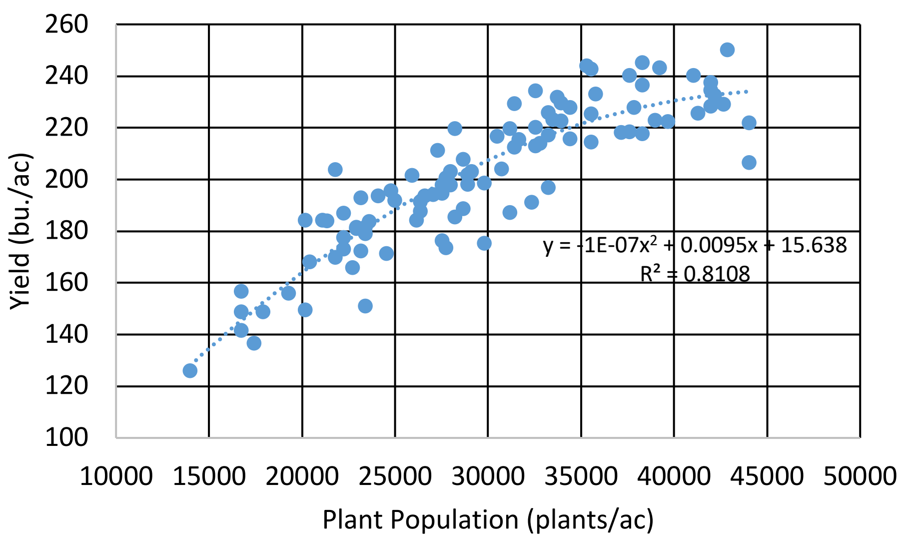

Fig. 2. Effect of plant population on corn yield, Rohwer, 2019.

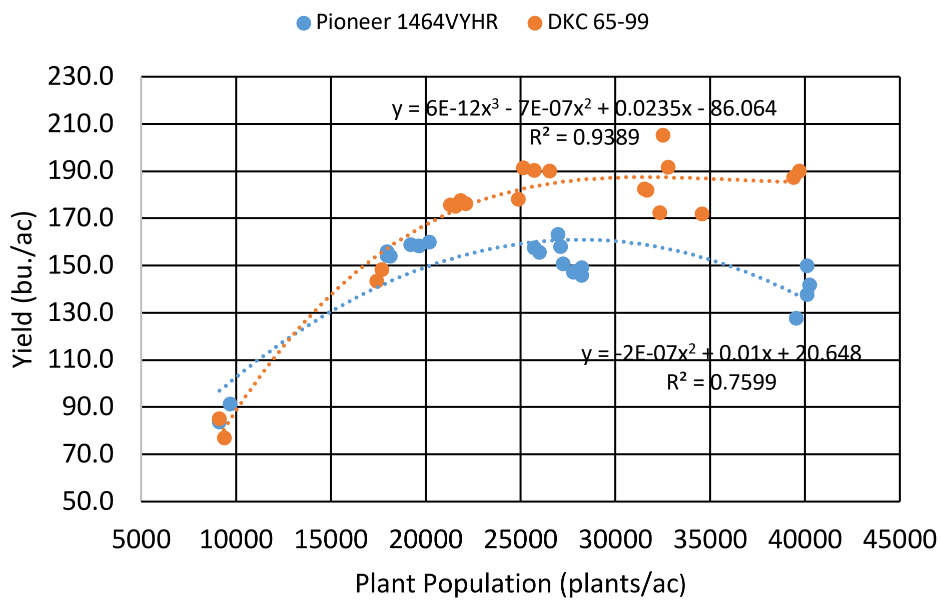

Fig. 3. Effect of plant population on corn yield, Marianna, 2020.

Cover Crop Selection Impacts Corn Plant Stand and Yield

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Abstract

The popularity of cover crops within Arkansas continues to increase, and more producers are implementing them into their corn and soybean rotations. A need for Arkansas-specific data on the effects of long-term no-till and cover crop implementation on corn performance will be essential. A study was established to determine the effects of various winter cover crop treatments on corn stand establishment and grain yield. Cover crop treatments included a winter fallow, a cereal rye every year, an Austrian winter pea every year, an alternating cover crop where a cereal was planted prior to soybean, and a legume was planted prior to corn, and a cover crop species blend based on the soil health recommendation (blend of cereals and legumes). During the 2020 growing season, there were no significant differences in corn plant population across all cover crop treatments. The data for stand establishment was highly variable across treatments and related to surface residue at planting, with higher surface residue leading to lower plant populations. Corn grain yield was significantly influenced by winter cover crop treatment ($P < 0.001$), with the winter fallow resulting in the lowest overall yield (82 bu./ac) and the alternating cover crop resulting in the highest (159 bu./ac). The yield data are not supported by the corn plant population data as the highest corn plant population resulted in the lowest overall corn grain yield. These results suggest that the implementation of cover crops into corn production systems is more complex than for other crops such as soybean. There is still much to be learned regarding the complex interaction of cover crop biomass production and the resulting impacts on corn productivity and soil health.

Introduction

Corn production is a key component for many crop rotations important to Arkansas agriculture. Although soybean accounts for the majority of row crop area, it is often rotated with corn as the yield of both crops can be improved. Improving the sustainability of Arkansas corn production via reduced input cost (i.e., synthetic fertilizers, irrigation, tillage, etc.) and a reduction in potential environmental impacts is important to the long-term success of Arkansas row crop producers. Cover-cropping has become a staple in sustainable agriculture discussions as cover crops can provide a variety of benefits such as reduced soil erosion and surface-water runoff, improved weed suppression, increased soil organic matter, and benefits to various soil quality characteristics. Introducing cover crops into production, however, does not come without challenges. The land area dedicated to cover crops in Arkansas is limited as less than 6% of total row crop acres utilize cover cropping, but this number has been increasing in recent years with a ~82% increase in cover crop acreage between 2012 and 2017 (Myers, 2019). Implementation of cover crops is likely limited due to a general lack of research and understanding of the effect of cover crops on production, and the agronomic hurdles producers may face. Determining the influence that various cover crops have on corn stand establishment and yield is important to provide research-based information to aid in the adoption and success of cover crops within corn rotations.

Procedures

The results presented here are a part of a long-term trial established at the University of Arkansas System Division of Agriculture's Pine Tree Research Station (PTRS) during the fall of 2015. The area in which this study was conducted was brought out of commercial agriculture production that was typically in a rice soybean rotation. Raised beds spaced 30-in. apart were established on which corn and soybean were rotated annually using no-till and furrow irrigation practices. In the first year of the study (2016), no cover crops were seeded prior to cash crops in order to obtain a baseline of production. Cash crops (corn-soybean) were rotated annually to capture the rotational effect commonly used in Arkansas production following the 2016 cash crop harvest. In the fall, cover crops were drill-seeded at 7.5-in. spacing over cash crop beds (Table 1). Cover crop treatments included two monocultures and one mixture as well as a winter fallow check and were seeded as early as possible following cash crop harvest in the fall. The winter cereal treatment was cereal rye (CR) each season, and the winter legume treatment was Austrian winter pea (AWP). The alternating cover crop treatment changed each season and was AWP prior to corn and CR prior to soybean in the rotation. The soil health recommendation (SHR) treatment was a blend of legumes (AWP) and cereals (black-seeded oats) in a 60:40 ratio based on the soil health assessment. In order to mimic producer practices with the cover crop treatments, this was

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implemented as a large-scale trial where plots were 8 rows wide (20 ft) and 240 ft long. Chemical termination was approximately 2–4 weeks prior to cash crop planting as per current University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) recommendations to help prevent the "green bridge" and decrease pest pressures. Cover crops were terminated using atrazine and paraquat prior to corn at 32 and 40 oz active ingredient/ac respectively (Palhano et al., 2018). Corn was no-till planted at approximately 35,000 seed/ac. Corn plant stands were determined at the V2 growth stage by counting the number of plants in a 17.5-ft section of one row. In order to mimic commercial corn production, nitrogen fertilizer was applied as urea with 30 lb N/ac following emergence and 190 lb N/ac near the V6–V8 growth stage. Corn received an in-season rate (following emergence) of K_2O and P_2O_5 as recommended by the CES soil test and was furrow irrigated as needed based on the Arkansas irrigation scheduler set to a 1.5-in. deficit. The inside two rows were harvested and adjusted to 15.5% moisture to determine grain yield.

The experiment was arranged in a randomized complete block design with four blocks. A simple one-way analysis of variance (ANOVA) was implemented to determine if cover crop treatment significantly influenced the corn stand establishment (plant population) and yield of the following corn crop. A Tukey-Kramer honestly significant difference ($\alpha = 0.05$) was used to separate yield means among cover crop treatment when appropriate. The statistical analysis was completed using JMP Pro 15.2.

Results and Discussion

The ANOVA indicated mixed results of the impact cover crop treatment had on both corn plant population and corn grain yield. There was no significant influence of cover crop treatment on corn plant population which ranged from 22,942 to 29,150 plants/ac in the alternating cover crop and fallow treatments, respectively (Table 2). The lack of significance can be attributed to a high variability within treatments and across replications of the study. The corn plant population in the alternating cover crop treatment had the most variability of all the cover crop treatments and ranged from 17,814 to 28, 340 plants/ac across all replications of the study. The results for corn plant population are what one might expect as the fallow treatment tended to have lower total surface residue at planting (but not bare due to winter weeds) and also resulted in the highest stand establishment numbers. The increased plant population following fallow may have been due to better soil conditions or increased seed to soil contact in the fallow treatments due to lack of residue to complicate planting, but further data needs to be collected to confirm this. Alternatively, the treatments with higher surface residue, such as the alternating winter cover crop treatment, tended to have lower plant populations and higher soil moisture at planting. Although the planter is equipped with row cleaners and other no-till options to deal with high residue at planting, there are still other factors that need to be considered like downforce. Future observations should look not only at plant population within each treatment but at overall stand uniformity as well.

Corn grain yield was significantly influenced by cover crop treatment with a range in yield of 82–159 bu./ac (Table 2). Corn grain yields were significantly less than the state average of 184 bu./ac (USDA-NASS, 2020) and could have been due to various reasons, including nutrient tie-up in the residue, compaction due to no-till production, poor stand establishment or non-uniform stands or other unknown causes. The lowest yielding treatment in the study was the winter fallow treatment, which had one of the highest reported plant stands. Conversely, the highest yielding treatment was the alternating cover crop treatment which had the lowest reported plant population. All treatments that included cover crops resulted in significantly greater corn grain yield than the fallow treatment with no clear trend as to what caused certain cover crop treatments to perform better than others. Observations indicate that treatments containing winter cover crops tend to have more soil moisture and less weed pressure, but higher variability in corn plant stands. The combination of these differences across the treatments and replications of this study need to be further investigated to provide more accurate management strategies for Arkansas corn producers.

Practical Applications

In order to maximize the benefits of cover crops, the producer needs to have a clear goal in mind. Utilizing a winter cover crop to improve on various aspects of a corn production rotation such as weed suppression, water retention/infiltration, improving soil organic matter, etc. should be the focus of producers when implementing cover crops. Cover crops may not provide a yield increase in the first few years of use; however, over time, profitability of corn production may improve via the benefits cover crops provide. Continued use of cover crops should lead to increases in efficiency of irrigation, planting, and harvesting as well as the lowered input cost associated with the reduction of tillage. Continued research may give insight into which cover crops provide the best long-term benefits for corn rotations, leading to more specific cover crop recommendations for Arkansas producers.

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.

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Table 1. Cover crop species and seeding rates.

Treatment	Species	Seeding Rate
		--------------lb/ac--------------
Fallow	N/A	N/A
AWP	Austrian winter pea	30–55
Alt CC	Austrian winter pea (prior to corn)	30–55
CR	Cereal rye	35–50
SHR†	Black-seeded oat: Austrian winter pea 40:60	40–55

† SHR = Soil Health Recommendation, the recommended cover crop blend is determined based on the soil health calculation.

Table 2. Corn plant population and yield as influenced by cover crop treatment, 2020.

Treatment	Plant Population†	Yield†
	-------------plants/ac------------	-------------bu./ac------------
Fallow	29,150 a	82 c
AWP	26,451 a	125 b
Alt CC	22,942 a	159 a
CR	27,800 a	137 ab
SHR	25,371 a	156 a

† Means within a column followed by the same letter are not different according to Tukey-Kramer's honestly significant difference test (α=0.05).

Development and Evaluation of Feral Swine Control Measures for Arkansas

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Abstract

The objectives of this study were to 1) conduct a survey of Arkansas counties and producers to determine the current extent of feral swine damage and control measures currently in use, and 2) to use domestic swine as a model to conduct a series of experiments to evaluate the use of feed containing cottonseed meal (as a gossypol source) as a means to inhibit swine reproduction. For Objective 1, a survey was distributed to Arkansas residents. For Objective 2, three experiments were conducted using domestic hogs. In Experiment 1, gilts were fed diets with cottonseed meal (CSM) containing 0%, 0.01%, 0.02% or 0.04% gossypol to evaluate effects on growth and reproductive performance. In Experiment 2, boars were fed diets with CSM containing 0%, 0.02%, or 0.04% gossypol to evaluate effects on growth and reproductive performance. In Experiment 3, pregnant sows were fed diets with CSM containing 0%, 0.04%, or 0.08% gossypol during early gestation to determine effects on offspring fertility. Upon the completion of Objective 1, survey responses were used to characterize a prominent feral hog population in the state of Arkansas. In Objective 2, Experiment 1, gossypol diets increased gossypol concentrations to levels reported to cause infertility in men and resulted in reduced rates of gain and feed efficiency of gilts. In Objective 2, Experiment 2, gossypol diets resulted in increased gossypol concentrations to levels reported to cause infertility in men, decreased feed efficiency and gain similar to that seen in Experiment 1, and no effect on semen quality in boars. In Objective 2, Experiment 3, prenatal exposure to gossypol did not impact the semen quality of boars. Although additional laboratory and data analyses are still in progress, limited effects on growth and reproductive performance traits were observed due to prenatal or postnatal exposure of domestic swine to gossypol.

Introduction

Feral swine are an invasive species that have been reported in at least 35 states in the United States, a range that has continuously expanded over the last few decades. The total estimated damages to crops, habitat, and private property in the United States is valued at over 1.5 billion dollars per year. The total estimated damage and loss of crops in the state of Arkansas is valued at over 20 million dollars per year. In addition to damage, feral hogs also pose a disease and health threat to people, livestock, wildlife, and pets (USDA, 2020).

There is an estimated feral swine population of 200,000 head in the state of Arkansas, and the state would need to eliminate around 70% of the population (140,000 head) each year to halt population growth. Hunting, trapping, and shooting are common control practices but are not effective enough to control the population of feral hogs. It is also important to note that currently, Arkansas law only allows poison bait for rodent control. Furthermore, control measures for feral hog control must be essentially non-toxic to humans, other wildlife, and scavengers. It is imperative that such control measures not enter or persist in the environment or be considered an environmental toxin.

Effective reproductive control measures in swine have the potential to be effective over time to reduce crop losses, as well as damage to forest land, wildlife habitat, and private property by suppressing or inhibiting population growth. Gossypol is an orally active polyphenolic compound found in cottonseed that has been found to inhibit male reproduction in various species, including humans (Gadelha et al., 2014; Morgan, 2015). The present study will evaluate gossypol as a potential method to inhibit the fertility of domestic swine as a model for feral hog control.

Procedures

Objective 1

Feral Hog Survey. In order to accomplish Objective 1, an 11-question survey was designed using the Qualtrics online survey system and distributed by email to Arkansas residents across the state using University of Arkansas System Division of Agriculture Cooperative Extension Service listserv databases.

Objective 2

Experiment 1. In order to evaluate the effect of gossypol on growth performance and plasma gossypol in growing domestic gilts, a total of 40 gilts at 63 days of age were randomly allotted to 1 of 4 treatments with 2 replicates/treatments. Treatments during phase 1 to 3 (14 days/phase) consisted of a nutrient adequate control diet (NRC, 2012) without cottonseed meal (CSM) (0% gossypol) and the same base diet containing increasing levels of CSM to produce diets containing 0.01%, 0.02% and 0.04% gossypol. All pigs were fed a common diet without CSM in phase 4 (14 days) and throughout the remainder of the study.

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Whole blood was obtained from two pigs at a close-to-average pen body weight at each phase to determine plasma gossypol concentrations. All data from Experiment 1 were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, N.C.) with treatment as a fixed effect. Reproductive characteristics were not evaluated in gilts from Experiment 1.

Experiment 2. To evaluate the effect of gossypol on growth performance, plasma gossypol, and reproductive characteristics in growing domestic boars, a total of 21 boars were randomly allotted to 1 of 3 treatments with 2 replicates/treatment. Treatments during phase 1 to 3 (14 days/phase) consisted of a nutrient adequate control diet (NRC, 2012) without CSM (0% gossypol) and the same base diet containing increasing levels of CSM to produce diets containing 0.02% and 0.04% gossypol. All pigs were fed a common diet without CSM in phase 4 (14 days) and throughout the remainder of the study. Whole blood was obtained from two pigs at a close-to-average pen body weight at each phase to determine plasma gossypol. Semen was collected at 238 ± 7 days of age using a breeding dummy. Average daily gain (ADG), average daily feed intake (ADFI), gain to feed ratio (G:F), gossypol concentration, sperm cell concentration, percentage of motile sperm cells, and percentage of progressively motile sperm cells were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, N.C.) with treatment as a fixed effect. In Experiment 2, semen was not successfully collected from every boar; therefore, chi-square analysis was used to assess semen collection status between treatment groups using the FREQ procedure of SAS.

Experiment 3. To evaluate the effect of gossypol consumed by a dam during gestation on the fertility of male and female offspring, pregnant sows (n = 5) were fed a diet containing 0% (n = 1), 0.04% (n = 2), or 0.08% (n = 2) gossypol between day 56 and 86 of gestation. Abortion was induced in a subset of sows and fetal tissues recovered to determine if gossypol crosses the placental barrier to affect developing fetuses. The remaining sows were allowed to give birth in a standard production scenario and male and female offspring were evaluated through maturity. Boars (n = 11) born to sows in each treatment group (0% gossypol n = 3; 0.04% gossypol n = 4; 0.08% gossypol n = 4) were fed a common diet without CSM, and semen was collected at 269 ± 2 days of age using a live sow in estrus. Sperm cell concentration, percentage of motile sperm cells, and percentage of progressively motile sperm cells were analyzed using the MIXED procedure of SAS (SAS Institute, Inc., Cary, N.C.) with treatment as a fixed effect and dam as a random effect. Gilts born to sows in each treatment group were monitored to determine age at first estrus. Gilt data analysis is currently in progress.

Results and Discussion

Objective 1

Feral Hog Survey. A total of 397 survey responses were received via the Qualtrics system. Feral hog sightings were reported in 52 of the 75 counties in the state of Arkansas (Fig. 1.1). Feral hog sightings were observed during every season of the year (Fig. 1.2) across a variety of landscape types (Fig. 1.3). Feral hogs of all ages and in group sizes from 1 to over 50 hogs were observed across the state (Fig. 1.4). Over 75% of survey takers were aware of damages or losses due to destruction by feral hogs in their county (Fig. 1.5). Estimated numbers of acres in crop losses ranged from 0 to hundreds of acres across the state, including corn, sorghum, soybean, rice, wheat, and forage crops (Fig. 1.6). Survey takers that owned or leased land in their county reported the use of various control practices (Fig. 1.7), but the most effective control practice reported by most survey takers was to trap and destroy hogs (Fig. 1.8). Interestingly, the second-highest response was that no method utilized by the survey taker was effective in controlling the feral hog population (Fig. 1.8). In light of the vast reports of crop losses by both survey takers in this study and USDA reports, the ineffective reports of feral hog control methods reaffirm the need for new and innovative approaches to control the feral hog population in the state of Arkansas.

Objective 2, Experiment 1

Growth. The bodyweight of gilts during phases 3 and 4 was impacted by gossypol exposure, specifically at the 0.02% gossypol concentration (Fig. 2.1). Average daily gain did not differ between treatments in phases 1 and 2 ($P > 0.05$; Table 1). In phase 3, ADG decreased linearly ($P < 0.05$) with an increasing level of CSM in gilts, while ADFI did not differ between treatment groups (Table 1; Fig. 2.2). The G:F ratio decreased quadratically with increasing levels of CSM (Table 1). Generally, plasma concentrations of gossypol increased with increased exposure to cottonseed meal over the feeding period (Fig. 2.3). Overall, consumption of gossypol from dietary cottonseed meal was found to increase plasma gossypol to concentrations previously reported to cause infertility in men and appears to slightly inhibit growth performance in domestic gilts.

Reproduction. Reproductive characteristics were not evaluated in gilts from Experiment 1.

Experiment 2

Growth. The average daily gain of boars did not differ between treatments in phases 1 and 2 ($P > 0.05$; Table 1). In phase 3, ADG decreased quadratically ($P < 0.05$) with increasing level of CSM in boars, while ADFI did not differ between treatment groups (Table 1; Fig. 2.4). Plasma gossypol increased with increasing level of CSM in boars during phases 1–3, and remained greater than controls after boars were fed a common diet for 14 days (Fig. 2.5). Overall, consumption of gossypol from dietary cottonseed meal was found to increase plasma gossypol to concentrations previously reported to cause infertility in men and appears slightly inhibit growth performance in domestic boars.

Reproduction. In Experiment 2, there was no difference in sperm concentration ($P = 0.45$; Fig. 2.6), percent motility ($P = 0.71$; Fig. 2.7), or percent progressive motility ($P = 0.27$; Fig. 2.8) between treatment groups. The ability of a semen sample to be successfully collected from a boar (an indicator of libido) was not affected by treatment ($P = 0.77$; Fig. 2.9). Overall, prenatal or postnatal exposure to gossypol from CSM did not influence semen quality in domestic boars. Testis tissue was collected and fixed for histological analysis to assess microscopic differences in seminiferous tubule diameter and shape. Histology and data analysis will be performed in the summer and fall of 2021.

Experiment 3

Reproduction. In Experiment 3, reproductive characteristics were evaluated in male and female offspring born to dams that consumed diets containing 0% (n = 1), 0.04% (n = 2), or 0.08% (n = 2) gossypol between day 56 and 86 of gestation. Abortion was induced in a subset of the sows and the remaining pregnant sows gave birth to male and female offspring, which were evaluated for reproductive characteristics.

- *Fetal tissues*. Fetal tissues were recovered from induced births to determine if gossypol crosses the placental barrier to affect the developing fetuses. There has been a delay in analyzing samples collected from the fetal tissues due to the USDA lab that was performing the analysis being forced to shut down due to COVID-19 virus.
- *Male offspring*. There was no difference in sperm concentration (P = 0.72; Fig. 2.10), percent motility (P = 0.17; Fig. 2.11), or percent progressive motility (P = 0.87; Fig. 2.12) between treatment groups. Testis tissue was collected and fixed for histological analysis to assess microscopic differences in seminiferous tubule diameter and shape. Histology and data analysis will be performed in the summer and fall of 2021.
- *Female offspring*. Gilt age at first estrus has been monitored and recorded. Gilt data analysis is currently in progress.

Practical Applications

Objectives of this study were to 1) conduct a survey of Arkansas counties and producers to determine the current extent of feral swine damage and control measures currently in use, and 2) to use domestic swine as a model to conduct a series of experiments to evaluate the use of feed containing cottonseed meal (as a gossypol source) as a means to inhibit swine reproduction. Objective 1 was successfully completed and provided unique perspective characterizing a prominent feral hog population and robust impact of feral hogs on agriculture commodities in the state of Arkansas. Domestic hogs were used as a model to evaluate the use of gossypol as a potential method to control the feral hog population. Results from this study do not support the use of gossypol from cottonseed meal as a measure to control the feral hog population

Acknowledgments

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Table 1. Effect of cottonseed meal on growth performance in growing pigs (least squares means).

Gossypol level	0%	0.01%	0.02%	0.04%	SEM	*P*–value[†]
Phase 3						
Gilt (Exp 1)						
ADG,[‡] lb (kg)	1.698(0.770)	1.499(0.680)	1.232(0.559)	1.279(0.580)	0.038	0.04[L]
ADFI, lb (kg)	3.664(1.662)	3.741(1.697)	3.089(1.401)	3.294(1.494)	0.099	0.43[Q]
G:F ratio	(0.462)	(0.397)	(0.396)	(0.390)	0.009	0.03[Q]
Boar (Exp 2)						
ADG, lb (kg)	1.982(0.899)	-	1.424(0.646)	1.834(0.832)	0.031	0.03[Q]
ADFI, lb (kg)	3.946(1.790)	-	3.417(1.550)	3.598(1.632)	0.091	0.29[Q]
G:F ratio	(0.501)	-	(0.421)	(0.511)	0.022	0.09[Q]

† L = linear, Q = quadratic.

‡ ADG = average daily gain; ADFI = average daily feed intake.

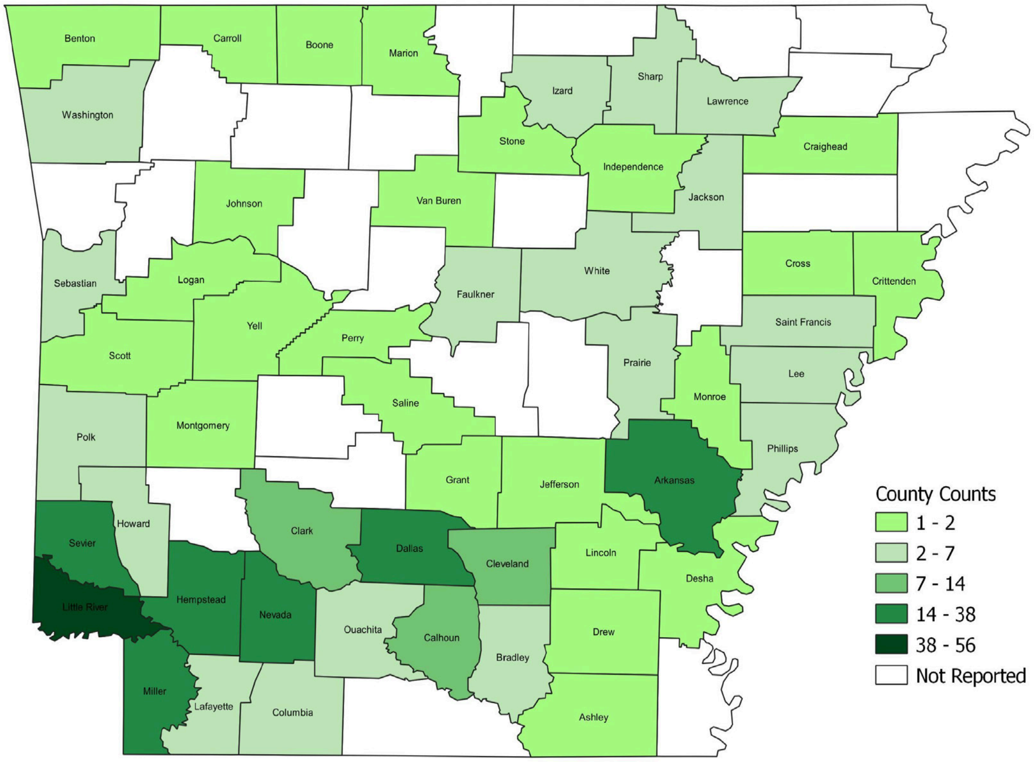

Fig. 1.1 Counties where feral hogs were observed ("counts" refer to the number of survey takers that observed feral hogs in their county).

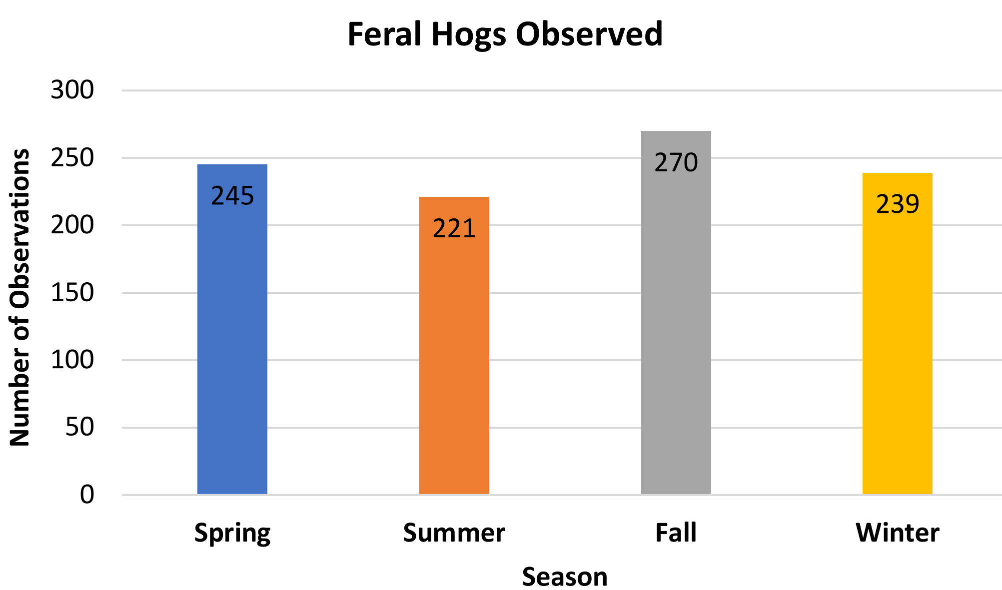

Fig. 1.2. Time of year when survey takers observed feral hogs.

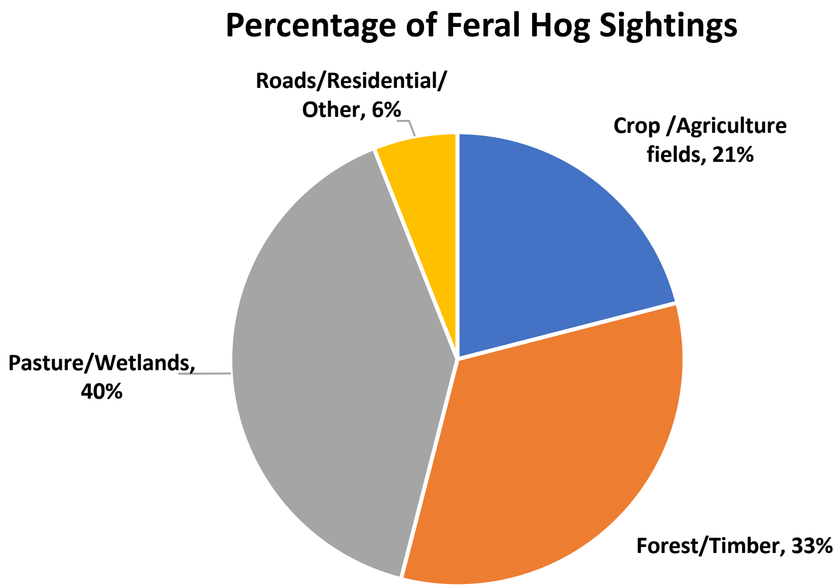

Fig. 1.3. Areas where feral hogs were observed by survey takers.

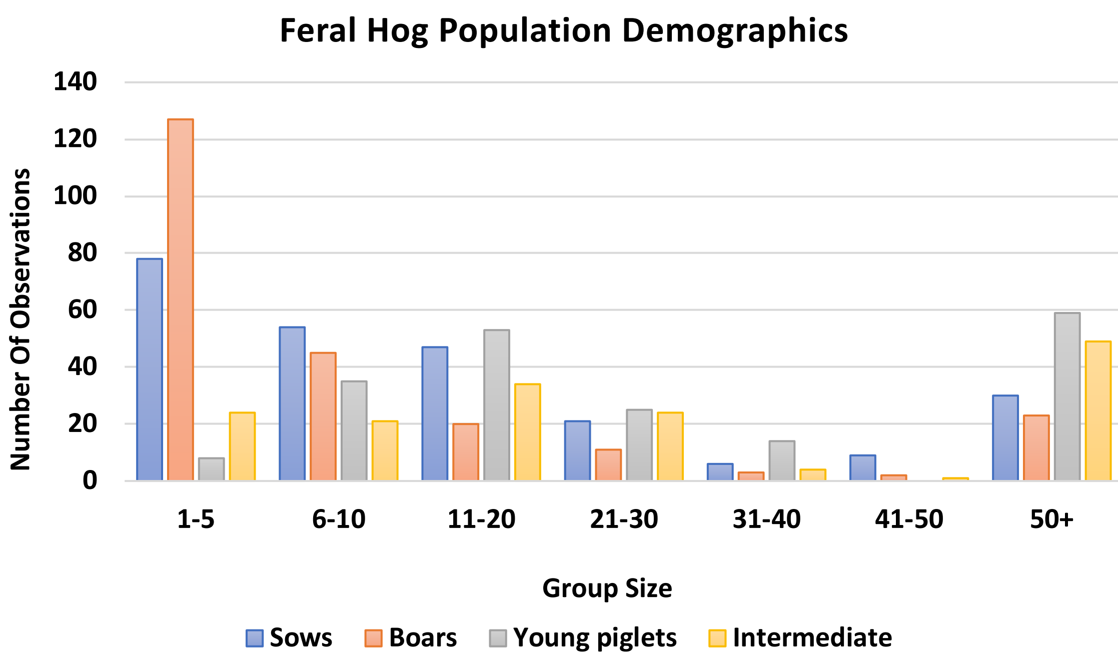

Fig. 1.4. Estimated number of feral hogs from each population demographic observed by survey takers.

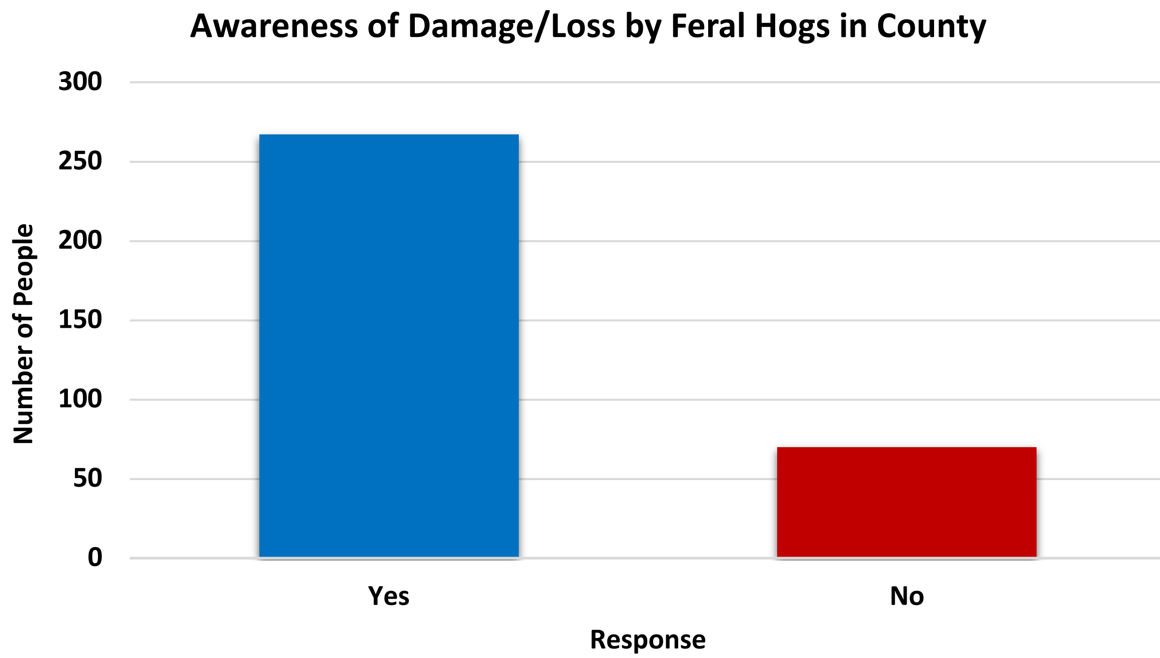

Fig. 1.5. The number of survey takers that were aware of damage or loss due to feral hogs in their county.

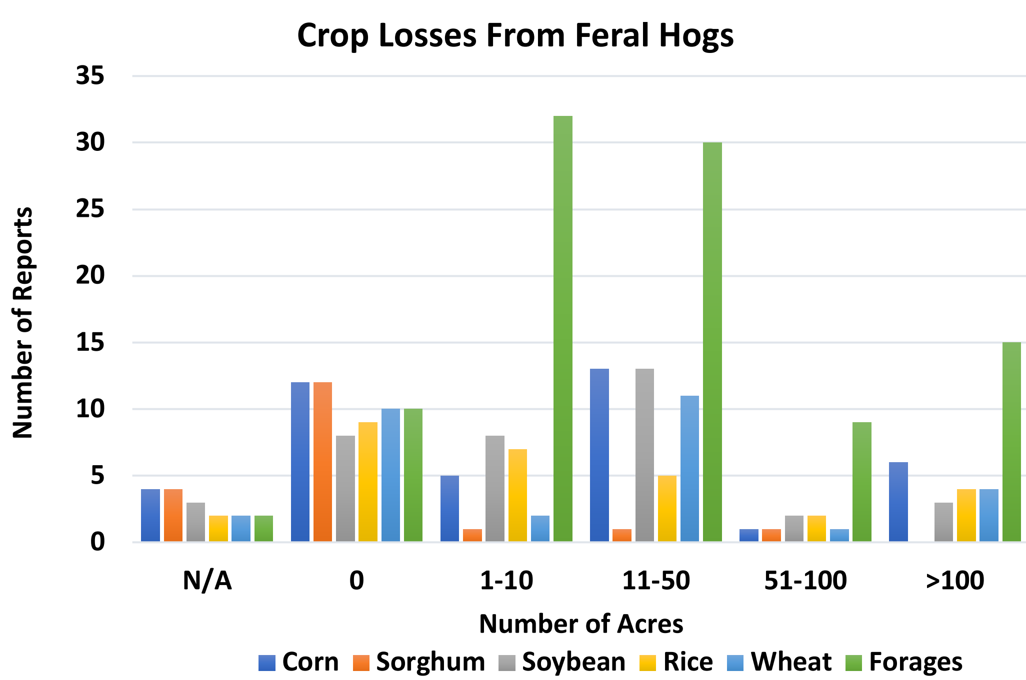

Fig. 1.6. Estimated acres of crop losses due to destruction by feral hogs.

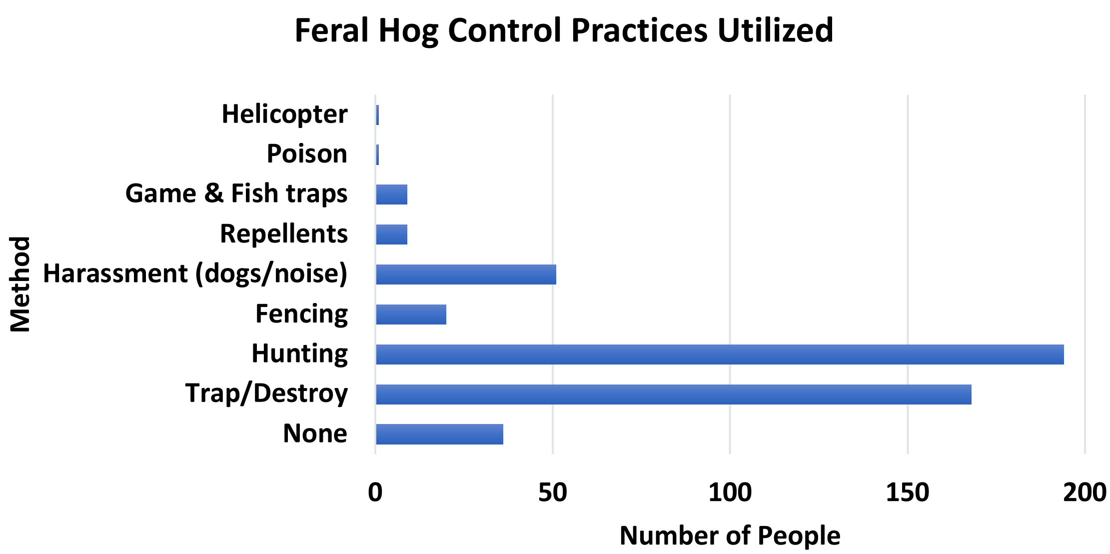

Fig. 1.7. Methods used by survey-takers to control the feral hog population on their land.

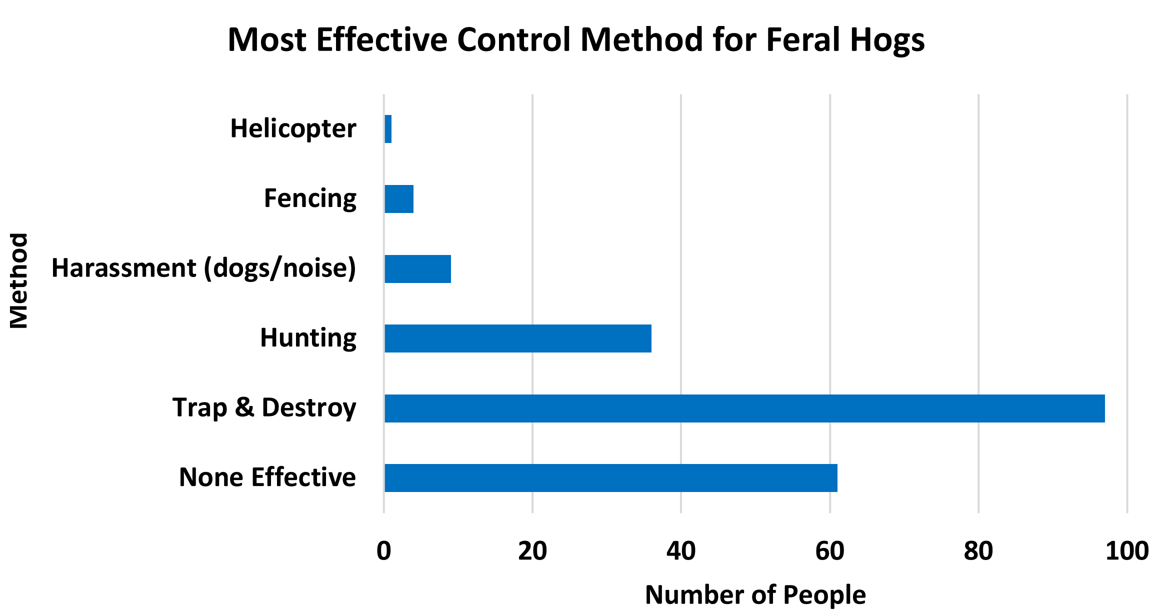

Fig. 1.8. The most effective control method used by survey-takers to control the feral hog population on their land.

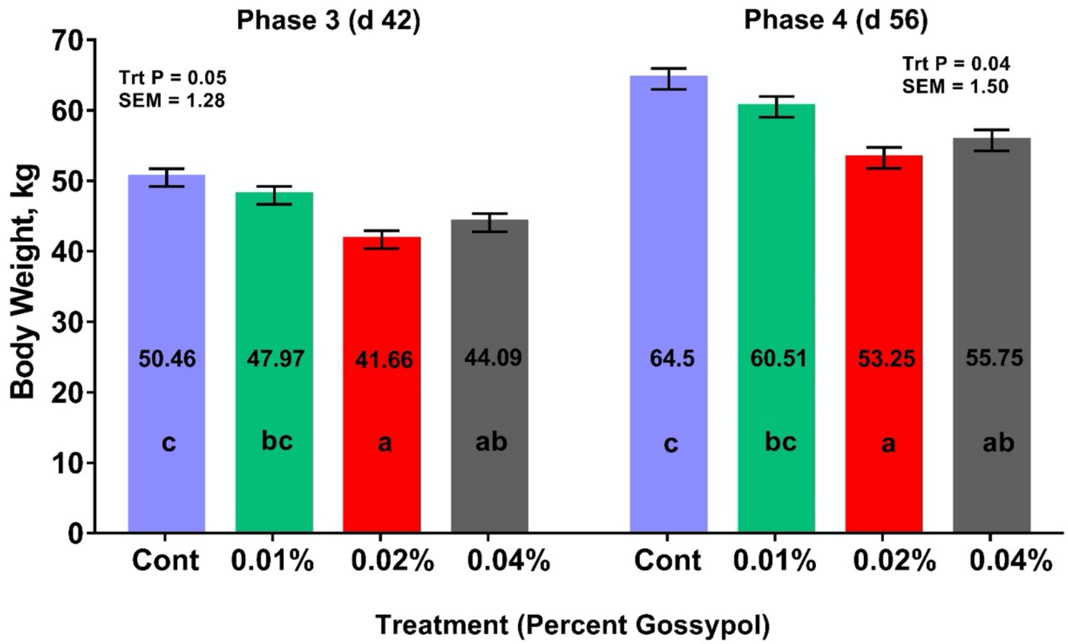

Fig. 2.1. The bodyweight of gilts in Experiment 1.

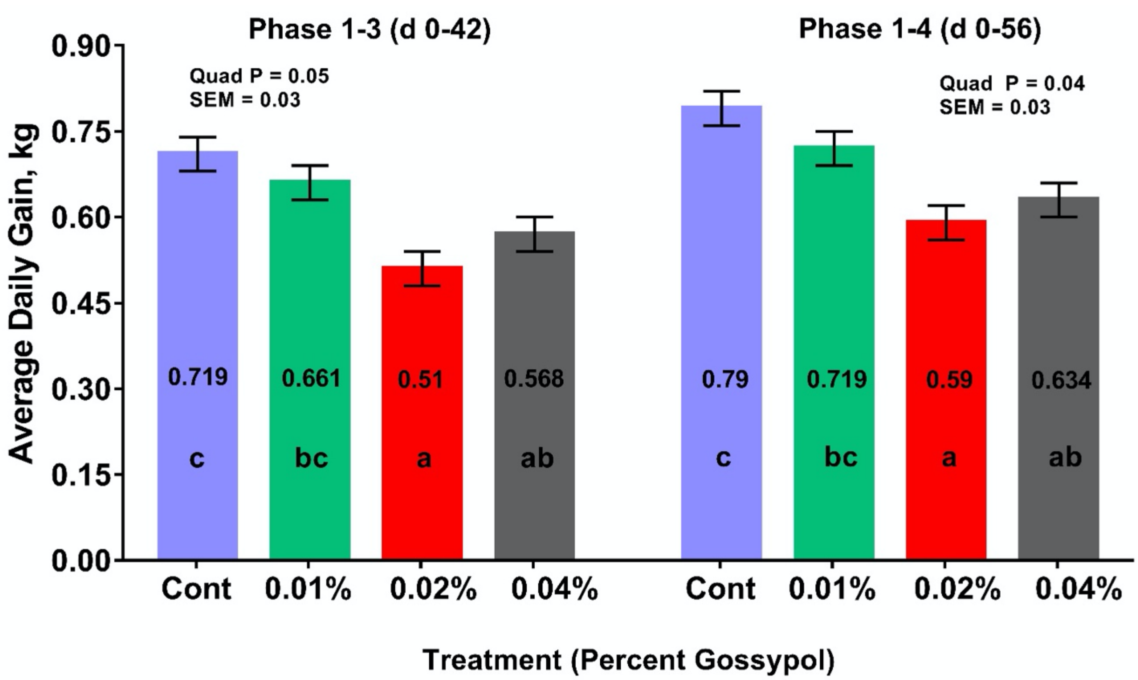

Fig. 2.2. The average daily gain (ADG) of gilts in Experiment 1.

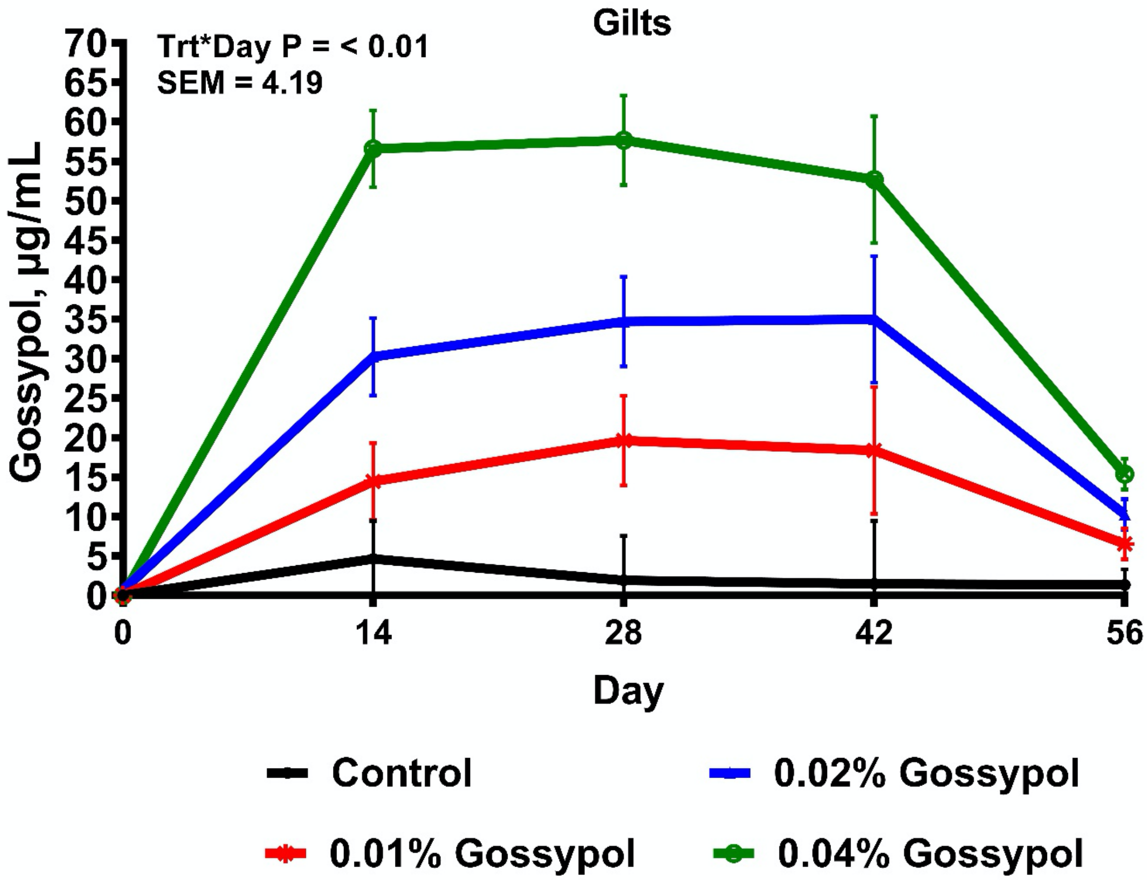

Fig. 2.3. The plasma gossypol of gilts in Experiment 1.

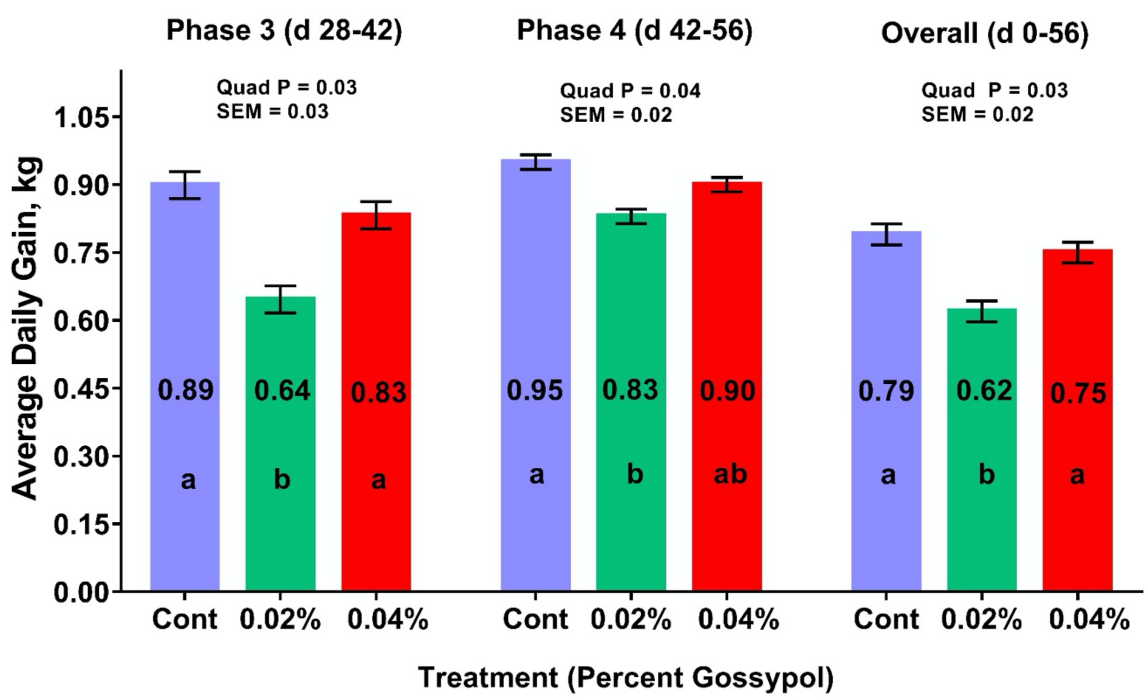

Fig. 2.4. The average daily gain (ADG) of boars in Experiment 2.

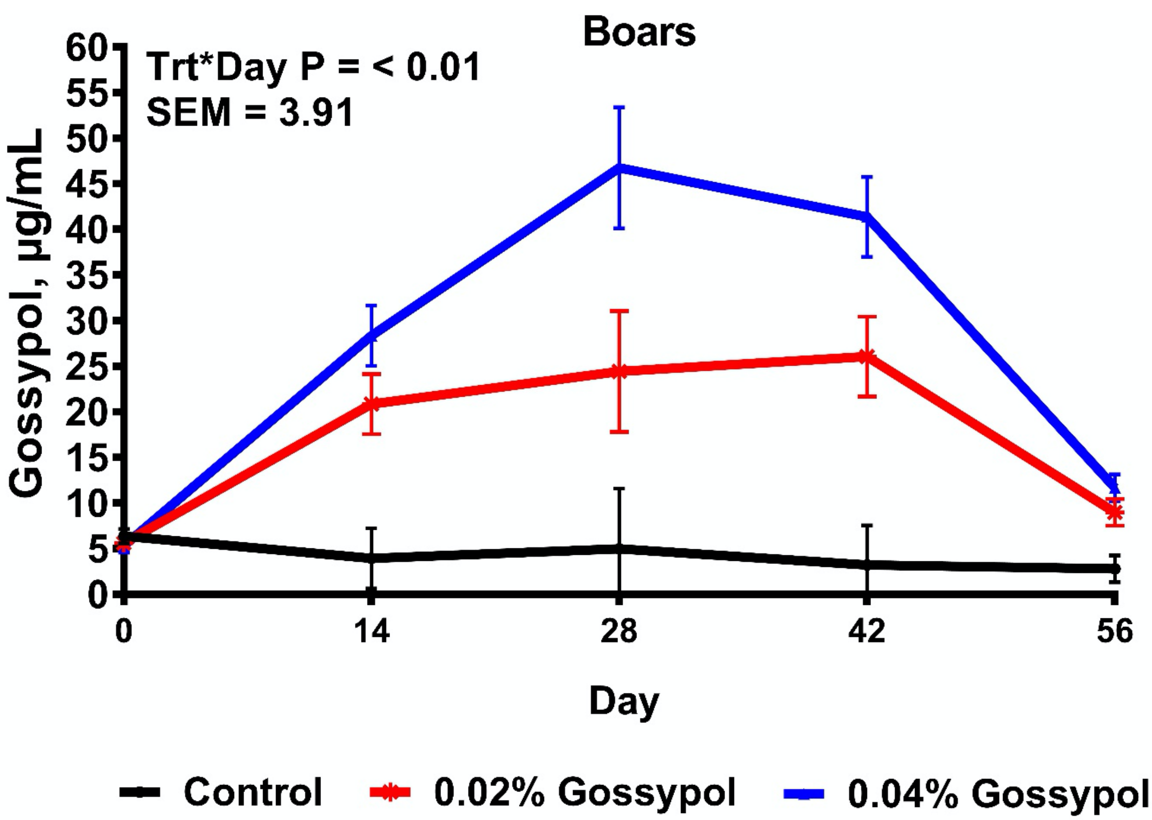

Fig. 2.5. The plasma gossypol of boars in Experiment 2.

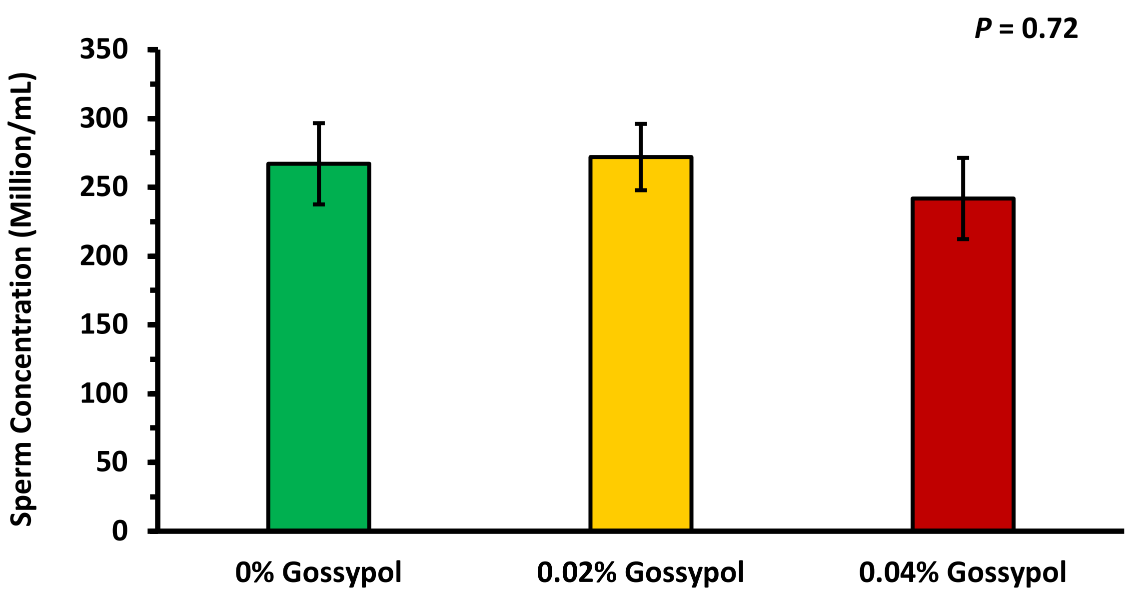

Fig. 2.6. The sperm cell concentration in semen collected from boars in Experiment 2.

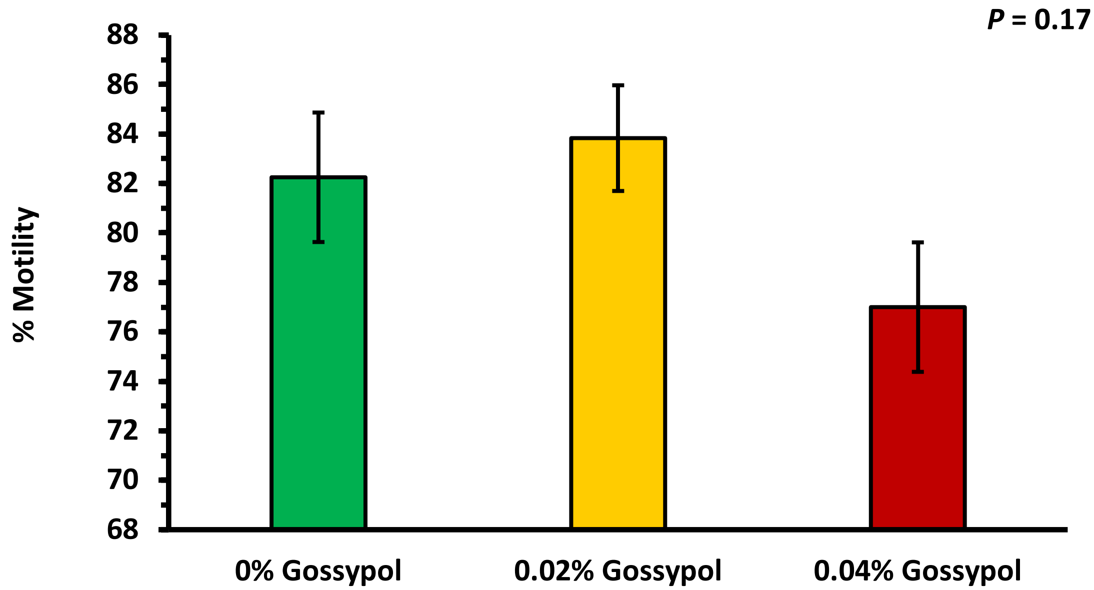

Fig. 2.7. The percent of motile sperm cells in semen collected from boars in Experiment 2.

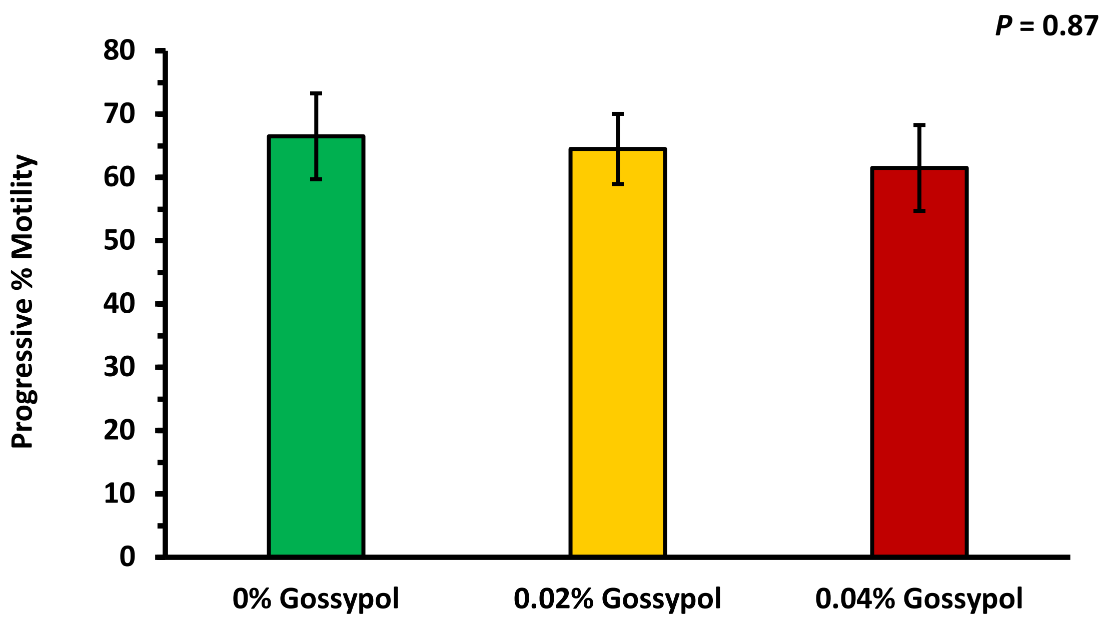

Fig. 2.8. The percent of progressively motile sperm cells in semen collected from boars in Experiment 2.

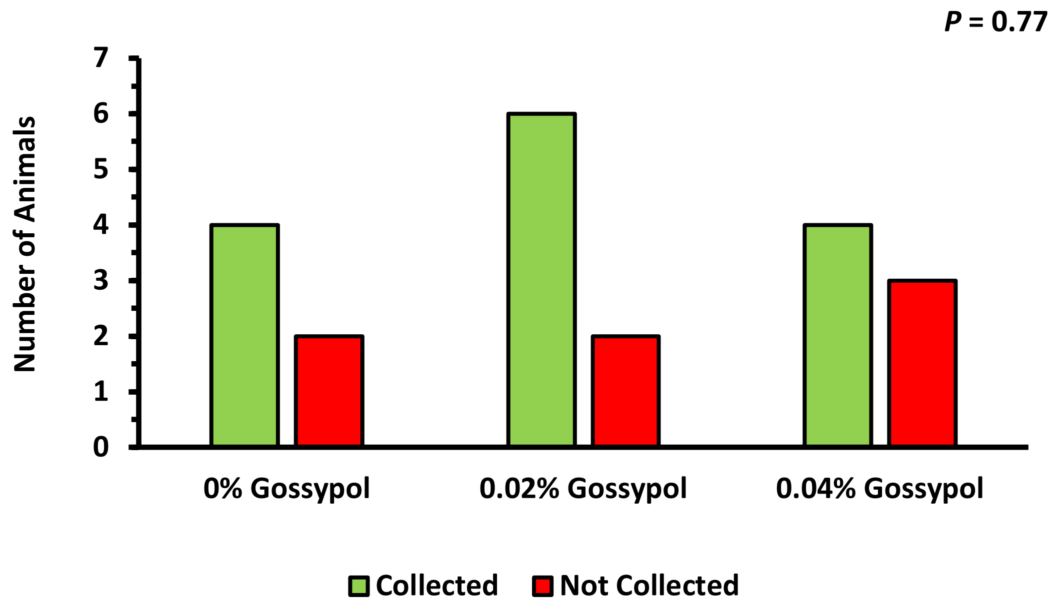

Fig. 2.9. The semen collection status of boars in Experiment 2.

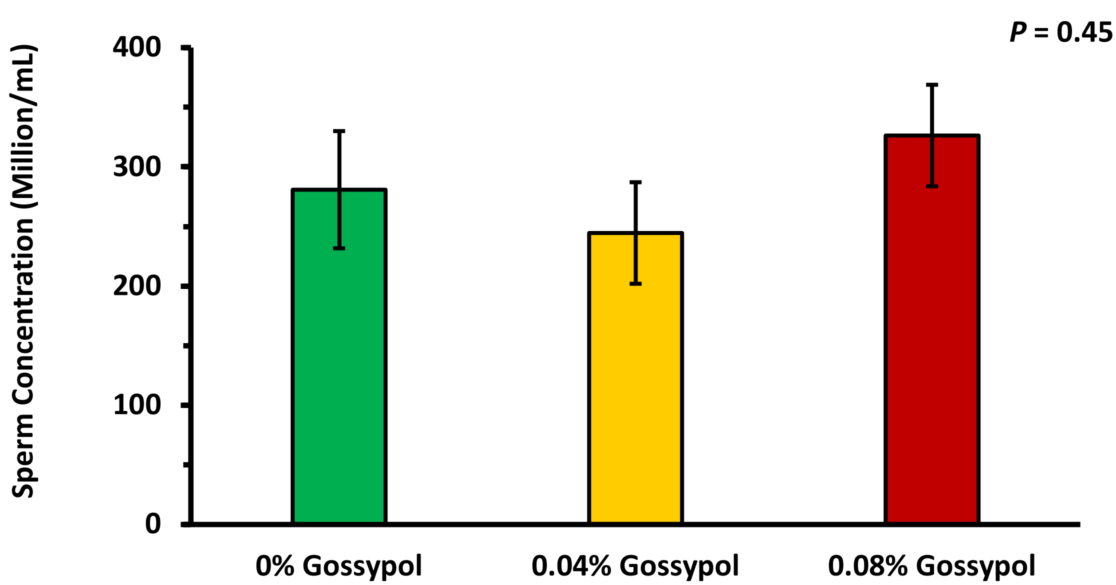

Fig. 2.10. The sperm cell concentration in semen collected from boars in Experiment 3.

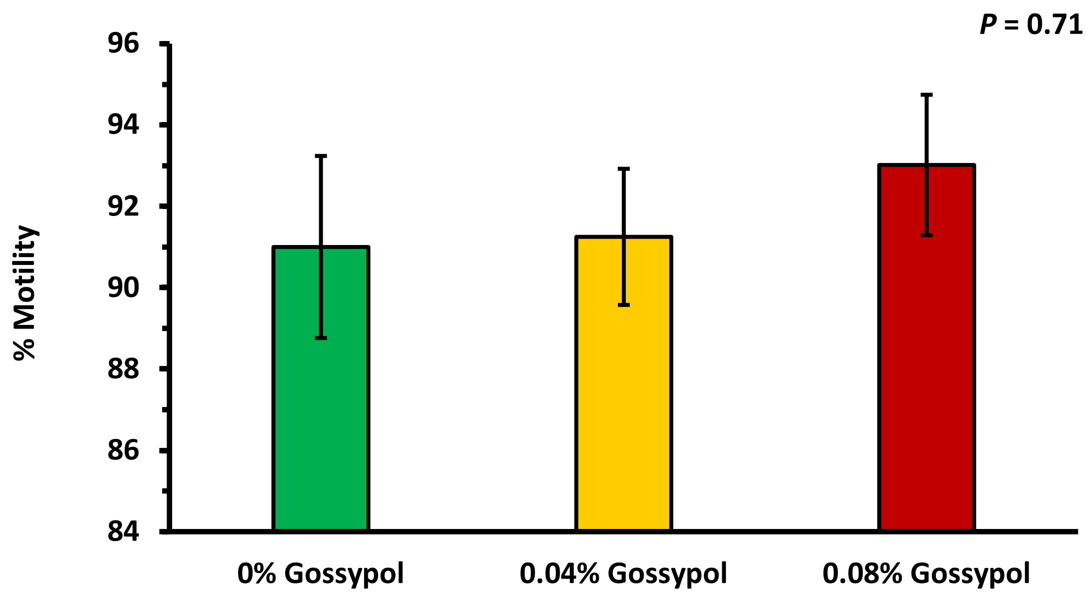

Fig. 2.11. The percent of motile sperm cells in semen collected from boars in Experiment 3.

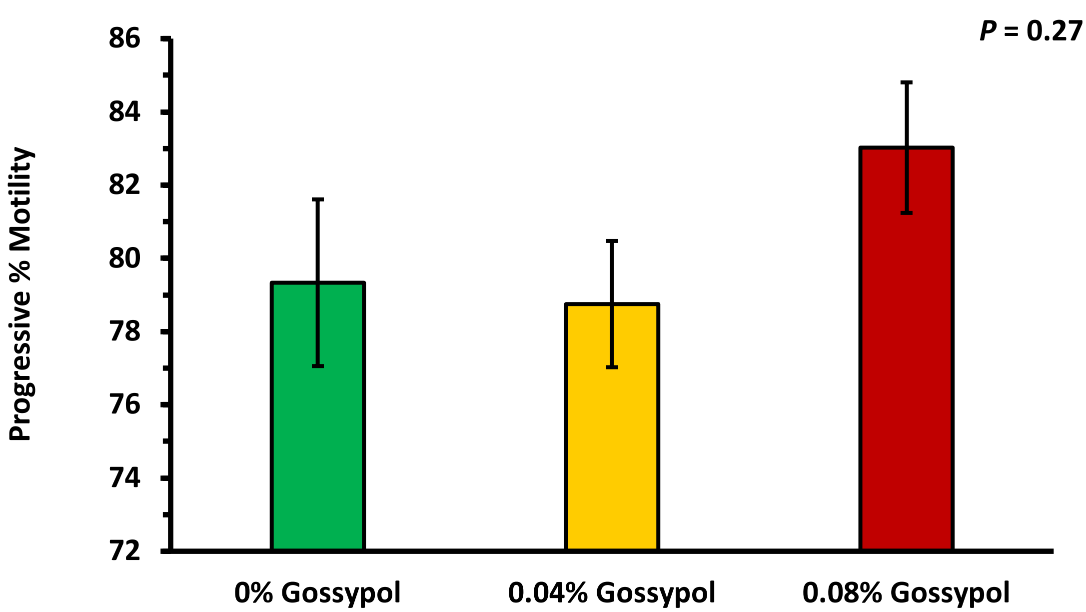

Fig. 2.12. The percent of progressively motile sperm cells in semen collected from boars in Experiment 3.

The Relationship Between Runoff and Nutrient Loss at the Edge-of-Field: Results from the Arkansas Discovery Program

M. Daniels,[1] P. Webb,[1] L. Riley,[1] A. Sharpley,[2] L. Berry,[2] and J. Burke[2], and M. Fryer[3]

Abstract

The overall goals of the Arkansas Discovery Farms program are to assess the need for and effectiveness of on-farm conservation practices, document nutrient and sediment loss reductions, soil health, and water conservation in support of nutrient management planning and sound environmental farm stewardship. The specific objectives of this study were 1) to compare nutrient concentrations in runoff from the major crops grown in Arkansas and 2) to determine the relationship between seasonal runoff volume and nutrient losses. Seasonal runoff volume, total nitrogen (TN), nitrate, soluble reactive phosphorus (SRP), and total phosphorus (TP) were measured utilizing state-of-the-art, automated edge-of-field runoff monitoring on several fields on Discovery row crop farms. The concentration of nitrate and TN in runoff from corn was slightly higher than for other crops, except for TN from cotton. Losses of SRP and TP from corn were not significantly higher than other crops. Data collected from four fields in Desha County (17 site years in cotton and 2 site years in corn) were used to determine the relationship between seasonal runoff and associated nutrient losses. Nutrient loss increased linearly for all nutrient constituents as total runoff increased during the monitoring period (Figs. 1 and 2). Linear regression coefficients suggest that NO_3-N and TN increased by 0.36 and 0.76 lb/ac, respectively per cm increase in total runoff, while SRP and TP increased by 0.14 and 0.18 lb/ac, respectively. The linear relationships were stronger for SRP and P than for NO_3-N and TN.

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 (USEPA, 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 to 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 nonpoint 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 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 (USEPA, 2018a). This consortium developed an action plan to reduce nutrients entering the Gulf, which includes nutrient reduction strategies prepared by each member State (USEPA, 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 goals of the program are to assess the need for and effectiveness of on-farm conservation practices, 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 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 objectives of this study were: 1) to compare nutrient concentrations in runoff from the

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major crops grown in Arkansas and 2) determine the relationship between seasonal runoff volume and nutrient losses.

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, during 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, Inc., Alpharetta, Georgia). The ISCO 6712, an automated portable water sampler (Teledyne-ISCO, Lincoln, Nebraska), 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). Seasonal runoff volume and nutrient loss were determined by integrating all runoff events across the sampling period from April through October of each year for each field.

To determine the relationship between cumulative nutrient loss during the growing season (planting to harvest) and cumulative runoff during the same time, the combination of field (four fields) by year (five years but Field 1 was not monitored during 2013) was used to generate 19 site years to use in regression analysis at the 0.05 level of significance.

Results and Discussion

The concentration of nitrate and TN in runoff from corn was slightly higher than for other crops, except for TN from cotton, which was higher presumably from organic N found in plant debris (Fig. 1). While slightly higher, nitrate and total N losses were not proportionally greater relative to N fertilizer applied even as N fertilizer recommendations for corn are much greater than the other crops. Losses of SRP and TP from corn were not much different than for other crops, presumably due to P adsorption by the soil. These results indicate that the amount of fertilizer applied is not nearly as important to nutrient loss runoff as is the amount of fertilizer applied relative to individual crop needs. Following soil test recommendations can minimize nutrient losses as these concentrations are relatively low.

Nutrient loss increased linearly for all nutrient constituents as total runoff increased during the monitoring period (Figs. 2 and 3). Linear regression coefficients suggest that NO_3-N and TN increased by 0.34 and 0.75 lb/ac, respectively, per cm increase in total runoff, while SRP and TP increased by 0.14 and 0.18 lb/ac, respectively. The linear relationships were stronger for SRP and P than for NO_3-N and TN. The range of nutrient losses measured is relatively small compared to fertilizer applied that year.

Often, losses are considered mostly as a function of source without consideration for hydrology and runoff. However, through regression analysis of cumulative nutrient and runoff losses of year by field combinations, it was determined that both cumulative N and P losses increase linearly with runoff volume.

Practical Applications

Data collected from Arkansas Discovery farms indicate that nutrient losses in runoff at the edge-of-field are less than 5% of the nutrient applied as fertilizer, so these losses are relatively small. Results also indicate that losses in corn are not that much greater than in other crops even though recommendations of N and P fertilizers are greater for corn, which reinforces that meeting individual crop needs via soil testing is critical to minimizing nutrient loss in runoff.

This study confirms intuitive thoughts that seasonal nutrient loss may increase with increases in seasonal runoff volume. The practical application is that one way of reducing nutrient losses based on this study is finding ways to reduce runoff.

Soil and water conservation practices can alter runoff hydrology. For example, land leveling can create a small but uniform slope that can help reduce runoff velocity by reducing slope and the gravitational gradient. Improving soil health through cover crops such as cereal rye can increase infiltration by creating larger pores such as root channels that can conduct water through restrictive pans, thus reducing runoff and increasing water holding capacity and depth of water penetration in the soil. Cover crops coupled with minimum tillage can create greater soil structure to increase infiltration rates.

Acknowledgments

The authors wish to acknowledge funding sources for the Arkansas Discovery Farm program, including the University of Arkansas System Division of Agriculture, soybean checkoff 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.

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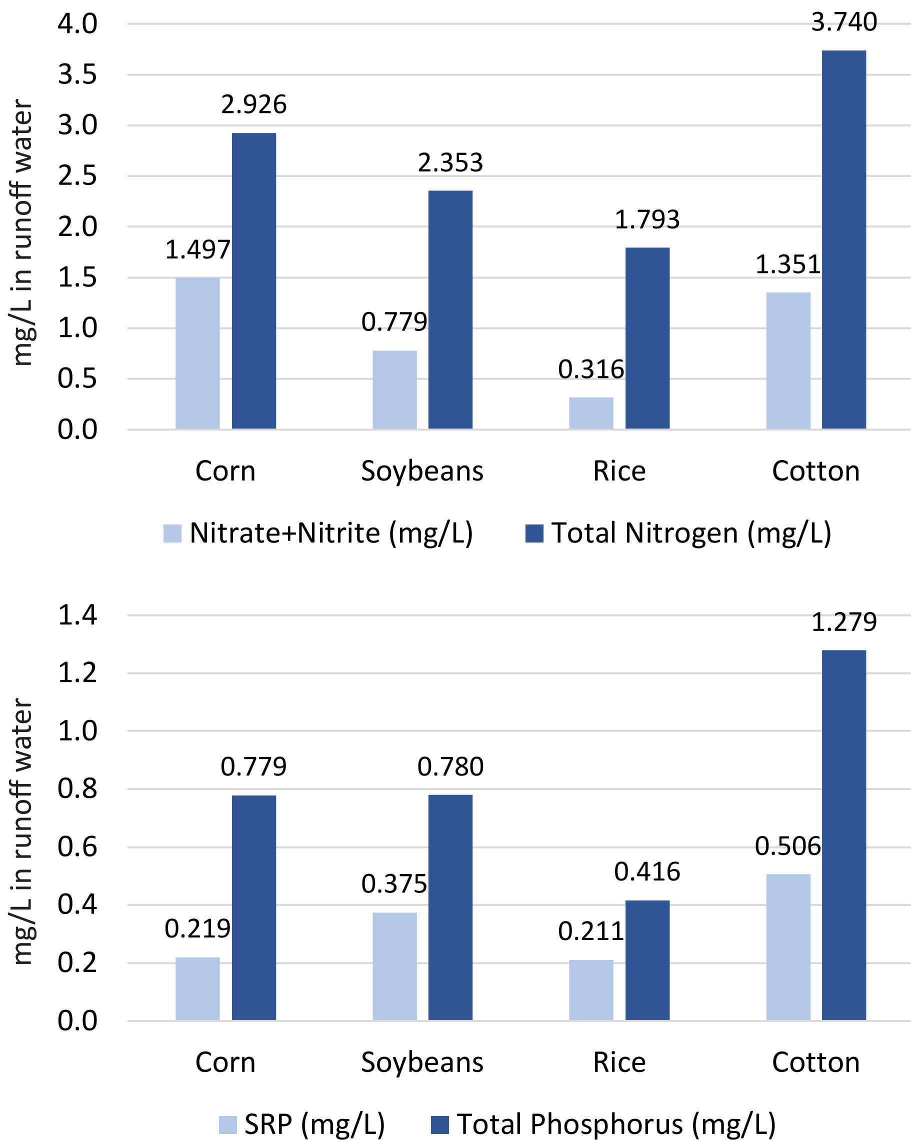

Fig. 1. Summary of all concentration (mg/L) data (Nitrogen on top and phosphorus on bottom) from runoff water on Discovery Farms fields for all crops at all locations.

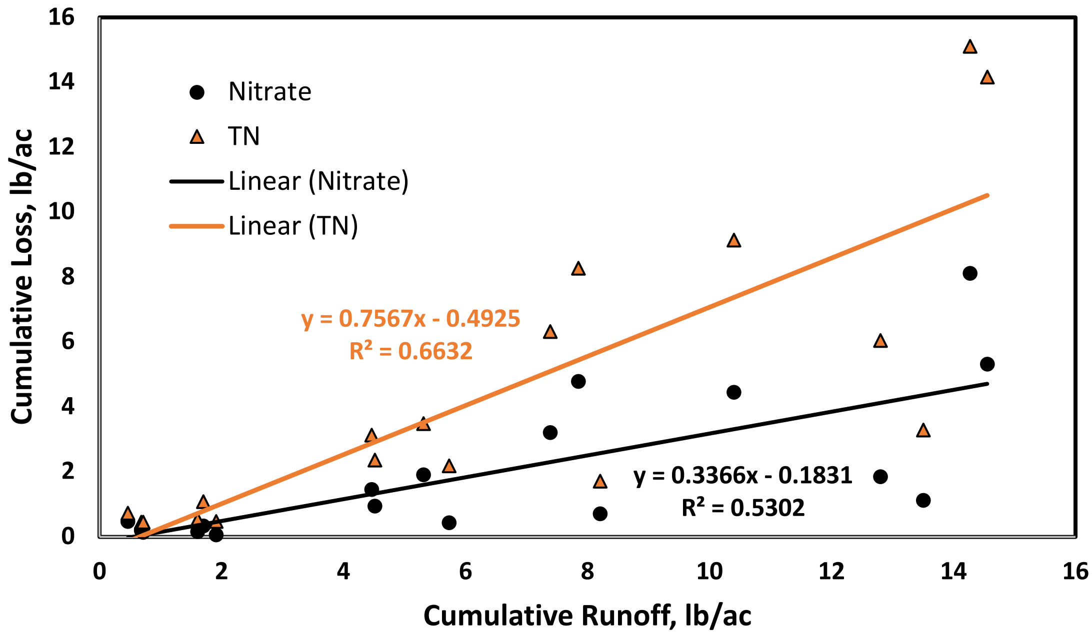

Fig. 2. Relationship of nitrate-N and total N with total runoff volume during planting to harvest. Regression analysis performed at α = 0.05.

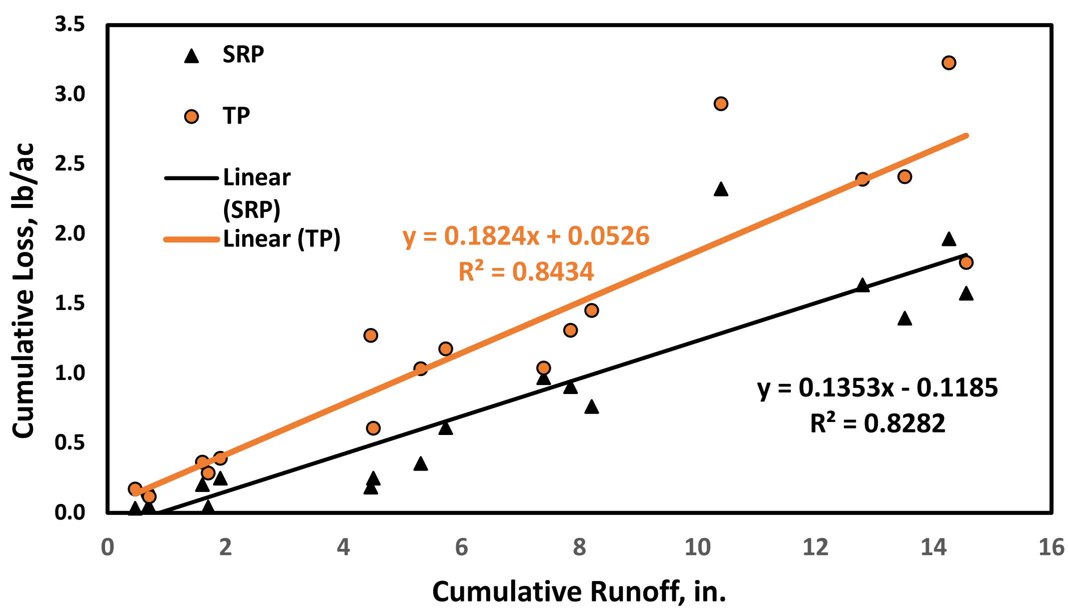

Fig. 3. Relationship of soluble reactive P and total P with total runoff volume during planting to harvest at the 0.05 level of significance.

2020 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 Service (CES) recommendations from Crop Specialists and from the Corn and Grain Sorghum Research Verification Programs. Unique budgets can be customized by users based on either CES recommendations or information from producers for their production practices. The budget program is utilized to conduct an economic analysis of field data for 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

The availability of a wide variety of seed technology amongst crops provides interesting and unique opportunities for producers across Arkansas. Coupled with low commodity prices and rising input costs, evaluating production methods and deciding what to grow has become crucial for producer's financial stability. The objective of crop enterprise budgets is to develop an interactive computational program, which allows stakeholders of the corn and grain sorghum industry to evaluate numerous production methods for comparative costs and returns dependent upon a wide range of inputs.

Procedures

Crop enterprise budgets are developed based upon input from crop specialists across the state. Input prices are gathered directly from suppliers to create cost estimates unique to the production year. Input costs for fertilizers and chemicals are estimated by applying prices to typical input rates based upon crop specialists' recommendations. Equipment prices, custom hire rates, and fees are estimated with information from those within the industry in Arkansas. The methods of estimating these operating expenses presented in crop enterprise budgets are identical to producers obtaining cost information for their specific farms.

Ownership costs and repair expenses for machinery are estimated by applying engineering formulas to representative prices of new equipment (Givan, 1991; Lazarus and Selly, 2002). Repair expenses in crop enterprise budgets should be regarded as value estimates of full-service repairs. Repairs and maintenance performed by hired farm labor will be partially realized as wages paid to employees. Machinery performance rates of field activities utilized for machinery costs are used to estimate time requirements of an activity which is applied to an hourly wage rate for determining labor costs (USDA-NASS, 2018). Labor costs in crop enterprise budgets represent time devoted to specified field activities listed at the beginning of each budget.

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). One should note this measure differs from typical depreciation methods, as well as actual cash expenses for machinery. Amortization factors applied for capital recovery estimation coincide with prevailing long-term interest rates (Edwards, 2005). Interest rates in this report are from Arkansas lenders as reported in October 2019. Representative prices for machinery and equipment are based on contacts with Arkansas dealers and industry list prices (Deere & Company, 2019; MSU, 2019). Revenue in crop enterprise budgets is the product of expected yields from following University of Arkansas System Division of Agriculture's Cooperative Extension Service (CES) research verification practices and average commodity prices over the month in which the budgets are created.

Results and Discussion

The University of Arkansas System Division of Agriculture's Department of Agricultural Economics and Agribusiness (AEAB) and Agriculture and Natural Resources (ANR) together develops annual crop enterprise budgets to assist Arkansas producers and other agricultural stakeholders in evaluating expected costs and returns for the upcoming field crop production year. Production methods analyzed represent typical field activities as determined by consultations with farmers, county agents, and information from Crop Research Verifica-

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tion 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 represents an example of the 2020 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 $96.28/ac. The budget program includes similar capabilities for center pivot irrigated and non-irrigated corn and grain sorghum production as well as providing for both stacked gene and conventional corn evaluation. Table 2. represents the 2020 grain sorghum non-irrigated enterprise budget. The budgets assume grower-owned land, and costs are given on a per-acre basis. In 2020, the net returns from non-irrigated sorghum were -$118.33/ac largely due to low grain price in the fall of 2019 when the budgets were originally developed for 2020. 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. 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 Arkansas Corn and Grain Sorghum Promotion Board. Support was also provided by the University of Arkansas System Division of Agriculture and Natural Resources Conservation Service.

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Table 1. 2020 Corn Enterprise Budget, stacked gene, furrow irrigation.

Crop Value	Grower %	Unit	Yield[a]	Price/Unit	Revenue
Crop Value, Enter Expected Farm Yield & Price	100	**bu.**	210.00	3.75	787.50
Operating Expenses		**Unit**	**Quantity**	**Price/Unit[b]**	**Costs**
Seed, Includes Applicable Fees	100	ac	1	116.80	116.80
Nitrogen 100%	100	lb/ac	200	0.38	76.13
Phosphate (0-46-0)	100	lb/ac	175	0.19	33.69
Potash (0-0-60)	100	lb/ac	130	0.17	22.43
Ammonium Sulfate (21-0-0-24)	100	lb/ac	100	0.16	15.75
Zinc Sulfate	100	lb/ac	29.00	0.60	17.40
Other Nutrients, Including Poultry Litter	100	ac	1.00	0.00	0.00
Herbicide	100	ac	1	71.51	71.51
Insecticide	100	ac	1	0.00	0.00
Fungicide	100	ac	1	0.00	0.00
Other Chemical	100	ac	1	0.00	0.00
Other Chemical	100	ac	1	0.00	0.00
Custom Chemical & Fertilizer Applications					
Ground Application: Fertilizer & Chemical	100	ac	0	7.50	0.00
Air Application: Fertilizer & Chemical	100	ac	0	8.00	0.00
Air Application: lb	100	lb	100	0.080	8.00
Other Custom Hire, Air Seeding	100	ac	0	8.00	0.00
Machinery and Equipment					
Diesel Fuel, Pre-Post Harvest	100	gal	4.188	2.50	10.47
Repairs and Maintenance, Pre-Post Harvest	100	ac	1	7.77	7.77
Diesel Fuel, Harvest	100	gal	3.082	2.50	7.70
Repairs and Maintenance, Harvest	100	ac	1	10.61	10.61
Irrigation Energy Cost	100	ac-in.	14	2.78	38.86
Irrigation System Repairs & Maintenance		ac-in.	14	0.24	3.36
Supplies (ex. polypipe)	100	ac	1	3.88	3.88
Other Inputs	100	ac	1	0.00	0.00
Labor, Field Activities	100	hours	0.947	11.33	10.73
Scouting/Consultant Fee	100	ac	1	7.00	7.00
Other Expenses	100	ac	1	0.00	0.00
Crop Insurance	100	ac	1	13.00	13.00
Interest, Annual Rate Applied for 6 Months	100	rate %	5.50	475.08	13.06
Custom Harvest	100	ac	0.00	0.00	0.00

Table 1. Continued.

	Grower %	Unit	Quantity	Price/Unit[b]	Costs
Post-Harvest Expenses					
Drying	100	bu.	210.00	0.19	39.90
Hauling	100	bu.	210.00	0.25	52.50
Check Off, Boards	100	bu.	210.00	0.01	2.10
Cash Land Rent		ac	1	0.00	0.00
Total Operating Expenses					**$582.65**
Returns to Operating Expenses					**$204.85**
Capital Recovery & Fixed Costs					
Machinery and Equipment		ac	1	82.64	82.64
Irrigation Equipment		ac	1	21.80	21.80
Farm Overhead[c]		ac	1	4.13	4.13
Total Capital Recovery & Fixed Costs					**$108.58**
Total Specified Expenses					**$691.22**
Net Returns					**$96.28**

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

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

[c] Estimate based on machinery and equipment.

Table 2. 2020 Grain Sorghum Enterprise Budget, no irrigation.

Crop Value	Grower %	Unit	Yield[a]	Price/Unit	Revenue
Crop Value, Enter Expected Farm Yield & Price	100	**bu.**	65.00	3.20	208.00

Operating Expenses		Unit	Quantity	Price/Unit[b]	Costs
Seed, Includes Applicable Fees	100	ac	1	13.64	13.64
Nitrogen 100%	100	lb	92	0.38	35.00
Phosphate (0-46-0)	100	lb	130	0.19	25.03
Potash (0-0-60)	100	lb	150	0.17	25.88
Ammonium Sulfate (21-0-0-24)	100	lb	0	0.16	0.00
Boron 15%	100	lb	0.00	0.55	0.00
Other Nutrients, Including Poultry Litter	100	ac	1.00	0.00	0.00
Herbicide	100	ac	1	26.11	26.11
Insecticide	100	ac	1	31.02	31.02
Fungicide	100	ac	1	0.00	0.00
Other Chemical	100	ac	1	0.00	0.00
Other Chemical	100	ac	1	0.00	0.00
Custom Chemical & Fertilizer Applications					
Ground Application: Fertilizer & Chemical	100	ac	0	7.50	0.00
Air Application: Fertilizer & Chemical	100	ac	1	8.00	8.00
Air Application: lb	100	lb	0	0.080	0.00
Other Custom Hire, Air Seeding	100	ac	0	8.00	0.00
Machinery and Equipment					
Diesel Fuel, Pre-Post Harvest	100	gal	3.388	2.50	8.47
Repairs and Maintenance, Pre-Post Harvest	100	ac	1	6.86	6.86
Diesel Fuel, Harvest	100	gal	3.082	2.50	7.70
Repairs and Maintenance, Harvest	100	ac	1	8.51	8.51
Irrigation Energy Cost	100	ac-in.	0	0.00	0.00
Irrigation System Repairs & Maintenance		ac-in.	0	0.00	0.00
Supplies (ex. polypipe)	100	ac	1	0.00	0.00
Other Inputs	100	ac	1	0.00	0.00
Labor, Field Activities	100	hours	0.705	11.33	7.99
Scouting/Consultant Fee	100	ac	1	6.00	6.00
Other Expenses	100	ac	1	0.00	0.00
Crop Insurance	100	ac	1	13.00	13.00
Interest, Annual Rate Applied for 6 Months	100	rate %	5.50	223.19	6.14
Custom Harvest	100	ac	0.00	0.00	0.00
Post-Harvest Expenses					
Drying	100	bu.	65.00	0.00	0.00
Hauling	100	bu.	65.00	0.25	16.25
Check Off, Boards	100	bu.	65.00	0.01	0.65

Table 2. Continued.

	Unit	Quantity	Price/Unit[b]	Costs
Cash Land Rent	ac	1	0.00	0.00
Total Operating Expenses				**$246.23**
Returns to Operating Expenses				**-$38.23**
Capital Recovery & Fixed Costs				
Machinery and Equipment	ac	1	76.29	76.29
Irrigation Equipment	ac	1	0.00	0.00
Farm Overhead[c]	ac	1	3.81	3.81
Total Capital Recovery & Fixed Costs				**$80.10**
Total Specified Expenses				**$326.33**
Net Returns				**-$118.33**

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

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

[c] Estimate based on machinery and equipment.

APPENDIX: CORN AND GRAIN SORGHUM RESEARCH PROPOSALS

2020-2021 Corn and Grain Sorghum Research Proposals

Principal Investigator (PI)	Co-PI	Proposal Name	Year of Research	Funding Amount (US$)
N. McKinney	J. Kelley	Arkansas Corn and Grain Sorghum Research Studies Series, an annual report and archival system for all Board-funded research	1 of 1	5,000
T. Roberts	T. Spurlock, T. Faske, A. Rojas, and J. Kelley	Implementing cover crops into corn rotations and the impact on soil health	1 of 1	55,000
S. Sadaka	G. Atungulu	Utilization of ozone fumigation to reduce aflatoxin and mycotoxins contamination from corn	1 of 1	46,000
J. Kelley		Development of a corn DD50 program	1 of 1	18,000
S. Green	J. Massey, A. Hashem, and E. Brown	Timing cover crop termination to optimize corn yields and water-use efficiency	2 of 3	14,000
N. Bateman	B. Thrash, G. Lorenz, and G. Studebaker	Evaluating the efficacy of *Bt* corn traits by survival of corn earworm and fall armyworm	2 of 3	20,000
T. Faske	K. Korth	Assess management options for corn nematodes in Arkansas	2 of 3	50,000
G. Lorenz	N Joshi, N. Bateman, and G. Studebaker	Insect management in on-farm grain storage	3 of 3	20,000
J. Kelley		Arkansas corn and grain sorghum research verification program	3 of 3	125,000
L. Espinoza		Evaluation soil sampling methods for variable rate fertilization	3 of 3	29,000
T. Barber	J. Norsworthy	Evaluation of herbicides, corn hybrid technologies, and cultural methods to improve season-long weed control in corn	Completed 3 of 3 New project period	72,000
B. Bluhm		Gene editing: A new approach to overcome mycotoxins and environmental stress in Arkansas corn production (Phase II)	Completed 3 of 3 New project period	40,000
M. Daniels	A. Sharpley	The Arkansas Discovery Farm Program	2 of 3	5,000
V. Ford	B. Watkins	Crop enterprise budgets and production economic analysis for corn and grain sorghum	Ongoing	10,000
C. Henry		Improving irrigation scheduling and irrigation efficiency for corn production in Arkansas	Completed 3 of 3 New project period	163,000
J. Kelley	J. Ross	Developing profitable irrigated rotational cropping systems for Arkansas	2 of 3	26,000
J. Kelley	L. Espinoza and T. Roberts	Overcoming yield limitations in corn	2 of 3	25,000
J. Norsworthy	T. Barber	Evaluation of emerging weed control technologies in grain sorghum	2 of 3	2,632
L. Purcell	T. Roberts	Calibrating mid-season N fertilizer rates based upon leaf N concentration and remote sensing	Completed 3 of 3 New project period	39,000
			Total Funding:	**764,632**

DIVISION OF AGRICULTURE

RESEARCH & EXTENSION

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